Growth May Encourage Less Factor Price Diversity

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Abstract

This paper examines the theoretical relationship between the neoclassical theories of international trade and of growth. Besides fundamental explanations of both theories, it comprises technological progress as the driving force for economic growth, thus extending Deardorff (2001). The paper comes to the conclusion that economic growth may reduce global factor price diversity, if technological progress is considered.

Introduction

The relationship between the international trade theory and growth models has always been of major interest in economic research. The Heckscher-Ohlin model of international trade predicts that global factor price equalization is possible if factor endowments of different countries are not too diverse. The neoclassical growth model shows that higher income per capita is achieved essentially by technological progress. Already a large number of empirical literature investigates that a correlation of per capita income and international trade exists.[1] Thus, the combination of both theories, the Heckscher-Ohlin model and the neoclassical growth model, should endeavor to ascertain whether there is a theoretical foundation for the convergence of per capita income and factor price equalization.

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[1]For a survey see Ben-David / Nordström / Winters (1999).

The theorem of global factor price equalization (FPE) shows that under free trade countries with similar factor endowments and two different goods of production may end up in the same cone of diversification. Further increasing the number of goods gives rise to the possibility of a two- or multiple-cone equilibrium and FPE only given within each cone. Hence, for full FPE to hold, the countries' factor endowments need to be sufficiently similar and world trade should be organized within one cone of diversification. The neoclassical growth theory emphasizes that countries converge to their long-run equilibrium level of output. Only with technological progress, sustained growth of output per worker is achieved. Thus, the question arises whether steady state growth in a model with two factors and three goods encourages less factor price diversity through a reduction of the number of cones of diversification.

Deardorff (2001), building on his earlier work (1974), has a very pessimistic view concerning the relationship between the neoclassical growth process and FPE. He examines different assumptions of the savings behavior and concludes that "there seems to be nothing in the available neoclassical growth models to suggest that the growth process is likely to bring the countries of the world sufficiently close together in terms of their factor endowments to permit global FPE" (Deardorff 2001: 197). Contrary to his study, this paper finds that the inclusion of technological progress to his growth model may lead to a solution that permits global FPE.

The remainder of the paper is organized as follows. Section 1 introduces the basic framework of the Heckscher-Ohlin model of international trade. The importance of the distinction between a one-cone versus multiple-cones equilibria is reconsidered. Furthermore, it evaluates the mechanism of two classical exercises of trade theory, namely the Rybczynski and Stolper-Samuelson effect. After having introduced the basic framework, the relationship between growth and trade in a small open economy are analyzed. Section 2 introduces technological progress and stresses the fact that sustained growth depends on technological progress. Further, it evaluates the consequences of technological progress for a two-cone trade equilibrium. The conclusion summarizes the main points of the paper and evaluates the findings.

1 The basic framework

According to the Heckscher-Ohlin Model of international trade with more goods than factors of production, several types of free-trade-equilibria are possible.[2] Depending on how large the differences between countries in terms of relative factor endowments are, world production under free trade is diversified in either one or in

[2] This section draws primarily on Deardorff (2002a, 2002b, 1974).

several different "cones of diversification". Several diagrams and techniques are introduced which form the basic framework of the analysis. Neoclassical trade and growth theory are combined to analyze the consequences of growth for the possibility of a "one-cone" versus a "several cones" trade-equilibrium.

1.1 One cone or two cones

In order to introduce the microeconomic foundations for the existence of just one or several cones in a trade equilibrium, the production decisions of a single country are examined. In figure 1, the curves labeled $X_i, i = 1, 2, 3$ are the unit value isoquants of three goods that are produced with two factors of production, K and L, at given relative good prices $p_i, i = 1, 2, 3$. All three isoquants represent the same value of production. The position of the isoquants depends on the relative good prices and the different production technologies.[3]

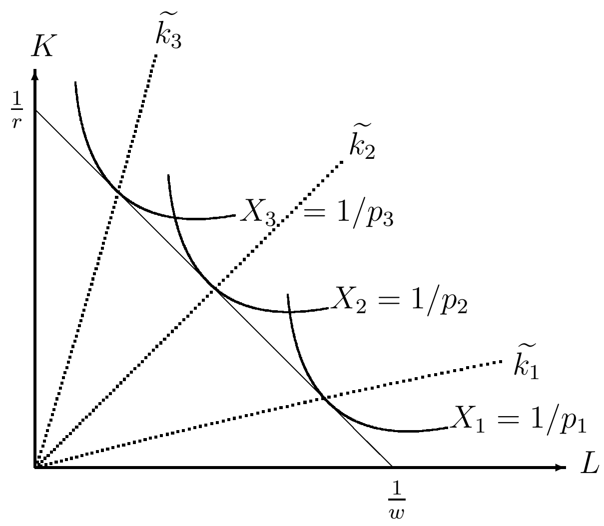

Figure 1: A One-Cone Equillibrium

Figure 1 shows a situation where all three isoquants are tangent to an isocost line, consistent with zero-profits or cost-minimization in the production of all three goods.[4] The intercepts of that isocost line with the K- and L-axis indicate the inverse of the corresponding factor prices r and w, respectively. Factors of production receive similar rents or wages, regardless in which sector they are used. The cost-minimizing use of the inputs K and L is given by $\widetilde{k}_1$, $\widetilde{k}_2$ and $\widetilde{k}_3$.

[3]Each point on an unit *value* isoquant provides information how many inputs are necessary for the production of one unit of a good, multiplied by its price.

[4]An isocost line $K = \frac{1}{r} - (\frac{w}{r})L$ closer towards the origin than another represents lower costs.

The capital-labor ratios, $\widetilde{k_1}$ and $\widetilde{k_3}$ represent the borders of a "cone". The concept of cones is explained in more detail in the following paragraphs.

The price system p_i does not necessarily ensure isoquants with a common tangent as in figure 1. In contrast to the first case, there are two other possibilities. In the second case, the relative price of good X_2 is higher compared to the first scenario. The position of the isoquant X_2 is shifted towards the origin as shown in figure 2.[5] As a result, the isoquant of good X_2 crosses the isocost line from the first case. With factor prices r and w as before, producers of X_2 could make a profit. This is not in line with the assumption of perfectly competitive markets. In such a case, there are two tangents corresponding to two different sets of factor prices that link the isoquants X_1 and X_2 and the isoquants X_2 and X_3. With the first set of factor prices, w_1 and r_1, good X_3 is not produced in the economy and with the second set, w_2 and r_2, there is no production of the first good. Because of intersectoral mobility in labor markets, it is impossible that two sets of r and w exist within a single country. Thus, one good is not produced in this case but maybe elsewhere in the world, where different factor prices are in place.[6]

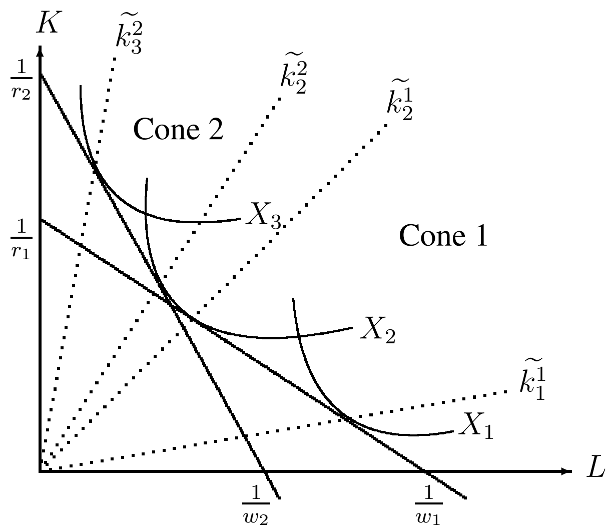

Figure 2: A Two-Cone Equillibrium

The remaining third case is a situation with a lower price p_2, corresponding to a shift of isoquant X_2 in the north-east direction of figure 1. This situation is impossible in a framework of perfect competition. As the reader might want to check, all tangents connecting isoquant X_2 with one of the two others would cross

[5]With a higher price p_2, the firm needs fewer inputs to produce the same value of output as before.

