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**Notes on Factor Price Equality and Biased Technical
Change
in a Two-Cone Trade Model***

by

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Notes on Factor Price Equality and Biased Technical Change in a Two-Cone Trade Model*

Abstract

We reconsider the effects of long-run economic growth on relative factor prices across cones of specialization. We model economic growth as exogenous technical change. Allowing for capital biased technical change with a sector bias and for endogenous commodity prices, we find that economic growth may increase or decrease factor price differences across cones. For a neutral demand side and capital biased growth in the most capital intensive sector, we find that economic growth encourages less factor price diversity across cones.

Keywords: factor price equality, economic growth, two cone trade model

JEL classification: F11, O40

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I. Introduction

The relationship between international trade and economic growth has always been of major interest in economic research. A recent paper by Deardorff (2001) addresses this topic by combining several neoclassical growth models with a two-cone Heckscher Ohlin (HO) model of international trade. Deardorff (2001) models growth as based on factor accumulation and thus considers which assumption about saving behavior might lead to factor price equalization (FPE) across countries with "large" initial factor endowment differences. He finds that neither an exogenous saving-income ratio (Solow), nor an exogenous saving-profit ratio (classical saving function), nor utility maximizing saving with infinite (Ramsey, Stiglitz) or finite life (Diamond) suggest that the capital stock in the labor abundant country would grow faster than in the capital abundant country. Hence alternative neoclassical growth models based on factor accumulation imply that factor endowments are unlikely to converge into a single cone with FPE.

We use a different starting point for modeling economic growth. We consider long-run growth as based on exogenous technical change, as in the seminal trade-and-growth paper by Findlay and Grubert (1959) and in the neoclassical growth model by Solow (1956). Findlay and Grubert (1959) use the Lerner diagram to show how growth in the form of exogenous technical change affects relative factor prices in a one-cone model of international trade. The subsequent discussion in the literature has mainly proceeded either within growth models with two goods or within higher-dimensional trade models without sector-biased or factor-biased growth.¹ Our contribution is to consider what a Solow-type modeling of growth implies for FPE in a two-cone trade model once the impact of exogenous technical change on relative commodity prices is taken into account.

With our modeling of growth, we find that growth does not encourage FPE if technical change is Hicks-neutral and simultaneously occurs in all sectors and if relative commodity prices remain unchanged, which resembles the result by Deardorff (2001). A more general result follows from our modeling of growth if we allow for capital biased technical change with a sector bias and for endogenous commodity prices. Depending on specific assumptions about technology and preferences, we then find that economic growth may increase or decrease factor price differences across cones of specialization.

¹ For surveys of this literature, see Findlay (1984) and Ethier (1984). For the effects of sector bias and factor bias of technical change on the interaction between trade and wages in the case of two goods, see Xu (2001).

We develop our argument in two steps. We first discuss how the two-cone equilibrium in the Lerner diagram is affected by capital biased and sector biased technical change. We then consider the general equilibrium effects of technical change on relative commodity prices when assessing the possibilities for FPE across cones, thereby following Krugman (2000). For a given set of assumptions about technology and preferences, we conclude that the growth process may actually bring the countries of the world closer together in terms of their effective factor endowments to permit less global factor price diversity.

II. Two Cones in the Lerner Diagram

Figure 1 is a Lerner diagram, where the curves labeled X_i ($i = 1,2,3$) are the unit value isoquants of the three goods that are produced with two factors of production, capital K and labor L , at given commodity prices p_i . The three isoquants represent alternative technologies for producing one euros worth of output. With $X_i = 1/p_i$, the relative position of an isoquant depends on the commodity prices and on the different techniques that are employed to produce the three goods.

Figure 1 illustrates a case where adding one good to the traditional HO setup with two goods and two factors of production leads to an equilibrium without FPE. Put differently, the world economy illustrated in Figure 1 cannot reproduce the equilibrium of a hypothetical integrated world economy (IWE), which would have perfect factor mobility.²As it is drawn, this outcome reflects a too diverse allocation of world factor endowments across countries for given levels of technology. More generally, the diversity in factor endowments that would be compatible with FPE was shown to be smaller for the case with three goods and two factors than in the traditional HO-model with two goods and two factors (Deardorff 1994).

