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# Technological Change, Trade, and Endogenous Factor Endowments

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**Technological Change, Trade, and Endogenous Factor Endowments***

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## Abstract

Factor endowments are usually taken as given in trade theoretical analyses of technological change. We use the Deardorff (1974) diagram to show how the steady state capital labor ratio endogenously adjusts to technology shocks in a two-sector small open economy, an effect which has largely been neglected in trade theory literature. We show that ignoring the endogeneity of the capital labor ratio with respect to technology shocks leads to biased predictions of changes in sectoral production and trade. Imposing stylized facts of growth as restrictions, we assess the relative size of the implied prediction bias that appears to matter for empirical studies of trade.

Keywords: Deardorff diagram, techology shock, factor endowments, factor bias, sector bias

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## 1. Introduction

The effects of technological change and low-skilled imports on employment and wages in advanced countries have received considerable attention in the literature. For instance, Leamer (1998) and Krugman (2000) discuss whether the factor bias or the sector bias of a technology shock matters for relative factor prices. They reach opposing views that are consistent under the specific assumptions being made on the nature of the technology shock and on the size of the economy. Xu (2001) generalizes this debate with reference to a wider range of preferences and technologies for a two-by-two Heckscher-Ohlin model. Findlay and Jones (2000) use a three-by-two model for a small open economy to point out that a technology shock in a labor intensive sector may push a country out of its cone of diversification such that the wage could fall, contrary to the prediction of a standard two-by-two model.

A common feature of these studies is that the factor endowments of countries are taken as given. Hence the impact of technical change on wages, production volumes and trade is held to be driven by the renewed optimization of input decisions after the technological shock occurs, thereby holding constant the capital labor ratio of the economy. This is peculiar because technological change is bound to have an impact on the steady state capital labor ratio. For instance, the traditional neoclassical growth model (Solow 1956) predicts that factor biased (Harrod neutral) technological change will cause the economy’s capital labor ratio to rise until the initial capital output ratio is reestablished in the new steady state. We show that ignoring the endogenous adjustment of the economy's capital labor ratio to a finite technology shock in a two-sector model results in a biased prediction of the change in the pattern of sectoral production.

Our point is illustrated by means of the Deardorff (1974) diagram. This diagram features a competitive two-sector economy with homogeneous production functions. Conditional on assuming that savings is proportional to income, it has been used to describe the transitional dynamics of a small open two-sector economy that adjusts to its steady state capital labor ratio by variation of its growth rate and its pattern of specialization.[3] The neglected major advantage of the Deardorff diagram is that it can also identify how a finite technology shock by itself affects the steady state capital labor ratio in a two-sector economy, in line with the basic insight of the traditional neoclassical growth model (Solow 1956).

3. See Deardorff (2001) for a discussion of the effects of alternative savings assumptions on factor price equality across cones of diversification.

Accordingly, the Deardorff diagram can be used to give a complete analysis of the sectoral consequences on production and trade due to technological change.

The structure of our paper is as follows. Section 2 provides a brief summary of the Deardorff diagram. Section 3 demonstrates the effect of a finite technology shock on the steady state capital labor ratio, on the pattern of specialization, and on relative factor prices. Section 4 compares our results with some stylized facts from growth analyses and considers possibilities to reconcile facts and findings. Section 5 concludes.

## 2. The Deardorff Diagram in a Nutshell[4]

The model economy has an investment good, $I$, and a consumption good, $C$, which are produced with the two factor inputs capital, $K$, and labor, $L$, with exogenous levels of technology, $A_j$, $j = C, I$. In terms of output per worker, the two linear homogenous production functions are given by

$$\overline{I} / L_I = f_I\left(A_I, K_I / L_I\right) = f_I\left(A_I, k_I\right) \tag{1}$$

$$\overline{C} / L_C = f_C\left(A_C, K_C / L_C\right) = f_C\left(A_C, k_C\right) \ , \tag{2}$$

where each production function exhibits diminishing returns to the two factor inputs. Bars indicate the supply of goods, demands for goods $C$ and $I$ will later be denoted without bars.