[6]For another application of the mechanics see also Choi (2002: 19-23). Contrary to Choi (2002), this paper assumes that prices are exogenous and determined on world markets.

the remaining isoquant, implying positive profits in the production of that good. Thus, looking at the production decision of a single economy for this third case, neither an equillibrium with a single set of factor prices (as shown in figure 1) nor an equillibrium with different sets (as shown in figure 2) exists.

The next step in the introduction of the basic framework is to use the above reasoning in a Heckscher-Ohlin trade model. Consider a model with two countries, three goods and two factors of production.[7] Assuming free trade, the prices p_i are determined by overall supply and demand in the world market for all three goods. For every individual country, these prices then imply either a situation as in figure 1 with one set of factor prices or a situation as in figure 2 with two different possible sets of factor prices. In the standard 2x2 Heckscher-Ohlin trade model, one of the strongest theorems is factor price equalization (FPE) in a free trade equilibrium. Several conditions have to be fulfilled for FPE (Jones 1987), for instance, factor endowments should not be too diverse for the countries under consideration. In a model with more goods than factors of production, the theorem has to be modified. Worldwide FPE occurs only if all countries produce in one cone of diversification. With several cones of diversification, factor prices are only equalized within cones of diversification but not across cones.

For a one-cone-equilibrium with worldwide FPE, relative world prices have to ensure that a situation as in figure 1 with a common tangent and one set of factor prices applies to *all* countries. The rays $\widetilde{k_1}$, $\widetilde{k_2}$ and $\widetilde{k_3}$ in figure 1 correspond to the cost-minimizing factor-proportions used in the production of good X_1, X_2 and X_3, respectively. Any country with factor endowments within the cone bordered by $\widetilde{k_1}$ and $\widetilde{k_3}$ is able to fully employ all its factors of production. The total amount of factors is distributed among the industries and in each sector X_i the relevant cost-minimizing factor-proportions $\widetilde{k_i}$ apply.

Factor prices are equal for all countries within the cone and represented by the common tangent of all three isoquants. Of course, it is possible that world prices p_i imply isoquants with a common tangent, but that there are countries with factor endowments outside the cone bordered by $\widetilde{k_1}$ and $\widetilde{k_3}$, nevertheless. Those countries are specialized in the production of good X_1 or X_3. The factor prices of those countries are not equal to the factor prices of the countries within the cone but are determined by the slope of the relevant isoquant, given their specific factor endowments. Thus, the more similar countries are in terms of factor endowments, the more likely is a world trade equilibrium with full factor price equalization.

An equilibrium with several cones (here: two cones) and FPE within cones occurs if the world price system implies for each country a situation as in figure 2 with two different sets of factor prices. This implies that not every good can be produced in each country. Thus, two different cones of diversification occur. The

[7]For a general discussion of higher-dimensional issues in trade theory, see Ethier (1984) and Choi (2002).

first cone includes countries with factor endowments between $\widetilde{k_1^1}$ and $\widetilde{k_2^1}$ which fully employ their factors of production if they either specialize in producing good X_1 or X_2 or both. The equilibrating factor prices for these countries are given by r_1 and w_1. Countries with factor endowments between $\widetilde{k_2^2}$ and $\widetilde{k_3^2}$ produce in cone 2. Comparable to cone 1, the countries can either specialize in the production of good X_2 or X_3 or both, at given factor prices r_2 and w_2. Again, a particular country's factor endowment may lie outside both cones. Such a country specializes in the production of just one good. Within each cone, factor prices are equalized, but they differ between both cones. Cone 1 characterizes a labor-abundant country with a low wage w_1 and a high rental rate r_1 while cone 2 characterizes a capital-abundant country with a high wage w_2 and a low rental rate r_2.

1.2 Rybczynski and Stolper-Samuelson in a two-cone world

This subsection illustrates the mechanics of two classic exercises of trade theory in a two-cone world. Small changes in *factor endowments* and in *prices* of the goods produced have similar effects in models with more than two goods than in the conventional 2x2 model.[8]

Taking first a change in factor endowments into account, a small increase in capital endowment leads to an increased output of its more capital-intensive good relative to the labor-intensive good. This is fully in line with the Rybczynski-Theorem if the changes in the capital endowment are small. In the case where the accumulation of capital is substantial, chances are that the country moves out of its cone, assuming here cone 1, and specializes in the production of good X_2 only. If the country further accumulates capital, the possibility exists that the country moves into cone 2. In cone 2 the country produces good X_2 and good X_3. Relative to the initial situation of the country (which was situated in cone 1), the composition of production has changed. Good X_2 is now the more labor-intensive good for the country under consideration, while good X_3 is the more capital-intensive good. As a result, the move from cone 1 to cone 2 through capital accumulation changes the composition of output. In this sense, the Rybczynski Theorem in a model with three goods does not hold in its strict version.

Likewise are the effects of a change in relative prices. According to the Stolper-Samuelson Theorem, changes in output prices affect the prices of the factors when positive production and zero economic profit are maintained in each industry. Thus, an increase in the price of a good will cause an increase in the price of the factor used intensively in that industry and a decrease in the price of the other factor. Looking at countries within a cone, any price change of a good results in the same changes of factor prices as predicted by the Stolper-Samuelson

[8]For a more elaborated discussion see Choi (2002).

Theorem. Thus, an increase in the price of good X_2, holding the remaining prices constant, means that the same amount of value can now be earned by a smaller quantity of production of good X_2. As a result, the unit value isoquant of good X_2 shifts towards the origin and both isocost lines rotate. The isocost line which corresponds to cone 1 rotates counter-clockwise. Since the production of good X_2 is more capital-intensive compared to good X_1 in cone 1, the consequences are that the wage in cone 1 decreases, while the rental rate for capital increases, as predicted by the Stolper-Samuelson Theorem. The adjustment process in cone 2 is contrary to the one in cone 1 because here, the production of good X_2 is relatively more labor-intensive compared to good X_3. Thus, in cone 2 the relative wage increases while the capital rental rate decreases. So both effects are according to the Stolper-Samuelson Theorem, however in a two-cone equilibrium it is important to note that the production of a good can be at the same time relatively capital- and labor-intensive, depending which cone is examined.

1.3 The geometry of growth and trade

In order to analyze the effects of growth and trade in a small open economy, Deardorff (1974) introduces a geometric technique assuming the production of two goods with two factors of production. The geometric technique represents per capita income as a function of the economy's capital-labor ratio in a two sector-economy assuming given prices of the two goods. The concerning figures give the *same* information about factor prices as figures 1 and 2, but in addition, the figures show the per capita output of each sector.

The standard model involves the production of a capital-intensive good and a labor-intensive good. Following Deardorff (1974), the homogeneous production function, $X_i = F(K, L), i = 1, 2$, can be written in terms of output per worker as follows:

$$\left(\frac{X_1}{L_1}\right) = f_1\left(\frac{K_1}{L_1}\right) = f_1\left(\widetilde{k_1}\right) \quad (1)$$

$$\left(\frac{X_2}{L_2}\right) = f_2\left(\frac{K_2}{L_2}\right) = f_2\left(\widetilde{k_2}\right) \quad (2)$$

Here, K_i and L_i represent the quantities of capital and labor employed in producing each good. Both functions are strictly increasing, strictly concave and satisfy the "Inada Conditions" by assumption.