In Figure 1, there is a free-trade equilibrium with two cones of diversification and two different sets of factor prices, where w_j is the wage rate and r_j the profit rate ($j = 1, 2$). Cone 1 includes countries with factor endowments between \tilde{k}_1^1 and \tilde{k}_2^1 , and equilibrium factor prices w_1 and r_1 . Cone 2 includes countries with factor endowments between \tilde{k}_2^2 and \tilde{k}_2^3 , and equilibrium factor prices w_2 and r_2 . Countries in cone 1 are labor-abundant and realize a lower wage relative to the countries in cone 2. Countries with factor endowments within cones

² The analytical concept of an integrated world economy (IWE) with perfect mobility of factors and goods is discussed in Dixit and Norman (1980), including the conditions for free trade in goods being sufficient to reproduce the IWE.

produce two goods. Countries with capital intensities outside the cones specialize in the production of just one good. Factors are mobile between different sectors but they do not leave their country. Within cones, factors share their rewards because of trade, but factor prices differ across cones.³ A major difference to a FPE-equilibrium is that different techniques of production are used in different countries to produce the good with intermediate capital-intensity, X_2 . In an integrated world economy, this would be inefficient. But the trading world economy here cannot reproduce the IWE just because the distribution of factor endowments is too unequal to allow for FPE for the given state of technology.

The question to be addressed is whether long-run economic growth would affect differences in factor prices across cones of diversification. If long-run growth is understood as a steady state process due to exogenous technical change, as in the Solow (1956) model, Figure 2 suggests a straightforward link between factor prices and growth: The position of all unit value isoquants in the extended Lerner-diagram with two cones depends on a given state of technology in all sectors. If commodity prices can be treated as fixed – a crucial assumption that will be relaxed later on – technical progress that occurs in any sector shifts the corresponding unit value isoquant inward and factor prices change accordingly.

For instance, the difference in factor prices across the two cones will tend to decline if technical change is relatively stronger in the production of the labor-intensive good 1 or in the production of the capital-intensive good 3, the latter as shown in Figure 2 with a relative decline of the wage in cone 1. But the difference in factor prices across cones (countries) will increase if technical change is relatively stronger in the production of the intermediate good 2. By contrast, a change in the relative position of the factor price lines in Figures 1 or 2 cannot arise if technical change uniformly affects the production of all goods in the same way, given that the assumption of fixed commodity prices is maintained. Hence it may seem at first sight that the sector bias of technical change is all that matters for the question of factor price convergence across different cones of specialization.

However, the factor bias of technical change also matters. Findlay and Jones (2000) show that capital biased technical change can cause a decline of the wage even if it is concentrated in the relatively labor-intensive sector, given that the country concerned has a factor endowment

³ One could allow for several countries within a cone that differ in a Hicks-neutral way and therefore do not share the absolute values of factor prices but only relative factor prices (see, e.g., Davis and Weinstein (2001)). But here we prefer to assume one country per cone (rich and poor), such that we have a world where both constituent countries are partially diversified in the production of two out of three goods.

near the border of two cones and ends up in a different cone after the technological adjustment has taken place.⁴ In addition, isolating the effects of technical change as in Figure 2 is based on the assumption that commodity prices do not react to technological shocks in a general equilibrium. This assumption implies that technical progress is limited to a small economy that cannot affect its terms of trade. Furthermore, it implies that the new technology is local in the sense that it is only available for firms in the same sector within the country, but not for firms located in a different country. In such a set up, the additional production possibilities generated by technical progress would not affect the goods market equilibrium of a trading world economy.

This restricted view of modeling technical change may sometimes be necessary to simplify the analysis, as in highly disaggregated trade models. But for a discussion of the effects of economic growth on relative factor prices across cones of specialization, modeling technical change without factor bias, without terms of trade effects, and as purely local appears to be a simplification of reality that may result in misleading thought experiments, as has been argued by Krugman (2000). Economic growth in the form of technical change has an impact on the goods market equilibrium in a trading world economy and this should not be assumed away when discussing the effect of growth on factor prices. Hence a less restricted view would hold that technical progress is likely to diffuse to other countries relatively quickly, not least through international trade in capital (-intensive) goods. This is not to deny that there may remain barriers to instant international technology diffusion, but it nevertheless appears that the assumption of fixed commodity prices is not appropriate for discussing our question whether growth encourages FPE in the world economy.