When the per capita production functions (1) and (2) are each multiplied by their given output price such that

$$z_I = p_I f_I\left(A_I, k_I\right) \tag{3}$$

$$z_C = p_C f_C\left(A_C, k_C\right) \ , \tag{4}$$

they can both be drawn in a single diagram with revenue per labor, $z_j\ \left(j = C, I\right)$, as the vertical axis and capital per labor as the horizontal axis (Figure 1). In a competitive equilibrium, goods will be produced when the value marginal product of capital equals the rental rate of capital. The revenue functions for the consumption good (light grey) and the

4. For a more detailed discussion, see Deardorff (1974). We mainly maintain the original notation, except that we include a term to identify the level of technology.

investment good (dark grey) are then connected by a common tangent,[5] $AB$, implying that the national revenue function of the two-sector economy, $z = 0ABz_I$, can be thought of as the "hull" of the revenue functions of the two sectors. The national revenue function identifies the ranges of capital labor ratios for which only consumption goods can be competitively supplied ($0\bar{k}_C$), for which both goods can be competitively supplied ($\bar{k}_C\,\bar{k}_I$), or for which only investment goods can be competitively supplied ($>\bar{k}_I$).[6]

(insert Figure 1 about here)

For given goods prices and given technology, the aggregate revenue function describes national per capita income in units of the numeraire good – we will use the investment good for that purpose – as a function of the economy's capital labor ratio. Information on factor prices can be read off from this curve in the same way as it is read off from an aggregate production function in the one-sector-economy: the slope at the point of operation equals the competitive capital rent, $r = \tan\alpha$, and the vertical intercept of a tangent to the point of operation equals the competitive wage, $w$.

The projections on the horizontal axis of the points of tangency to the national per capita revenue curve – the perpendiculars $AE$ and $BF$ – confine the range of capital labor ratios within which both goods will be produced, i.e., they determine the cone of diversification. Hence for all ratios between $\bar{k}_C$ and $\bar{k}_I$, factor prices are the same and consistent with diversified production patterns. For any capital labor ratio within the cone of diversification, and for given goods prices and technology, the diagonals $AF$ and $EB$ can be used to identify the sectoral pattern of production. For instance, the economy would only produce the consumption good if it had a capital labor ratio of $\bar{k}_C$, as in point $E$. The supply of the consumption good falls when the capital labor ratio rises and can be read off as the vertical difference between the diagonal $AF$ and the capital labor ratio of the economy. When the economy has a capital labor ratio of $\bar{k}_I$ or beyond, it only produces the investment good. The corresponding production share of the investment good can be read off as the vertical difference between the diagonal $EB$ and the capital labor ratio. This equals the

5. The possibilities of no common tangent or more than one common tangent are excluded by assumption.
6. At this point, the similarity between the Deardorff diagram and the Lerner diagram will become apparent, with the linear part of the "hull" indicating the cone of diversification.

vertical difference between the linear part of the hull and the diagonal $AF$ as sectoral production values add up to the national production value.

Much like the Lerner diagram (Lerner 1952), the Deardorff diagram can be used to study the adjustment of a small open economy to shocks in goods prices and factor endowments. Different from the Lerner diagram and as shown by Deardorff (1974), it can also be used to study the adjustment of a small open economy to its steady state capital labor ratio for a given level of technology. The reason is that the national per capita revenue curve of the small open two-sector economy plays the role of the single per capita production function in the one-sector economy. Hence comparing an initial steady state with a new steady state due to a finite technology shock can also proceed along the lines suggested by Solow (1956) for the one-sector economy. This is a major advantage of the Deardorff diagram over the Lerner diagram. It allows for a complete treatment of the production and trade effects of technological change since it also includes the effect on the endowment ratio.

To determine the steady state capital labor ratio, a per capita savings function and a capital dilution function can be inserted, which turns the Deardorff diagram into a textbook Solow growth model. The standard assumptions are that there are constant proportional rates of population growth, $n$, and capital depreciation, $\delta$, that investment always equals savings, and that savings is a constant fraction, $s$, of national income[7]. Hence,

$$dL/L = n \tag{6}$$

$$dK = I - \delta K \tag{7}$$

$$I/L = sz \tag{8}$$

$$dk = (I/L) - (\delta + n)k \tag{9}$$

where $d$ denotes the change of a variable over time.

Assuming that goods prices and technology are constant and setting $p_I = 1$, this implies that the per capita savings function mimics the national per capita revenue curve, $z$, with $s$ as the factor of proportion. Per capita savings and investments are given by $I/L$, and the effective capital depreciation locus is $(\delta + n)k$. Steady-state equilibrium is where per

7 Our focus is on the trade-technology nexus and we therefore ignore that a small open economy may also borrow or lend capital on international markets.

capita savings are just sufficient to keep the per capita capital stock constant, point $G$ in the figure. Hence the steady state capital labor ratio, $k^*$, is determined by the savings propensity and sectoral technologies, among other things.