Before plugging the production functions of good X_1 and good X_2 into the revenue/labor ($y = p \cdot Y/L$) and capital/labor ($k = K/L$) space like in figure 3, one needs to multiply both functions (1) and (2) with the concerning given price

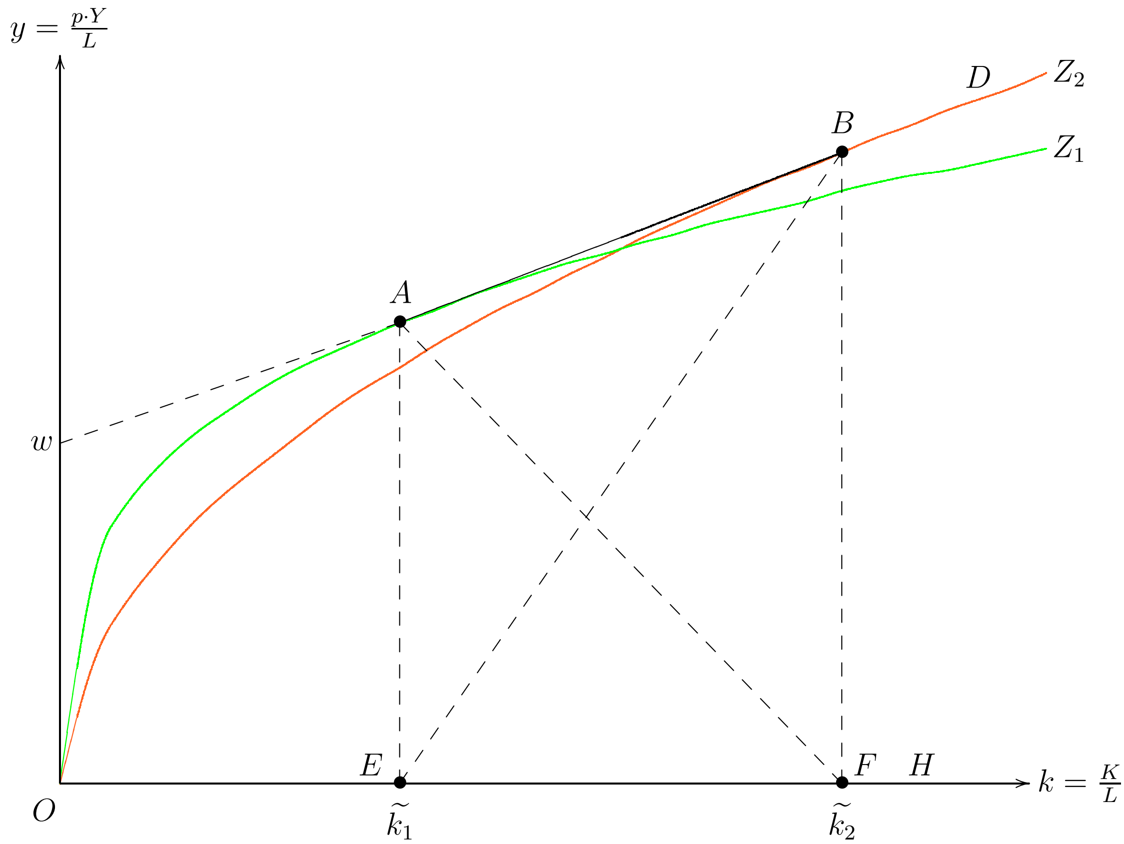

Figure 3: The "Deardorff Production Function"

in order to be able to compare both in a single diagram. The result of the transformation is Z_i which represents the production function of sector i multiplied by its price p_i.[9] After having drawn the figure, the next step is to connect both revenue functions by their common tangent, AB. Thereafter, a vertical line is drawn, connecting points A and B with the capital/labor axis. The resulting points are E and F respectively. Furthermore, a diagonal line connects point A and F while a second one connects point B and E. The section OA shows that an economy with factor endowments smaller than $\widetilde{k}_1$ is specialized in producing good X_1. The tangent part AB shows that an economy with factor endowments between $\widetilde{k}_1$ and $\widetilde{k}_2$ produces both kinds of goods while in the last part, BD, the economy produces only good X_2.

[9] In all following diagrams, the production (or revenue) functions are calculated with the Cobb-Douglas function in intensive form: $y = k^{\alpha} \cdot A^{1-\alpha}$, see equation (5) and (6). The values used for the calculations are stated as follows: The prices of good X_1, X_2 and X_3 are specified by $p_1 = 0.17$, $p_2 = 0.35$, $p_3 = 0.45$. The revenue functions Z_1, Z_2, Z_3 are calculated with $\alpha_1 = 0.05$, $\alpha_2 = 0.3$, $\alpha_3 = 0.5$. The variable A, representing technology for each sector, is assumed to be $A_1 = 55$, $A_2 = 50$, $A_3 = 40$, respectively. Technological progress in the third sector leads to an increase of A_3 to 47.

The run of the curve $OAFH$ shows the production of good X_1 while the run of the curve of good X_2 is $OEBD$. The factor prices can be read off the convex hull of the two curves $OABD$. This convex hull is from now on referred to as the "Deardorff Production Function". The capital-labor ratio can be simply read off the k-axis, while the slope of the Deardorff Production Function is equal to the factor price of capital r, and the intercept of the tangent to the Deardorff Production Function with the y-axis is the factor price of labor or simply the wage, w. Throughout the section AB, the rental rate of capital is equal to the slope of the tangent, while the wage is equal to the intercept of the tangent as indicated by w. Thus, a country with a capital labor ratio which lies in between $\widetilde{k_1}$ and $\widetilde{k_2}$ (in the section AB) will produce both goods at unique factor prices determined by the slope and the intercept of the tangent. As Deardorff (2001: 171) states, the "diagram is completely analogous to the more familiar Lerner diagram where these factor ratios are identified by a common tangent to the industries' unit-value isoquants, and where the corresponding rays from the origin in the L and K space form a cone." Thus, the space between $\widetilde{k_1}$ and $\widetilde{k_2}$ in figure 3 is fully comparable with the diversification cone in figure 1 (assuming for a moment only two goods).

As previously described, the geometric technique handled only the production of two goods. In the following paragraph a third good is added to figure 3. Comparable to section 1.1, two possibilities exist. The first one is that there will be exactly one cone of diversification. This means that all three revenue functions have exactly one common tangent.

However, there is also another possibility. Assuming that the goods are produced somewhere at different sets of factor prices and with identical technologies, the outcome is that not all goods are produced within a country. Since the prices are too different, the countries specialize in the production of only two goods. The more different revenue functions are displayed in figure 4 and it can be seen that there are two different lines of tangency, tg_1 and tg_2. The steeper line of tangency, tg_1, touches the revenue functions of the relatively more labor-intensive goods, X_1 and X_2. The flatter line, tg_2 is tangent to the revenue functions of the relatively more capital-intensive goods, X_2 and X_3. Comparable to the Lerner-Pearce Diagram in figure 2, there are two separate cones of diversification. The section starting at $\widetilde{k_1^1}$ to $\widetilde{k_2^1}$ indicates the first cone of diversification with a lower wage rate and a higher rental rate compared to the second cone. The section $\widetilde{k_2^2}$ to $\widetilde{k_3^2}$ displays the second cone of diversification with a higher wage rate ($w_2 > w_1$) and a lower rental rate. Any country which produces outside the two cones is fully specialized in the production of one good and has different factor prices as the ones determined within the cones.