III. Technical Change and Wages in General Equilibrium

From a standard 2x2 trade model with exogenous commodity prices, it follows that it is the sector bias of technical change that determines the effect on relative wages. Extending the standard model to the case with three goods and 2 factors, Findlay and Jones (2000) question that the factor bias of technical change is immaterial for the effects on relative factor prices. Krugman (2000) argues that the factor bias of technical change is only immaterial once such a change takes place in a small open economy as opposed to an economy that can affect world

⁴ Following Findlay and Jones (2000), we consider an exogenous factor bias of technical change. That is, we do not model how an endogenous factor bias of technical change might reflect the relative price of production factors, as in Samuelson (1965) and more recently in Acemoglu (2003).

prices and where technical change occurs only in that economy rather than occurring simultaneously in other economies as well. We next define the factor bias of technical change and assess its effects in a 2x2 trade model with endogenous commodity prices. Introducing a third good into the model then allows us to study the conditions under which a two-cone free-trade world economy without FPE evolves into one that resembles the hypothetical integrated world economy with FPE.

III.1 Definition of Factor Bias

For the definition of the factor bias of technical change, a concept of neutrality is needed. There are at least three different ways to define neutral technical change in terms of an exogenous shift of the production function (see, e.g., Barro and Sala-i-Martin (1995, p. 33)). In the neoclassical production function $F[A(t)K, B(t)L]$, t is an index of time, and $A(t)$ and $B(t)$ are augmenting factors that are evolving over time. These factors represent the shift parameters of the production function. According to the Harrod concept of technical change, $A(t)$ is a constant but $B(t)$ is increasing. According to the Solow concept of technical change, $A(t)$ is increasing but $B(t)$ is constant. According to the Hicks concept of technical change, which is most popular in trade theory, $A(t)$ and $B(t)$ increase with an identical rate so that the production function can be written as $C(t)F[K, L]$, with $C(t) = A(t) = B(t)$.

Given these formal definitions of the various concepts of technical change, each variant can be identified as a specific shift of the production function that leaves unchanged the factor shares of capital and labor. Hence Hicks neutral technical change is defined as a shift of the production function that leaves unchanged the factor price ratio for a constant capital intensity. Solow neutral technical change is defined as a shift of the production function that leaves unchanged the real wage for a constant labor output ratio, and Harrod neutrality is defined as a shift of the production function that leaves unchanged the profit rate for a constant capital output ratio. Given these textbook definitions of neutral technical change, it follows that Harrod neutral technical change can be considered as an extreme form of capital biased technical change, which is the type of technical change considered in Figure 2.

When technical progress is no longer considered to be local but improvements are available worldwide, a trading world economy may be best modeled as a closed economy with endogenous prices. Our main interest is to clarify whether price reactions in the general equilibrium counterbalance the impact of technical improvements on relative factor prices. For example, the technical improvement in the most capital-intensive sector in Figure 2 is likely to be followed by a decline in the price of that good. This would shift the unit value

isoquant of good 3 back along a ray through the origin and the question is if there remains a net-inward shift due to technical change in order to maintain the tendency towards less factor price diversity across cones. We first discuss the effects of technical progress in a closed economy with two goods and will then reconsider the case considered by Deardorff (2001) with three goods and two cones of diversification.

III.2 Biased Technical Change with Two Goods

The Edgeworth-Bowley box diagram in Figure 3 can be used to calculate the net effect of technical change, including the price effect. We follow Krugman (2000) and assume that demand is homothetic and Cobb-Douglas so that income is spent in fixed proportions on the different goods. This is a convenient border case that simplifies the demand side of the model. There is one capital-intensive good, X_3 , and one labor-intensive good, X_2 . The length and the height of the box in Figure 3 correspond to the economy's endowment with the two factors capital and labor. The use of capital and labor in the X_3 sector is measured from the origin O_3 , factors employed in the X_2 -sector are measured from the origin O_2 .

The two solid curves X_3 and X_2 represent the initial situation. Their tangency point A gives the allocation of labor and capital in the X_3 -sector and in the X_2 -sector. The dashed line through A is the initial factor price line with slope $-(w/r)$. The dotted lines indicate the initial K/L -ratios in the two sectors. The isoquants are no longer unit value isoquants, hence they do not represent the input requirements for producing one euro worth of output. Instead, they now represent the input requirements for producing the worth of total output of good X_3 or X_2 , for given commodity prices in the initial situation.