As drawn, an economy with the steady state capital labor ratio $k^*$ would produce relatively more of the labor intensive consumption good. This can be seen by comparing the lengths of the vertical intersections of $k^*$ with the diagonals $AF$ (consumption good) and $EB$ (investment good). Therefore, the supply of the investment good would fall short of the domestic demand for the investment good, which is given by $k^*G$. Hence, in this particular case the economy exports consumption goods and imports investment goods. In the following, we will show how a finite technology shock affects sectoral production patterns and trade when the capital labor ratio is endogenous.[8]

## 3. The Effects of a Technology Shock in the Two-Sector Model

Figure 2 demonstrates the effects of a finite positive technology shock in the investment good sector. The sector specific technology shock is represented by an upward shift of the per capita revenue function of the investment good, so the new national per capita revenue curve is given by $0A'B'z_I'$. Several implications arise.

(insert Figure 2 about here)

An upward shift of the $z_I$-curve implies that the linear stretch of the national per capita revenue function becomes steeper – the wage-rental ratio goes down – and the cone of diversification changes. As Figure 2 is drawn, the cone of diversification moves to the left to $E'F'$.[9] Corresponding to the new national per capita revenue function, there is a new per capita savings function, $sz'$, which determines the new steady state with the higher capital labor ratio $k^{*}{}'$ at $G'$. Since the new steady state lies within the new cone of diversification, the economy continues to produce both goods after the technology shock.[10] The capital-labor intensities of competitive production have however changed: technological change in the

8. Deardorff (2001) uses the diagram to show how alternative assumptions about savings may affect the likelihood and persistence of a multi-cone world in the presence of economic growth.
9. Depending on the curvature of the two per capita revenue functions, the cone of diversification may also grow.
10. Deardorff (1974) considers a case where the new steady state after a price shock lies outside the cone of diversification.

capital-intensive investment good sector implies that both goods become more labor intensive.[11]

The effect of a technology shock on the steady state capital labor ratio is of course well known from discussions of the textbook Solow model, but this effect is usually ignored in discussions of technical change in the textbook two-by-two trade model, where factor endowments are taken as given. Ignoring the adjustment of the economy's capital labor ratio in response to a technology shock does not have an effect on the predicted change of the cone of diversification. As can be easily verified from the diagram, sector specific technological change in the capital intensive sector makes the cone of diversification more labor instensive, while technological change in the labor intensive sector – here the consumption good – makes the cone of diversification more capital intensive. However, ignoring adjustments in the capital labor ratio leads to biased predictions of the sectoral reallocation of production and trade volumes.

Figure 3 reveals the size of the prediction bias that would occur from ignoring the change in the steady state capital labor ratio. As explained, the revenue levels of the consumption good and the investment good can be read off from the crossings of the diagonals of the cone of diversification, $AF$ and $A'F'$ (or alternatively $EB$ and $E'B'$) with the vertical intersection of the steady state capital labor ratios. For given goods prices, the sectoral revenue levels reflect the sectoral production values. Hence the initial production value of the consumption good is given by the length of the light grey vector at the initial steady state $k^*$ and the initial production value of the investment good is given by the length of the dark grey vector at $k^*$. The technology shock moves the cone of diversification and the steady state, so the new level of production of the consumption good is given by the much shorter light grey vector at $k^{*}{}'$ and the extended production of the investment good by the dark grey vector at $k^{*}{}'$. Without taking into account that the technology shock affects the capital labor ratio, i.e., by keeping the steady state constant, one would have predicted a level of production of the consumption good of $k^*H$, which is higher than the true steady state value.

Figure 3 also shows the corresponding bias in predicted trade volumes. The technology shock turns the country into a large exporter of the investment good. At the new steady state capital labor ratio, the value of the production of the investment good is given by the length of the dark grey vector at $k^{*}{}'$, which exceeds domestic demand for the investment

11. This is inconsistent with the stylized facts of growth, an issue we will deal with in the next section.

good as given by $k^*{}'G'$. This effect is at least underestimated when the factor endowment change is ignored. Keeping the old steady state constant at $k^*$, Figure 3 would predict the difference between the domestic supply and the domestic demand of the investment good as given by $MG$. This difference between supply and demand is substantially smaller than the unbiased difference given by $NG'$ at the new steady state $k^*{}'$.

The actual size of these prediction biases is an empirical question, but its existence is a theoretical question. We think that the prediction biases have largely gone unnoticed in the trade theory literature because of the popularity of the Lerner diagram, where the endowment effects of technological change cannot be deducted. By using the Deardorff diagram, this is mended for.