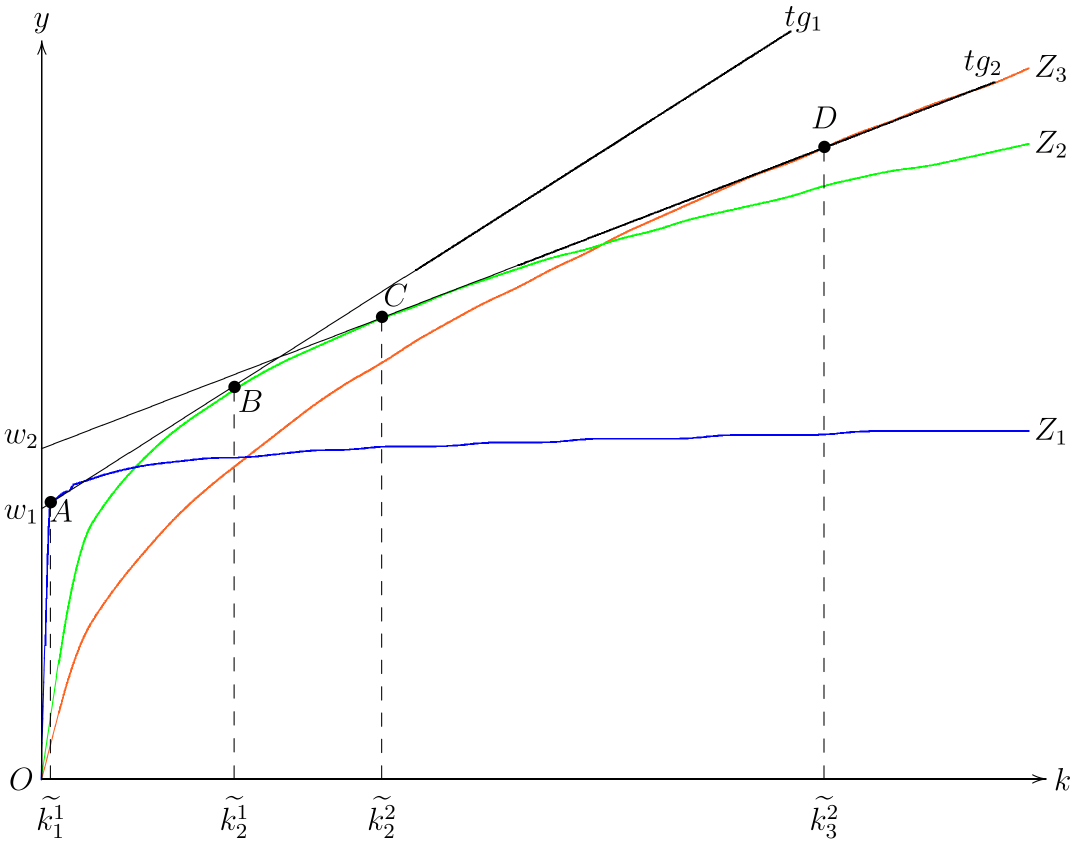

Figure 4: The Deardorff Production Function with Two Cones

2 Technological Progress and Cones of Diversification

2.1 Economic growth, driven by technological progress

In this paper, the effects of technological progress on the pattern of diversification in a trading world economy are analyzed. In a neoclassical growth model in the tradition of Solow (1956), it is technological progress that is the driving force of economic development. This is supported by Hahn (1987: 629): "Growth theory without technological progress seems pretty useless." Without technological progress, in the steady-state output per person and the capital-labor ratio would remain constant over time.

Thus for a discussion "whether the dynamics of economic growth tend to steer the countries of the world into the same cone, or into different ones" (Deardorff 2001: 169), the consideration of technological progress seems to be important. Deardorff (2001) discusses the consequences of different formulations of an economy's saving-behavior in a model with several cones of diversification and growth. His first approach is to illustrate growth by the fixed savings function in the neoclassical growth model. A second approach considers the "classical" (or Marxian) savings function in the early growth models. The underlying assumption in classical growth models is that savings are only composed out of profits. The final approach Deardorff regards is a reformulated neoclassical growth model with a two-period overlapping generations economy. In all three approaches, he comes to the conclusion, that growth does not reduce the number of diversification cones. This means that as a result of growth, the trading countries are unlikely to converge in terms of their factor endowments to permit global FPE.

Contrary to the second and third approach of Deardorff, this paper assumes that savings are proportional to income. With proportional savings, the steady state values of the capital-labor ratio may imply a trade equilibrium with one or several cones of diversification, depending on how diverse the countries are in terms of their savings propensities (Deardorff 2001: 176). Without differences in the savings rate, steady states imply equal factor endowments for all countries. Here a situation with diverse savings propensities that lead to a trade equilibrium with several cones of diversification is considered. Figure 5 illustrates the combination of the neoclassical growth theory and the Deardorff Production Function. The revenue function Z is similar to the production function in the standard neoclassical textbook diagram. The savings function, sZ, is a fixed proportion of the revenue function. Ignoring capital depreciation for simplicity, the steady state is given by the interception of the savings function with the nk-line, where n is the population growth rate.

Countries with a low savings propensity and thus a low capital-labor ratio may find themselves in the cone bordered by $\widetilde{k_1^1}$ and $\widetilde{k_2^1}$, others with a higher savings propensity in the cone bordered by $\widetilde{k_2^2}$ and $\widetilde{k_3^2}$. Other countries, like the one shown in figure 5 by the steady state S, lie between the cones. Technological progress is introduced in this situation and the consequences for steady state capital labor ratios are then discussed in the next subsection.

The concept of technological process comprises many different ways of technological innovation. For instance; new products replace old ones, or products are permanently upgraded and improved in quality. One of the concepts, which is defined as disembodied technological change, assumes that the productivity of the factors of production is increased. As a result of disembodied technological change, less factors of production (capital and labor) are needed to produce a given amount of output. In the following subsection, we focus on process innovations which take the form of disembodied technological progress.

There are different definitions of factor saving technological progress. Hicks-neutral technological change is probably the most known one. According to the analysis of Hicks, a change in technology leads to a vertical upward shift of the production function in a neoclassical growth setting. The Hicks-neutral techno-

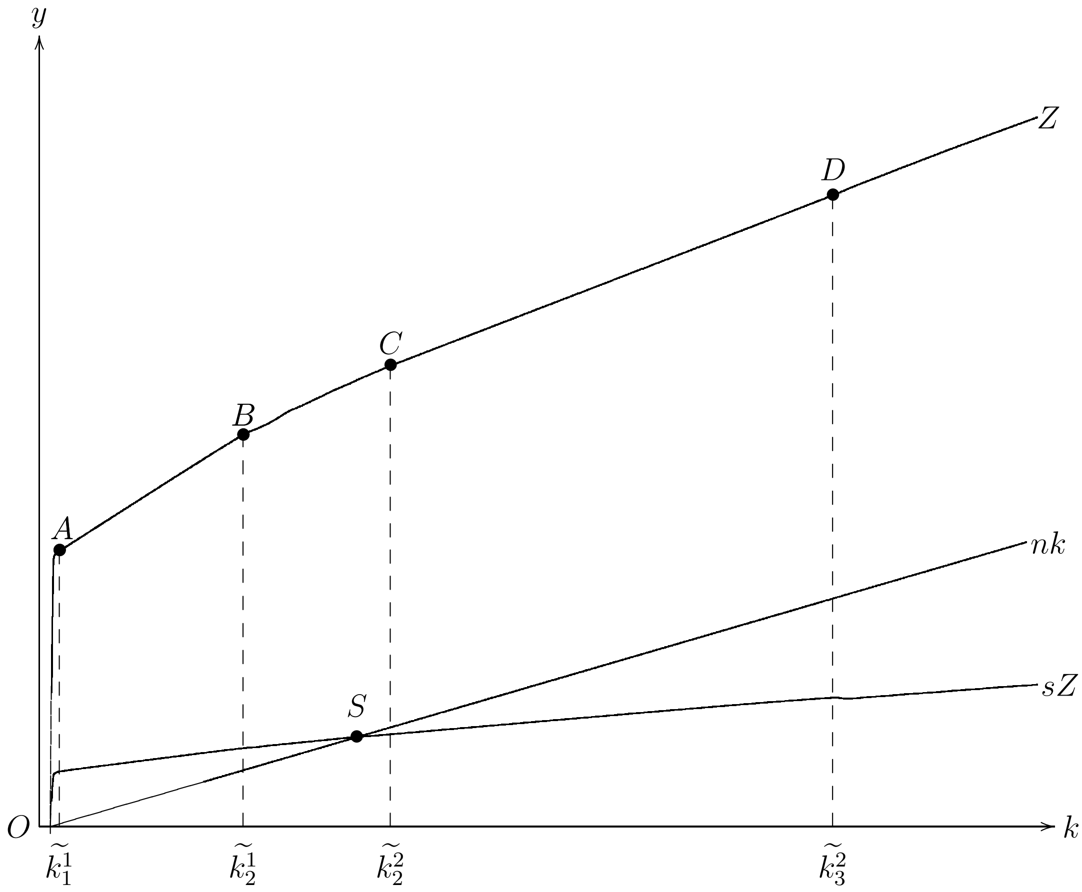

Figure 5: Combining Neoclassical Growth Theory and the Deardorff Production Function

logical change moves the production function but does not change the capital intensity $\widetilde{k}$ for any constant factor price relation w/r. According to Solow-neutral technological progress, the production function shifts horizontally upward. This means that changes in technology leave the labor-output ratio constant for any constant real wage rate. The definition of *Harrod-neutral* technological progress focuses on the capital-output ratio which means that the capital-output ratio does not vary for a constant rate of capital.[10] The rest of the paper assumes *Harrod-neutral* technological progress, because this is the only form of neutrality which is consistent with a steady state not only for as Cobb-Douglas production function, but also for a more general production function.