For a start, we consider capital biased technical progress in the X_3 -sector. The curve X_3' is the resulting isoquant with a strong bias towards K , representing a situation where the amount of labor as measured in effective units has increased.⁵ The progress in technology is biased towards capital because for the initial factor price ratio w/r , an X_3 -sector firm would use relatively more capital than before (not shown in the figure). As a result of technical progress, the initial allocation of capital and labor no longer represents an equilibrium. Given the new technological possibilities, a different factor intensity would be optimal if the old factor price ratio would prevail. Furthermore, the initial allocation of factors would create an excess

⁵ We consider Harrod-neutral technical change as a form of capital-biased technical change that would be consistent with steady state growth for a general functional form of the underlying production function.

supply of good X_3 that is not matched by additional demand when income is spent in fixed proportions on the two goods.

There are two ways to restore equilibrium when demand is characterized by constant expenditure shares, namely a change in commodity prices or a change in factor allocations. We first consider the price adjustment. We choose good 2 as numeraire and thus a decline in the price of good 3 is one way to a new equilibrium as it would alter the position of the isoquant X_3' . The isoquant X_2 will remain at its position as neither the price of good 2 nor the underlying technology has changed. Also, let the quantity of good 2 be fixed for a moment. If only a price adjustment is possible, point B would be the new equilibrium where the isoquants X_3'' and X_2 are tangent to each other. Note that whereas the initial shift of the value isoquant was assumed to be capital biased (or Harrod neutral as in an extreme form), the subsequent change of a commodity price moves a value isoquant in exactly the opposite way as Hicks-neutral technical progress – hence a decline in price shifts the value isoquant like Hicks neutral technical regress.

If the decline in the price of good 3 happens to be large enough, this would restore equilibrium where the expenditure shares are the same as before the technical improvement. But this would also mean that all the additional income that is generated by technical progress would be used exclusively to consume more of the progressing good 3. This is a very special situation that would require the assumption of quasi-linear utility. With Cobb-Douglas demand, additional income would also be used to consume more of good 2. This implies that the isoquant X_2 would also move, not because of a price change or a change in technology, but because of higher quantities demanded by consumers at the same price. In such a case, the new equilibrium would be somewhere inside the lens spanned by X_3' and X_2 , which means that the additional higher consumption possibilities due to technical progress would result in a higher consumption of both goods.

What does this imply for the factor price ratio w/r ? If the new equilibrium would be in point B, the dashed factor price line w/r' would be flatter than the initial factor price line, indicating that the relative position of labor has been worsened by capital biased technical change and the subsequent change in the price of the progressing good. Capital-biased technical change implies that capital becomes more productive and hence it receives a higher relative factor reward. The same net-effect of capital-biased technical change can be found when the new equilibrium results somewhere inside the lens spanned by X_3' and X_2 . All other things constant, this result confirms that the effect of a capital biased (Harrod neutral)

technical change in the X_3 -sector is not completely counterbalanced by the resulting fall in the relative price of good 3 and, therefore, generates a tendency towards a less steep factor price line.

Further possibilities may be considered. If preferences (and demand) are still homothetic but the elasticity of substitution is lower than 1, the adjustment process in Figure 3 would be qualitatively the same, since the new equilibrium would still be inside the lens spanned by X_3' and X_2 , but closer toward the X_3' -isoquant. With an income elasticity of demand for good 3 that is less than 1, the expenditure share of the numeraire good 2 increases with the rise in its (relative) price that is induced by technical progress in the X_3 -sector. Producers of X_2 face additional demand and increase their output. Thus, in Figure 3, there would be an upward shift of X_3' as before but at the same time the then relevant X_2' isoquant (not shown) would be corresponding to a higher output level of good 2 than before.