(insert Figure 3 about here)

## 4. Consistency with Stylized Facts

The problem with Figure 3 is that it predicts a fall of the wage and a rise of the capital rent for all economies within the cone of diversification after a technology shock in the capital intensive investment good sector. This outcome is in conflict with the stylized facts. At least in the developed economies as a group, wages have persistently risen relative to the capital rent for more than a century, notwithstanding the presence of tremendous technological change.

According to Kaldor (1961), modern economic growth can be characterized by the following stylized facts: the shares of capital and labor in total factor income remain constant, the economy's capital output ratio remains constant (so by implication the capital rent remains constant), and technology, wages, and the capital labor ratio all grow with the same long-run rate. These stylized facts appear to be consistent with the long-run time series evidence for the United States, and they also appear to be consistent with cross-country evidence (Gundlach 2007). Moreover, they can be derived as steady state predictions from the Solow model (Solow 1956).

To reconcile the two-sector model of Figure 3 with the stylized facts for an economy that continues to produce both goods, the national per capita revenue function must be shifted in a way that increases the wage for a constant capital rent and leaves the capital output ratio unchanged. For given goods prices, such an outcome can only occur under two conditions.

First, it is not possible that the technology shock only happens in one sector. If it does, the factor price ratio $w / r$ will change in a way that either the wage or the capital rent falls, which is inconsistent with the stylized facts. In order to generate a parallel shift of the linear part of the national per capita revenue function, there has to be technological change in both sectors as a necessary condition, unless one allows for an increase of the price of the good that is produced in the sector without a technology shock.[12]

Second, the new steady state that results from a shift of the national per capita revenue function can only display a constant capital output ratio if the shift is Harrod neutral.[13] That is, the old and the new national steady state per capita income must both lie on a straight line through the origin, because the inverse of the slope of such a line in the $z, k$ -space equals the capital output ratio.

Starting with the same initial steady state as in Figures 1-3, Figure 4 takes account of both conditions. The technology shock in the investment good sector is also the same as before, but now there is a technology shock in the consumption good sector as well. A technology shock in both sectors does not guarantee but allows for a parallel shift of the linear segment of the national per capita revenue function. The corresponding shift of the savings function to $sz''$ determines the new steady state $G''$ at the intersection with the capital dilution function. Per capita income in the new steady state is given by $z^{*}''$, which lies on the same straight line through the origin $0R$ as the initial steady state per capita income $z^{*}$ and hence exhibits the same capital output ratio. Of course the latter outcome is also not guaranteed by the shift of the per capita revenue function, but to accommodate a constant capital output ratio the shift of the per capita revenue function has to be Harrod neutral. Conditional on the assumptions being made, the two-sector model of Figure 4 is consistent with the aggregate stylized facts predicted by the Solow model.

(insert Figure 4 about here)

12. In the present paper, we maintain the small country assumption and do not further discuss the possibilities and complications that arise with endogenous goods prices. For a discussion of the effects of technological change on goods prices in a two-cone trade model, see Becker and Gundlach (2007).
13. For the economy as whole, a technology shock will only lead to a new steady state equilibrium with a constant capital output ratio if it is labor augmenting, i.e., if it is Harrod-neutral, given that there are no functional restrictions imposed on the production function. If the technology shock were Hicks-neutral, the economy would end up in a new equilibrium with a different capital output ratio. So if the aggregate technology is Hicks neutral, the equilibrium changes in per capita income and the capital labor ratio would be partly due to the technology shock and partly due to additional capital accumulation, but if the aggregate technology is Harrod neutral, the equilibrium changes in per capita income and the capital labor ratio would be entirely due to the technology shock. See, e.g., Barro and Sala-i-Martin (1995) for a proof that the technology shock must be labor augmenting in order for the model to have a steady state equilibrium.

As is intuitively clear, the change in the sectoral pattern of production is less pronounced if the technology shock hits both sectors rather than one, for the simple reason that the cone of diversification will move by less if at all. This is shown in Figure 5, where the cone of diversification shifts to the right conditional on the underlying assumptions. Hence the production of the consumption good remains substantially larger in the new steady state as compared to the case where only the investment good sector is hit by a technology shock (see Figure 3). But the prediction bias clearly remains, as can be easily verified by comparing production levels at $k^*$ with those at $k^*''$.