[10]The production function is augmented for the different concepts of technological progress as follows:
Labor-augmenting or *Harrod-neutral* technological progress: $Y = F(K, A \cdot L)$
Capital augmenting or *Solow-neutral* technological progress: $Y = F(A \cdot K, L)$
Hicks-neutral technological progress: $Y = A \cdot F(K, L)$. For a more elaborated discussion and empirical implications see Gundlach (2001).

The linear homogenous production function

$$F_i\left(\frac{K_i}{L_i}\right) = L_i \cdot f_i\left(\frac{K_i}{L_i}\right) \tag{3}$$

with the subscript i indicating the sectors $i = 1, 2, 3$ in Deardorff (2001) is rewritten as

$$F_i = F_i\left(K_i, A_i(t) \cdot L_i\right) \tag{4}$$

For simplicity, we assume a Cobb-Douglas production function with *Harrod-neutral* technological progress:

$$Y = K^{\alpha} \cdot (A(t) \cdot L)^{1-\alpha} \tag{5}$$

where $A_i(t)$ with $A_i(t) > 0$, $dA_i/dt \geqslant 0$ is a shift factor depending on time that represents technological progress in sector i. $A_i(t) \cdot L$ can be interpreted as the amount of effective labor endowment used in industry i. The functional form of $A_i(t)$ shows that persisting technological progress is an ongoing process which shifts the production function outward over time. Assuming an exogenous shock to technology, only two points in time are considered. The following figures compare the situation in these two points in time.

The production function in intensive form is derived from (1) as follows:

$$\begin{aligned}
Y &= K^{\alpha} \cdot (A \cdot L)^{1-\alpha} \Leftrightarrow \\
Y &= K^{\alpha} \cdot A^{1-\alpha} \cdot L^{1-\alpha} \Leftrightarrow \\
y &= (K/L)^{\alpha} \cdot A^{1-\alpha} \Leftrightarrow \\
y &= k^{\alpha} \cdot A^{1-\alpha} \qquad (6)
\end{aligned}$$

As before, y represents the value of output per hour worked and k the capital-labor ratio. Assuming an one time improvement in technology, the position of the production function changes. According to the *Harrod-neutral* technological progress, the production function shifts outwards in the northeast direction, as shown in figure 6.

The shift of the production function in figure 6 is the result of growth in the parameter A, here representing labor-augmenting technological progress. The

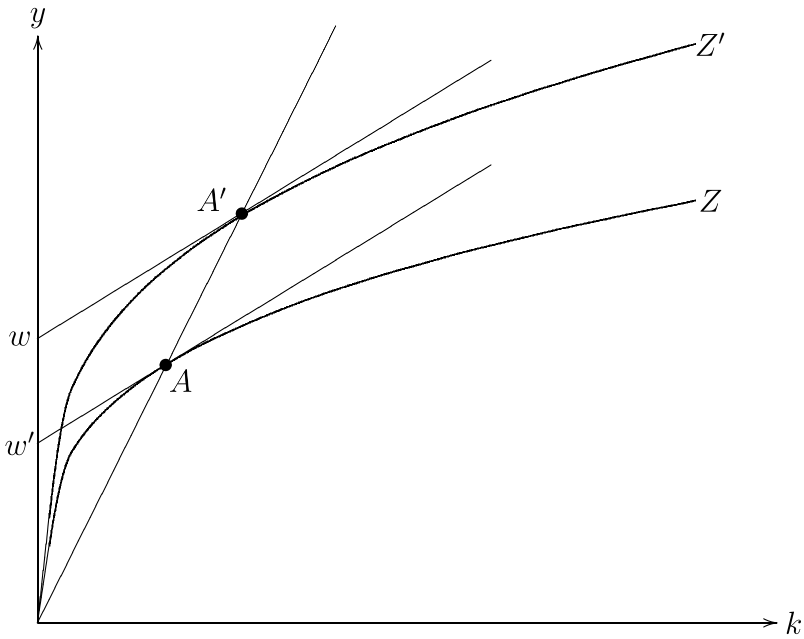

Figure 6: A *Harrod-neutral* shift of the Production Function

per capita production function rotates counter-clockwise. Along a ray from the origin, which represents the control K/Y-ratio, the old and the new, *Harrod-neutrally* shifted curve have the same derivative in point A and A'. Hence, the shift leaves unchanged the capital-output ratio for any constant return to capital r. The movement from point A to A' along the displayed line is an example for an unchanged capital-output ratio with a constant rate of return to capital, which is represented by the slope of the production function.[11] The figure also shows that by assuming an unchanged capital-output ratio and a constant rate of capital, the factor price relation w/r increases, implying an relative increase in the wage rate.

2.2 Consequences of technological progress for a two-cone trade equilibrium

The standard neoclassical model with *Harrod-neutral* technology investigates the alterations of the production function, the factors of production and the steady state. After having introduced the concept of *Harrod-neutral* technological change, the analysis is extended to the two-cone trade equilibrium. The following subsection analyzes technological change in the context of the Lerner-Pearce diagram. Thereafter, technological change is modelled within the setup including all production functions. Both ways analyze the effect of technological progress in a

[11]Only *Harrod-neutral* technological progress is consistent with steady state growth. The exception is the special case of a Cobb-Douglas production function.

two-cone world and thus on the possibility of FPE.

2.2.1 The Lerner-Pearce Diagram

Since unit value isoquants in the Lerner-Pearce Diagram reflect production technology, technological progress alters the position of the isoquant. Starting point of the analysis is figure 2 which is redrawn in figure 7. The initial situation is described by the isoquants X_1, X_2, X_3, the corresponding isocost lines and the resulting two cones of diversification. Introducing technological progress in the most capital-intensive sector X_3 leads to an inward shift of isoquant X_3.[12] For simplicity, a crucial assumption in this paper is that technological change has negligible impacts on the system of relative world prices p_1, p_2 and p_3.[13]

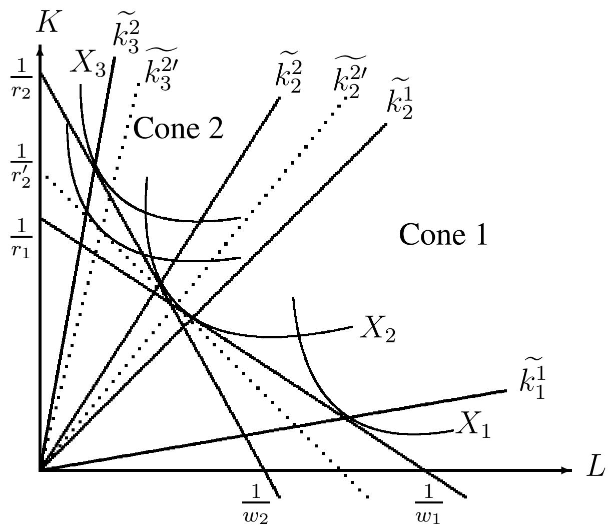

Figure 7: Technological Progress in the Lerner-Pearce Diagram.