In summary, we have four major effects of capital biased technical progress with homothetic preferences and a unit elasticity of substitution in a 2x2 trade model. First, there is a reallocation of labor away from X_3 - and towards X_2 -production. Second, the capital-intensity in the progressing sector increases. Third, the factor reward of capital rises relative to labor, as is represented by a flatter factor price line in the new equilibrium. The exact position of the new equilibrium point B depends – aside from the demand considerations just discussed – on the curvature of the isoquant X_3' and more generally on the elasticity of substitution between capital and labor in the production of both goods. Fourth, the *sector* bias of technical change does not matter for the change in relative factor prices, since technical progress biased towards capital in the production of good X_2 would have similar consequences. What matters in the present context is the *factor* bias of technical change, which changes factor intensities and relative commodity prices that cause changes in relative factor prices.

III.3 Cone Convergence Because of Biased Technical Change

In a model with three goods and two cones of diversification, the above logic still applies but a diagram like Figure 1 has to be used to sketch out the implications. To keep the analysis as simple as possible, we maintain the assumption that demand is Cobb-Douglas with fixed expenditure shares so that consumers want to spend additional real income in fixed proportions on all goods. As before, we consider capital-biased technical progress in the most capital-intensive sector. The direct effect of the technological improvement – namely an inward shift of the unit value isoquant of good 3 - is the same as before. But for the price effect – namely the subsequent outward shift of the unit value isoquant of good 3 - there is a

slight difference. Technological improvements in the capital-intensive cone 2 generate additional income that leads to additional demand not only for the goods 3 and 2, which are produced in that cone, but also for good 1, which is only produced in the labor-intensive cone 1. Thus for the given assumptions about demand, biased technical progress in the X_3 -sector and the subsequent decline in the price of good 3 relative to the price of the numeraire good 2 will cause a less pronounced increase in the output of good 2 if there are three goods in the model and not only two as in the previous subsection.⁶

The adjustment process in the labor-intensive cone 1 provides a further important insight. Even if output of good 1 or good 2 increases due to the additional income generated by technical change in the production of good 3, the respective unit-value-isoquants will not change for *this* reason. Only direct technical change or changes in relative commodity prices can alter the position of the unit value isoquants in cone 1 in a Lerner diagram. Good 2 is chosen as numeraire and therefore the corresponding isoquant does not move when technical change occurs in the most capital-intensive sector 3. If we maintain our assumption that additional income in the capital-intensive cone will lead to additional demand for good 1, it follows that this will in part lead to a higher output of good 1 and in part to a higher (relative) price of good 1. A higher price of good 1 shifts the unit value isoquant inward, because less capital and labor is then necessary to produce one euros worth of output.⁷ In a Lerner diagram like Figure 1, this would mean that the slope of the unit value isocost line in cone 1 becomes steeper because of a demand-induced increase in the relative price of good 1 that causes an inward shift of the unit value isoquant X_1 . All other things constant, this effect would imply that the factor price ratio in cone 1 becomes steeper and thus changes towards less factor price diversity across cones.

The question remains how the adjustment process with endogenous commodity prices would look like in the capital-intensive cone 2. In the last subsection, we have discussed the reallocation of capital and labor for an integrated economy with 2 goods. We have seen that it is impossible to determine the exact position of the new allocation of capital and labor in the capital-intensive cone without detailed knowledge of the parameters of utility if the adjustment process comes about both through a decline of the relative price of good 3 and

⁶ With three goods in the model rather than with two, our qualitative results for the change of relative factor prices tend to hold for a wider range of parameters for the elasticity of substitution in demand.

⁷ We assume throughout the paper that there is no situation where the endowments of the labor-intensive cone are not sufficient to meet the demand for the most labor-intensive good. Thus we assume that countries in cone 1 remain diversified in producing goods 2 and 1.

increased production of good 2. Nevertheless, we have also seen that the new factor price line becomes flatter than before when technical progress in the production of the capital-intensive good 3 is biased towards capital, at least for given assumptions about the demand side. Adopting this insight for a Lerner diagram like Figure 1, we conclude that the general equilibrium effect of capital-biased technical change in the most capital-intensive sector brings about a tendency towards less factor price diversity across cones.⁸

This reasoning has an interesting implication for the volume of trade across cones. As long as the income generated by technical change is not solely used for more production and consumption of the progressing good 3, countries with factor endowments within the labor-intensive cone would produce more of the most labor-intensive good 1 and would exchange it for more of the most capital-intensive good 3. Thus, if technical progress has a bias as we have assumed, we would expect to see increasing trade in goods that are produced with large differences in capital intensities, given that all participating countries have access to the same technology. In addition, there may be increased trade flows of the intermediate good 2 from the capital-intensive cone to the labor-intensive cone, again in exchange for the most labor-intensive good 1. Hence the labor-intensive cone would rely more than before on the production of the labor-intensive good 1, but this would not lead to more factor price diversity but rather to less factor price diversity across cones.