An sideline result of Figure 5 is that the predicted supply of the consumption good in the new steady state $k^*''$ appears to be very similar in size to the one that was predicted for a technology shock in the investment good sector without taking into account that the steady state capital labor ratio adjusts, which is indicated by $k^*H$ (cf. Figure 3). This result cannot be generalized as it depends on the assumed sector bias of the technology shock. However, it reveals how empirical studies of trade may reach plausible conclusions based on theoretically unjustified restrictions. For instance, one may end up with realistic estimates of the pattern of specialization and trade (such as a value of production of the consumption good of about $k^*H$ ) by assuming a cross-country difference in the investment good technology and by ignoring that such a technology difference per se implies a cross-country difference in the capital labor ratio. Such an empirical strategy would be entirely misleading, however, not only because it would be the effect of a technology shock on the factor endowment ratio. Figure 5 also reveals that imposing the stylized facts of growth implies that the sector bias of a technology shock is larger in the consumption good sector than in the investment good sector.[14] It remains to be seen if empirical studies of trade could be improved by imposing the restrictions that there are aggregate Harrod neutral technology differences across countries and a relative bias of technology in labor intensive sectors.

(insert Figure 5 about here)

14. The relative size of a sectoral technology shock can be assessed by comparing the resulting shift of the revenue function at the initial factor price ratio (not shown), see, e.g., Findlay and Jones (2000).

## 5. Conclusion

The Deardorff diagram can be used, like the Lerner diagram, to predict the change in the sectoral pattern of production that follows from a finite technology shock. The advantage of the Deardorff diagram is that it immediately shows how the steady state capital labor ratio adjusts to a technology shock. Our impression is that the trade theory literature has largely neglected the endogenous change in the capital labor ratio that is at the core of the traditional neoclassical growth model. Ignoring the response of the capital labor ratio to a technology shock leads to biased predictions of the pattern of specialization and trade. Allowing for an endogenous capital labor ratio and using some stylized facts as restrictions, we can assess the relative size of the implied prediction bias. Our results suggest that empirical studies of trade may benefit from imposing the restriction that cross-country differences in Harrod neutral technology determine cross-country differences in steady state capital labor ratios.

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Figure 1. The Deardorff Diagram