A technologically driven inward shift of the isoquant implies that with the same amount of capital, less labor is needed to produce the same amount of output. As a consequence, the factor price line of cone 2 rotates counter-clockwise. The capital rental rate in cone 2 increases to r_2' while the wage rate decreases. The

[12]Acemoglu (2002) discusses in which sectors technological progress is most important and also shows the implications for the labor market. He concludes that technical change has been skill-biased for most of the twentieth century. In this paper, the analysis could be done with skilled and unskilled labor instead of capital and labor as production factors. Technological progress then would be assumed to change the technology in the skill-intensive production sector.

[13]This is a tough assumption, as technology is usually assumed to be shared by all countries worldwide. That this has no impact on world relative prices is hard to justify. In further research, we will allow for price changes. We thank Wilfred Ethier for clarification and suggestions on this point.

intuition is as follows: Everything else equal, the enhanced production efficiency in the third sector leads to more output. Since good X_3 uses relatively more capital in its production compared to good X_2, the rental rate of capital in cone 2 increases while the wage rate falls.

From the figure, it is straightforward to see the relationship between technological progress and FPE. This can be seen in two ways. First, the area between cone 1 and 2 diminishes because $\widetilde{k_2^2}$ shifts to the right to $\widetilde{k_2^{2\prime}}$. Second, the difference in the factor prices decreases. A big enough shift of the isoquant X_3 down to the isocost line of cone 1 results in a one-cone solution with full FPE.

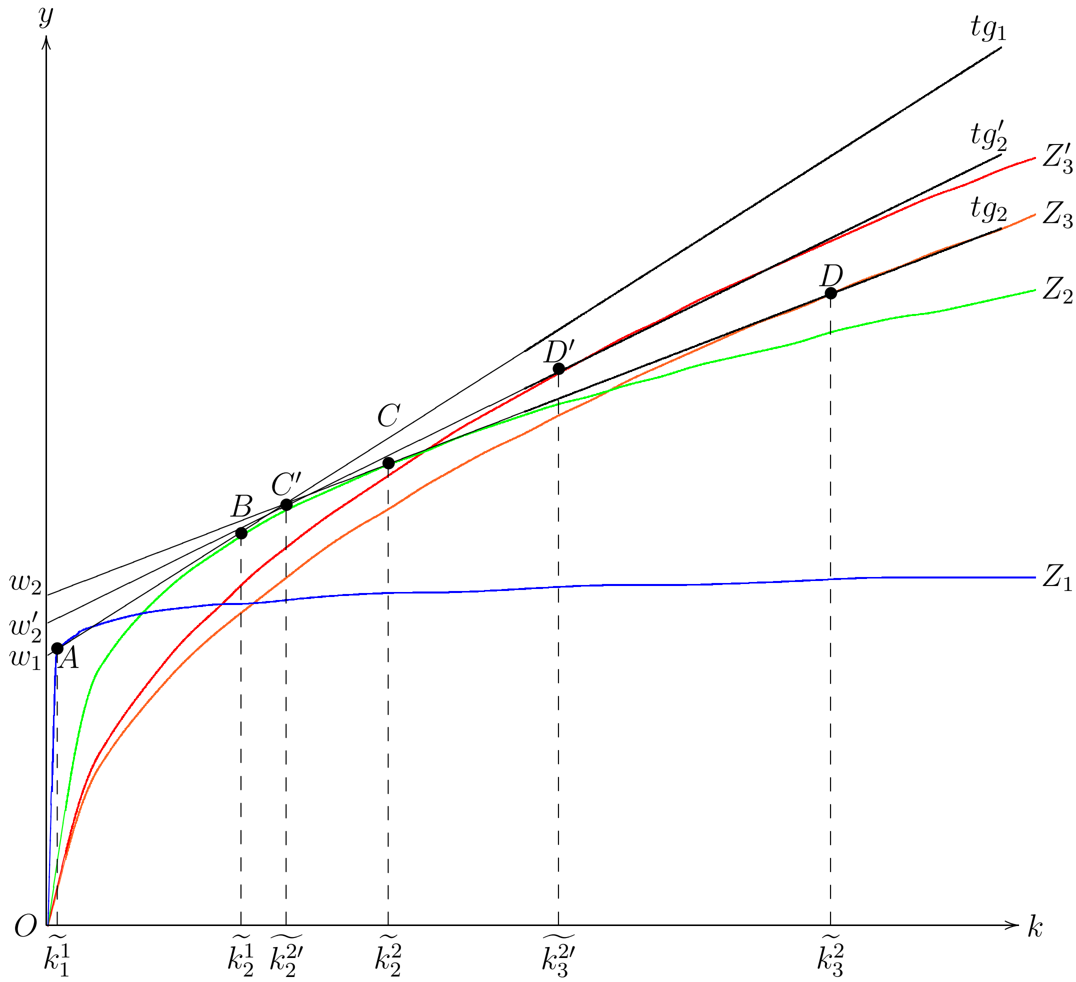

Figure 8: Technological Progress and the Deardorff Production Function

2.2.2 The Deardorff Production Function

The most natural way to analyze technological change is to use a diagram with production or revenue functions. Figure 8 illustrates the same initial situation as figure 4. The production functions of each sector are given by Z_1, Z_2 and Z_3, and the initial Deardorff Production Function is established by the convex hull $OABCD$. The lines of tangency, tg_1 and tg_2, with the boundary points AB and CD connect the production function of different sectors and determine the cones of diversification. Both cones are given by the capital-labor ratios $\widetilde{k_1^1}$, $\widetilde{k_2^1}$ and $\widetilde{k_2^2}$, $\widetilde{k_3^2}$. These capital-labor ratios are the same as the ones stated in the Lerner-Pearce Diagram.

The already mentioned productivity increase in the third sector shifts the corresponding production function Z_3 to Z_3'. This movement is *Harrod-neutral* and results in a new Deardorff Production Function, $OABC'D'$. Note that the flatter tangent, tg_2, connecting sector two and three changes its slope and position to tg_2' because of the outward shift of Z_3 to Z_3'. This is also reflected by the change of the boundary points C and D to C' and D'. As no change in technology is assumed for sector one and two, the position of production functions and the slope of the tangent tg_1 do not change.

The distinctive feature of the technology driven change is that the borders of the second cone of diversification approach the first one. The capital-labor ratios of cone 2 change from $\widetilde{k_2^2}$ to $\widetilde{k_2^{2\prime}}$ and $\widetilde{k_3^2}$ to $\widetilde{k_3^{2\prime}}$. Since tg_2' is now flatter than tg_2, the set of factor prices in both cones are becoming more equal. With a big enough shift of the third production function, tg_2 and tg_1 would merge, thus having the same slope and intercept. In Figure 8, the wage of cone 2 changes from w_2 to w_2', moving closer to w_1 in cone 1. Also the capital rent increases, which is shown by the steeper slope of tg_2' compared to tg_2.

Contrary to Deardorff (2001), this paper considers technological progress – not savings – as the main force that influences the pattern of diversification. Trade theory shows that countries may find themselves in different cones with different sets of factor prices. Growth theory may give an answer whether the world economy – once in a situation with several cones – may change or improve to a situation with one cone and a equalized set of factor prices within that cone. The analysis above suggests that technological progress could be one of the driving forces that may lead to a reduction of global factor price diversity.