Our conclusion that capital-biased (or Harrod-neutral) technical change helps to reduce factor price diversity across cones is of course subject to several qualifications. Identifying the exact effects of biased technical change on factor price diversity is complicated by the general equilibrium effects that are generated by alternative assumptions about demand. The fact that technical change in cone 2 creates additional income that is likely to lead to increased production and consumption of *all three goods* produces a spillover to the labor-intensive cone 1 that further complicates the picture. One needs to know how strong the quantity adjustment (increased production of good 2 in the capital-intensive cone 2) is compared relative to the price adjustment if one wants to keep track of the changing capital intensities in all sectors and cones.

⁸ Complete FPE is of course also a possibility. In the Lerner-Diagram, this occurs when all three isoquants, after the various shifts because of technical change and because of price-movements, can be drawn along a single unit value cost line. The case of complete FPE could be illustrated by using the concept of a factor price lens (Deardorff 1994). It can be shown that technical change can bring countries closer to the situation where the “factor lens condition” (Xiang 2001) is met.

Obviously it is necessary to draw on a number of very specific assumptions in order to show that long-run economic growth in the form of technical change may in fact lead to less factor price diversity or even FPE. These assumptions establish specific configurations of factor bias, sector bias, demand conditions, and adjustment processes, and each assumption appears to be debatable. What we want to suggest with this note is that neoclassical models of trade and growth in principle allow for a rich set of possible outcomes with regard to the effects of growth on relative factor prices, with less factor price diversity across cones being one of them.

IV. Conclusion

Using a neoclassical two-cone trade model with three goods and two factors and specific assumptions about the nature of technology and preferences, we find that long-run economic growth based on technical change can encourage less factor price diversity across cones. The major difference to the paper by Deardorff (2001) is that we do not model growth as driven by factor accumulation but instead as driven by exogenous capital-biased technical change. Therefore, we need to take into account general equilibrium effects of biased technical change on relative commodity prices. Modeled this way, economic growth results in a shift of cones of specialization, which in turn must have an impact on factor price diversity across cones, though not necessarily in the direction we have emphasized in the preceding section of the chapter.

We attempt to show how general equilibrium effects of factor- and sector biased technical change bring forward changes across cones in factor allocations and relative wages. What is missing from our analysis so far is to discuss in detail how technical change impacts on factor endowments and on the steady state. Technical change needs to be Harrod-neutral to ensure the existence of a steady-state under rather general conditions. Since Harrod-neutrality is an extreme form of a Hicks-bias toward capital, this requirement as such does not seem to provide a major complication. However, so far we have not considered that Harrod-neutral technical change would lead to endogenous capital accumulation, as in the Solow (1956) growth model. Taking this effect into account would mean that the size of the box diagram and the endowment points in the cone diagrams would have to change once technical progress is modeled as a shift of the (unit) value isoquant. We leave this additional aspect for further research.

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Figure 1: The Two-Cone Equilibrium