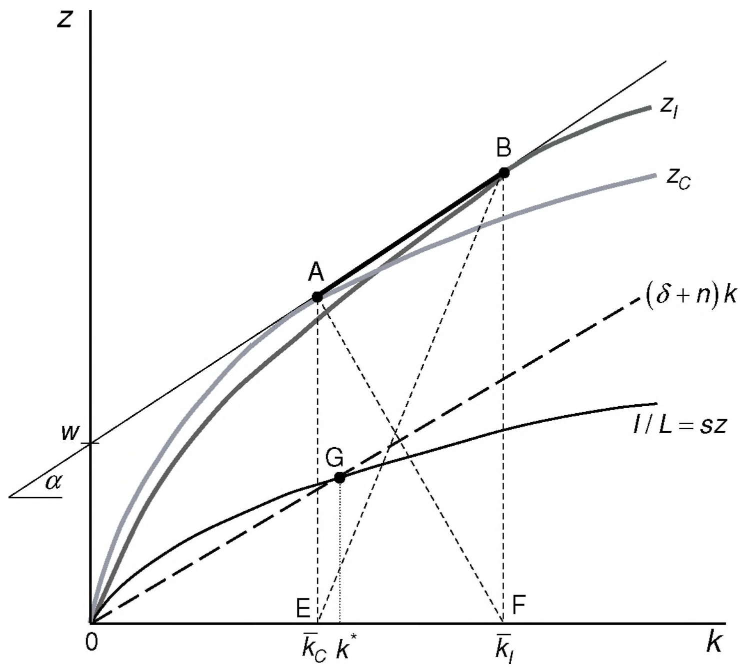


Figure 2. A Technology Shock in the Two-Sector Model

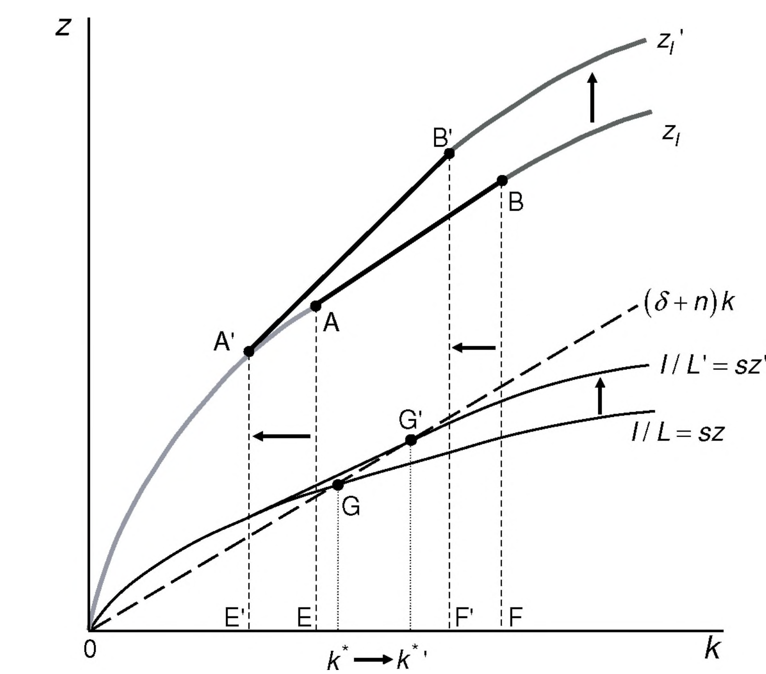

Figure 3. The Predicted Change in the Pattern of Specialization

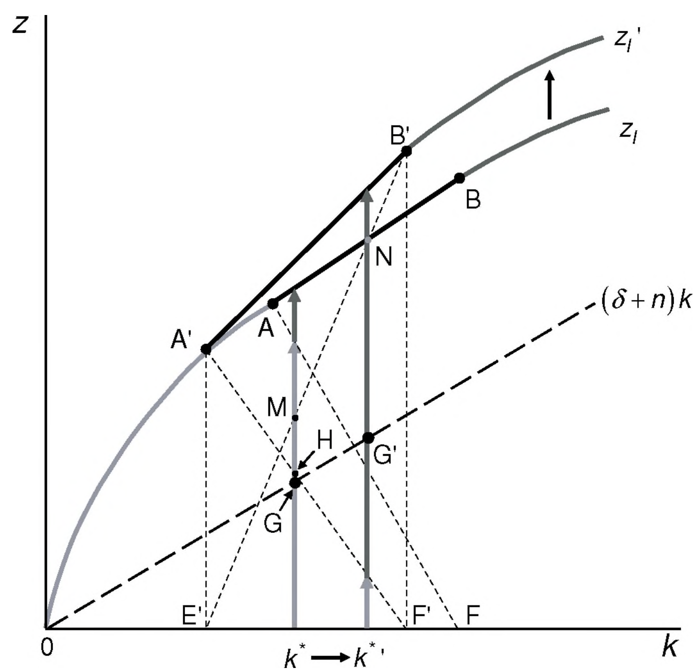


Figure 4. Reconciling the Two-Sector Model with Stylized Facts

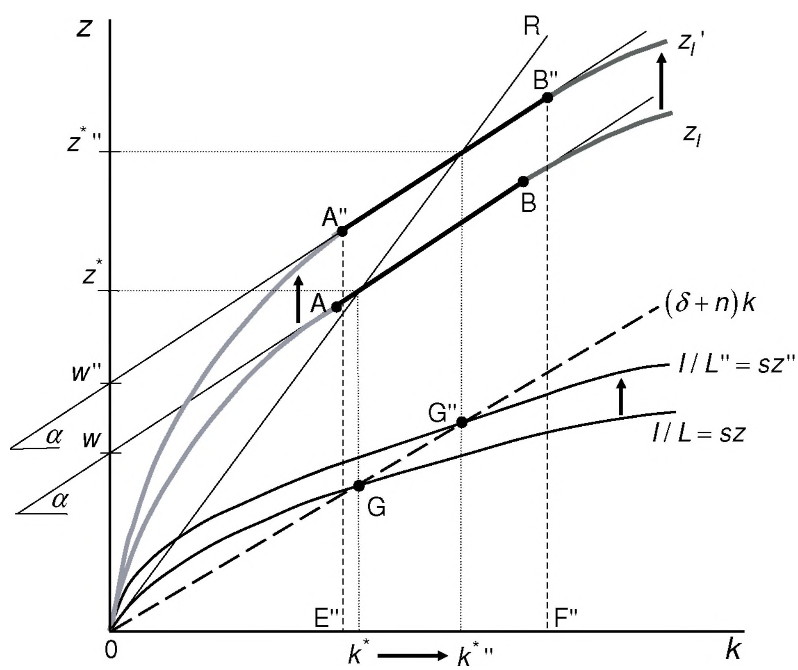

Figure 5. Stylized Facts and the Pattern of Specialization