To illustrate the above reasoning, consider a country which is specialized in the production of good two. Point S in Figure 9 represents the initial steady state for this country. Recalling the assumption of a fixed proportional savings rate, technological progress results not only in a shift of the Deardorff Production Function but also of the savings function. Several effects can be recognized in the diagram. The steady state moves from S to S' and the economy faces a higher

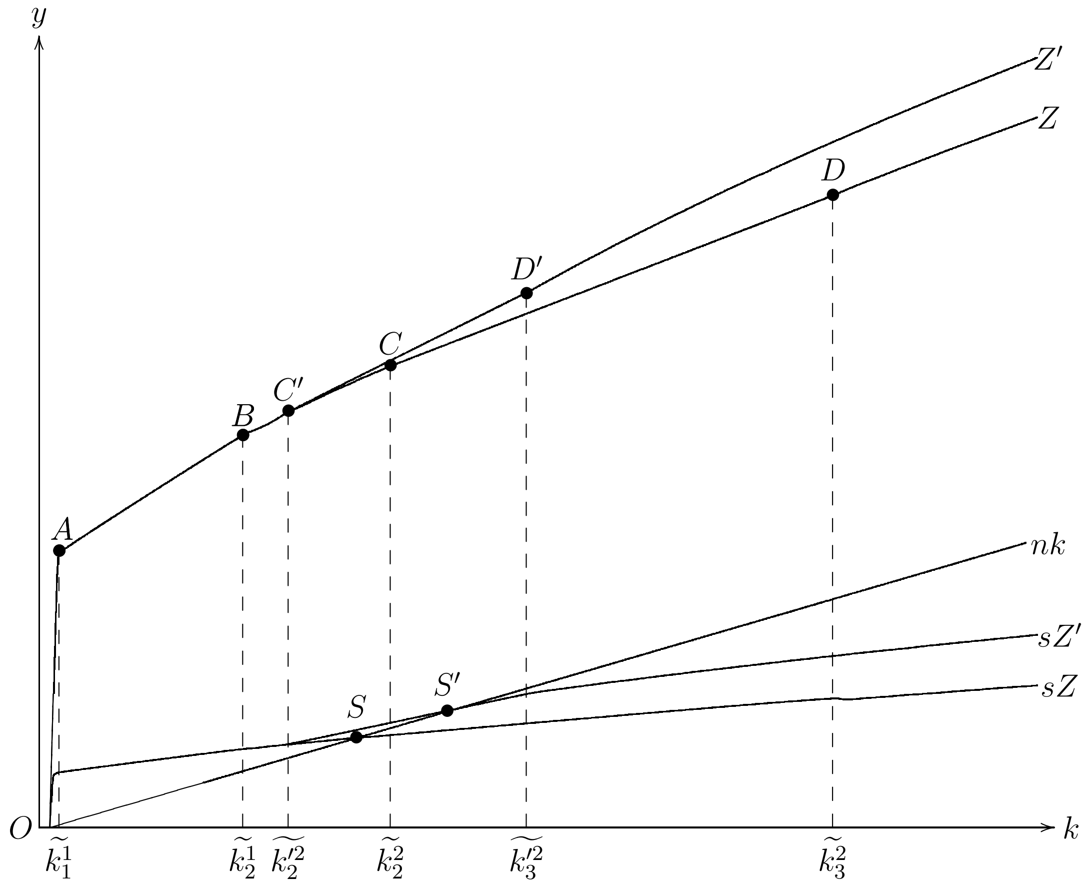

Figure 9: Entering the Cone

per capita income. Due to the shift of the borders of cone 2, the country's new steady state lies within that cone. The country is no longer specialized in the production of good X_2 but produces both goods X_2 and X_3 because this is now consistent with profit maximizing firms. The country is now a member of the club of high income countries in cone 2 with factor prices equalized within that cone. In case the technological progress leads to a one cone solution, factor prices would be equalized for a set of countries which are not too diverse in their factor endowments and saving rates.

3 Conclusions

In several steps, this paper analyzes the relationship between economic growth and the existence of a one-cone versus a several-cones trade equilibrium. Section 1 introduces the basic framework of the analysis and extends the usual 2x2 Heckscher-Ohlin world by one dimension, resulting in three goods and two factors of production. Besides the Learner-Pearce diagram the concept here called the "Deardorff Production Function" is extensively used throughout this paper. This function is derived by transforming the production functions to revenue functions of all sectors. The resulting convex hull then defines an overall production function for an economy, with either one or several cones of diversification.

Section 2 shows how the standard neoclassical trade model and the Deardorff Production Function can be combined. For simplicity, Cobb-Douglas production technologies and proportional savings are assumed. It is then possible to describe a trade equilibrium with two cones, where the steady state may lie within or outside one of those cones, depending on the savings rate. In the steady state, without differences in the savings rate, there are no ever-lasting differences of factor endowments and factor prices.

Furthermore, section 2 tackles the main question of this paper whether an initial situation with several cones of diversification and two different sets of factor prices is changed by technological progress. Assuming Harrod-neutral technological progress in the most capital-intensive sector, the capital intensities bordering the cones of diversification substantially change - in contrast to the models in Deardorff (2001). This is shown in both the Learner-Pearce and the Deardorff Production Function framework. The differences between the crucial factor intensities shrink, with an one cone solution as a special border case. This goes hand in hand with a lower difference between factor prices in both cones, again with the special border case of factor price equalization.

The message of this paper is less discouraging as Deardorff (2001) concerning the prospects of labor-intensive and low-income countries. Figure 9 gives an example of a possible catching up of a country. Technological progress may encourage less factor price diversity. In the neoclassical growth model in the tradition of Solow (1956), it is technological progress that is the driving force of economic development. The analysis of the relationship between growth and trade should thus take technological progress into account.

This paper shows that it is crucial in which sector technological progress arises. Interestingly, it is progress in the most capital-intensive sector that opens the door for a catch-up process of countries producing relatively labor-intensive goods in the initial situation.

However, some extensions of this analysis are obvious, since several simplifying assumptions are used in this paper. To keep the analysis tracetable within the framework used here, the assumption of constant good prices is crucial. Thus, it would be interesting to include possible changes in the system of relative good prices because of technological progress in the production of one good in the analysis. Furthermore, other assumptions on the savings behavior could be drawn, as in Deardorff (2001). On the empirical side, this analysis emphasizes that it is important to know whether technological progress arises more likely in the more capital-intensive or in the more labor-intensive sectors.

References

Acemoglu, D. (2002): Technical Change, Inequality, and the Labor Market. In: *Journal of Economic Literature 40: 1* - pp. 7-72

Ben-David, D. / Nordström, H. / Winters, L. A. (1999): *Trade, Income Disparity and Poverty.* (WTO - Special Studies). Geneva - 69 p.

Choi, E. K. (2002): *Implications of Many Industries in the Heckscher-Ohlin Model.* [Paper presented at a workshop of the Kiel Institute for World Economics, 25 November 2002, to be published in the Handbook of International Trade.]. - 43 p.

Deardorff, A. V. (1974): A Geometry of Growth and Trade. In: *Canadian Journal of Economics 7: 2* - pp. 295-306

Deardorff, A. V. (1994): The Possibility of Factor Price Equalization, Revisited. In: *Journal of International Economics 36* - pp. 167-175

Deardorff, A. V. (2001): Does Growth Encourage Factor Price Equalization? In: *Review of Development Economics 5: 2* - pp. 169-181

Deardorff, A. V. (2002a): *Introduction to Two-Cone HO Equilibrium.* [Handout for students, published on the website http://www.econ.lsa.umich.edu/∼alandear/courses/441/handouts/]. University of Michigan

Deardorff, A. V. (2002b): *Introduction to the Lerner Diagram* [Handout for students, published on the website http://www.econ.lsa.umich.edu/∼alandear/courses/441/handouts/]. University of Michigan

Dixit, A. K. / Norman, V. (1980): *Theory of International Trade. A dual, general equilibrium approach.* Cambridge MA: Cambridge University Press - 339 p.

Eatwell, J. / Milgate, M. / Newman, P. (Hrsg.) (1987): *The New Palgrave. A Dictionary of Economics.* London: Macmillan

Ethier, W. (1984): Higher Dimensional issues in trade theory. In: Jones, R. W. / Kenen, P. B. (Hrsg.) (1984): Handbook of International Economics, Vol. I. - pp. 131-184

Gundlach, E. (2001): *Interpreting Productivity Growth in the New Economy: Some Agnostic Notes.* (Kiel Institute for World Economics: Kiel Working Paper; 1020). - 28 S.