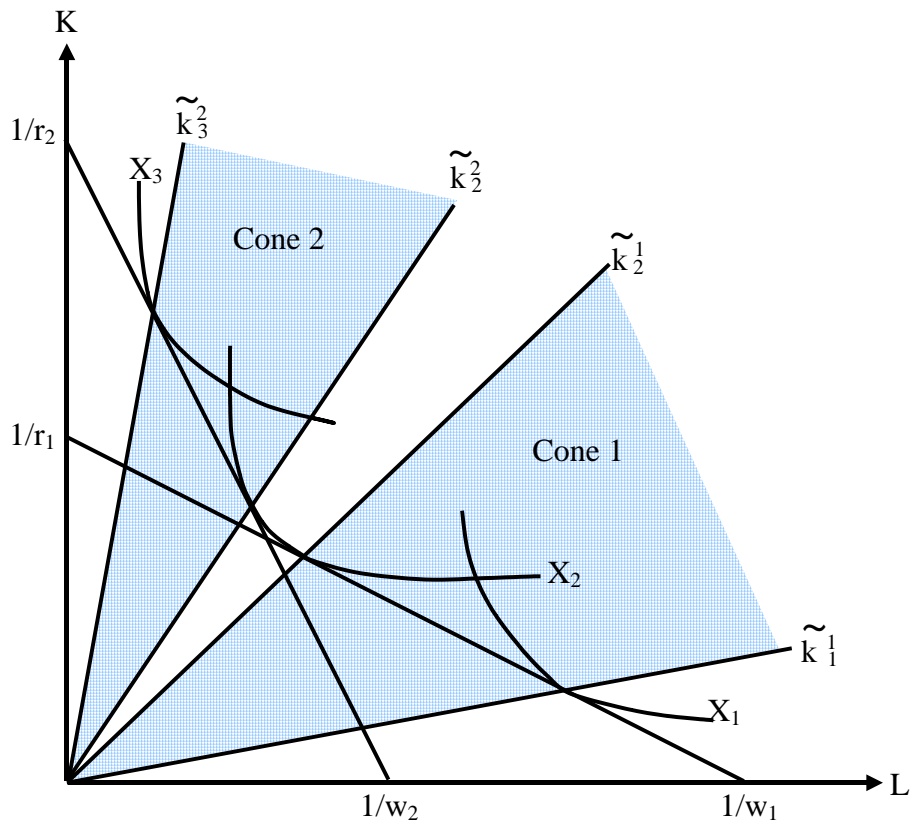


Figure 2: Capital-biased Technical Change and Relative Factor Prices with Constant Commodity Prices

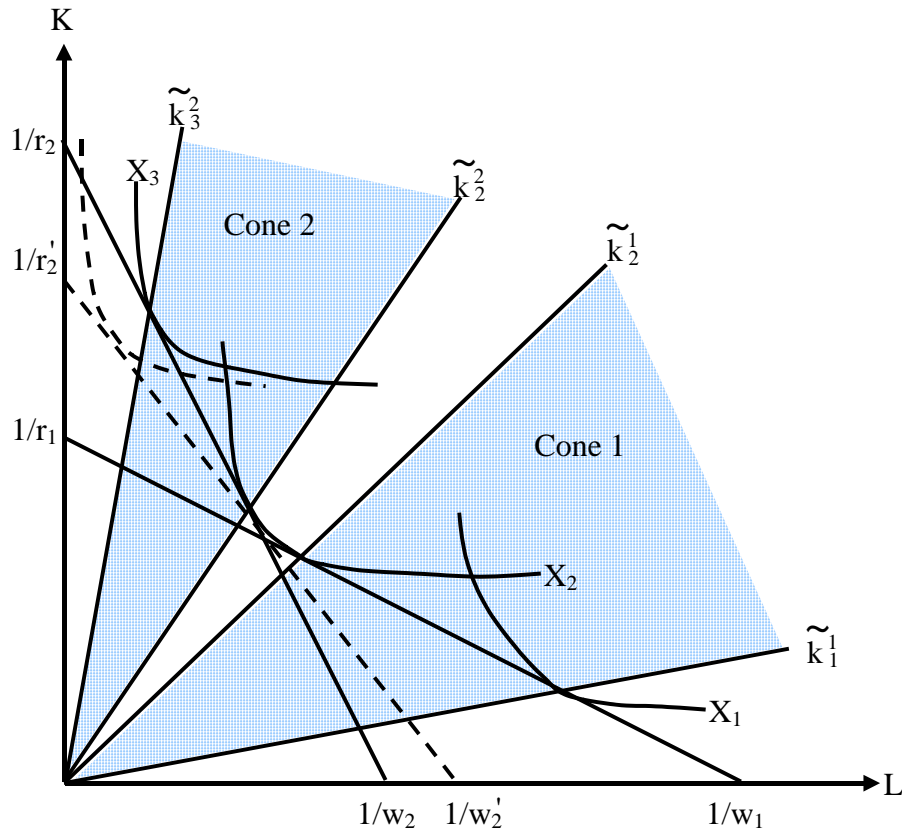


Figure 3: Capital-biased Technical Change with Endogenous Commodity Prices