Hahn, F. H. (1987): Neoclassical Trade Theory. In: Eatwell / Milgate / Newman (1987): *The New Palgrave. A Dictionary of Economics*

Jones, R. W. (1987): Heckscher-Ohlin trade theory. In: Eatwell / Milgate / Newman (1987): *The New Palgrave. A Dictionary of Economics*

Jones, R. W. / Kenen, P. B. (Hrsg.) (1984): *Handbook of International Economics, Vol. I.* (Handbooks in economics; 3) Amsterdam u.a. : North-Holland

Solow, R. M. (1956): A Contribution to the Theory of Economic Growth. In: *Quarterly Journal of Economics 70* - pp. 65-94

Xiang, C. (2001): The Sufficiency of the 'lens condition' for factor price equalization in the case of two factors. In: *Journal of International Economics 53* - pp. 463-474

Appendix:

Selection of equilibrium: The lens condition

Extending section 1, this appendix discusses whether a world characterized by free trade ends up in a one-cone or a two-cone equilibrium. The necessary (Deardorff 1994) and sufficient (Xiang 2001) condition for FPE with perfect competition and constant returns to scale has been first worked out by Dixit and Norman (1980). They use the concept of an Integrated World Economy (IWE) as a starting point. In an IWE by definition both goods and factors of production are perfectly mobile across countries. In this framework, factor prices are equalized. The Dixit-Norman-condition is fulfilled if it is possible to reproduce the integrated world economy without international mobility of factors but with international trade of goods. Then the outputs of the integrated world economy can be produced by using the technology of the integrated world economy but without cross border mobility of labor and capital (Xiang 2001). Trade is then a substitute for the mobility of factors. In a world economy with the Dixit-Norman-condition fulfilled, there is FPE or an one-cone-equillibrium. However, if it is impossible for countries to produce the total amount of each good by fully employing their factor endowments, then an equilibrium with FPE will not occur.

The Dixit-Norman-Condition is best explained in an Edgeworth box set-up. A simple example shows how figures 1 and 2 are transformed. In order to keep it simple we redraw figure 1 for the case of two goods only. Assuming that point E in figure 10, which lies in between the rays of $\widetilde{k}_1$ and $\widetilde{k}_2$ and above the isocost line, is the total world's endowment of capital and labor. For the derivation of

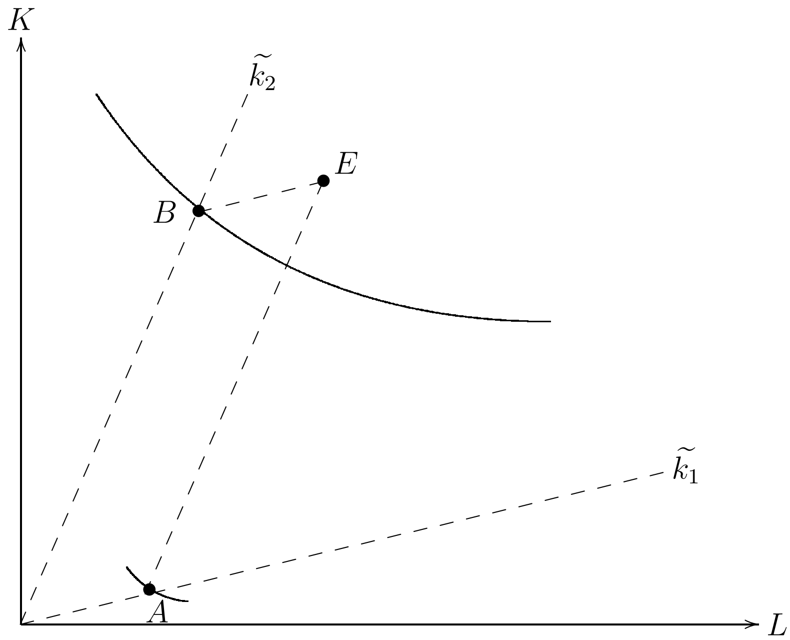

Figure 10: The Edgeworth Box in the Lerner Diagram

the isocost line, the principles from subsection 1.1 apply. The first step towards deriving the Edgeworth box is to sketch two straight lines from point E to the ray $\widetilde{k}_1$ and $\widetilde{k}_2$ which are parallel to both lines in order to get a parallelogram. The next step is to draw isoquants through the corners of the new parallelogram. Both points A and B show the factor allocation of labor and capital. They also denote each country's output of both goods.

The simple introduction shows how the Edgeworth box is set up. In order to show whether FPE is possible with two countries, two factors of production and three goods, Deardorff (1994) uses this kind of Edgeworth box to better visualize the condition. The set-up of the Edgeworth box in figure 11 is as usual, on the horizontal axes are the world's endowment of labor, on the vertical axes are the world's endowment of capital. The lower left corner represents the Home country's endowment, while the upper right corner shows Foreign country's endowment. In order to show how FPE evolves in an IWE with three goods one needs to go back to figure 1. Figure 1 shows a single set of factor prices for producing all three goods when the relative goods prices were determined in such a way that no profit opportunities existed. Thus, the IWE prices are consistent with a one-cone solution. To satisfy the world demand of goods, the countries employ their factors of production according to the capital-labor ratios $\widetilde{k}_1$, $\widetilde{k}_2$, and $\widetilde{k}_3$. Again, the quantity produced by the two countries depends on the allocation of factor endowments. Figure 11 shows the result in an Edgeworth box.

Starting from the Home country, the vectors $\widetilde{v}_1$, $\widetilde{v}_2$ and $\widetilde{v}_3$ show the amount of labor and capital used to produce good X_1, X_2 and X_3 at the corresponding labor-capital ratios $\widetilde{k_1}$, $\widetilde{k_2}$ and $\widetilde{k_3}$ for each industry in the IWE. By including the same vectors for the Foreign country starting in the upper right corner, the result is an six-sided plain. This plain represents the factor allocation between both countries for which FPE is given.

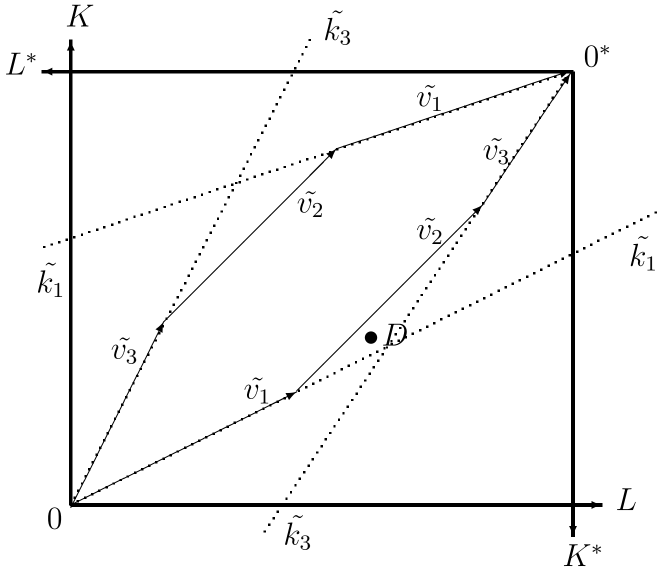

Figure 11: The Lens Condition

The polygon shows that with immobile factors of production an IWE can be replicated and FPE is possible. Any point outside the polygon corresponds to an allocation of factors of production and FPE is not given. This is the same result as seen in figure 1 which shows that any country which is outside the diversification cone, specializes its production in only one good. The two diversification cones of figure 2 can also be shown in figure 11 by point D. Even if point D lies between the capital-labor ratios $\widetilde{k_1}$ and $\widetilde{k_3}$, FPE does not occur.

From figure 11 it can be seen that if factor endowments are similar enough, the FPE will be possible and world prices will define a single diversification cone as in figure 1. Increasing the number of goods, the polygon would be transferred into a FPE lens. Again as in the case of only two or three goods, the diagonal of the box would be included and thus shows again that if factor endowments are similar enough, an one-cone solution is likely.