The Simplest Factor Price Non-Equalization When Countries Have Different Productivities

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Abstract – This study derived the solution of general trade equilibrium for the $2 \times 2 \times 2$ Trefler Hicks-Neutral HOV Model (Trefler, 1993), which incorporates productivities different across countries. This is the first theoretical result of price-trade equilibrium under factor price non-equalization. The non-equalized factor price at the equilibrium is with two useful properties. The first one is that the equilibrium price (world commodity price and two sets of localized factor price) are the functions of world effective factor endowments so that it remains the same when the allocation of equivalent factor endowments changes. The second property is that the equilibrium factor prices ensure gains from trade for countries participating in trade. A new logic explored from this study is that the world effective factor endowments determine world commodity price and local factor rewards of all countries.

Keywords:
Factor content of trade; factor price non-equalization; General equilibrium of trade; Integrated World Equilibrium; IWE

1. Introduction

Giving factor endowments of two countries in an open economic system with different technologies across countries, under identical consumption preference and constant return, how are world price and local factor rewards determined? This is a central question in international economics. The world price (localized factor prices and commodity price) determination and general trade equilibrium are the same issues by different descriptions. Fewer studies focused on this issue directly.

The Leontief paradox inspired many researchers to make new investigations on the trade pattern of various other countries. It also inspired the numerous HOV studies to incorporate different technologies across countries by assorted approaches.

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Vanek (1968)'s HOV model provided a powerful vehicle for the analyses of factor contents of trade, which are flexible in equilibrium analyses both for the same technologies and for different technologies. The share of GNP in the HOV model connected prices with trade and consumption.

The Integrated World Equilibrium (Dixit and Norman, 1980) is remarkable to illustrate equalized factor price by factor content of trade. It provided a practical view of price-trade equilibrium. It identified the feature of equalized factor price with mobile factors. Helpman and Krugman (1985) normalize the assumption of integrated equilibrium, which presented equilibrium analyses in a simple way. Deardroff (1994) derived the conditions of the FPE for many goods, many factors, and many countries by using the IWE approach. He discussed the FPE for all possible allocations of factor endowments.

Many studies, like Gale and Nikaido (1965), Chipman (1969), Krugman (2000), Fisher(2011), Leamer (2000), and Rassekh and Thompson(1993) had argued the need of factor price non-equalization when considering different technologies across countries.

Deardroff (1979) proposed a two-cone approach to present productions with different technologies. He identified the Heckscher-Ohlin chain of the rank of comparative advantage for the case of two factors.

Trefler (1993) extended Leontief (1953) idea of the productivity-equivalent unit to introduce productivity parameters for factors across countries in HOV studies. He provided an effective and simple way to measure factor endowments by equivalent productivity. He provided an artful model to present relative factor prices across countries. Trefler (1995) turned to another method to introduce technology matrix differences by a uniform argument parameter across countries.

Fisher and Marshall (2008) and Fisher (2011) introduced another insight approach to characterize different technologies. They measure the factor endowments with different technologies by virtual factor endowments. Fisher (2011) also proposed another two important terms: the goods price diversification cone and the intersection of goods price cones, which are very helpful to understand price properties in equilibriums. Feenstra and Taylor (2012, p.102) provided the concept of effective factors to interpret factor endowments with different productivities.

Guo (2015) derived a price-trade equilibrium for the Heckscher-Ohlin model and demonstrated that the equalized factor price and common commodity price at the equilibrium depended directly on world factor endowments (the rental-wage ratio equals to the world labor-capital ratio as $r/w = L^W/K^W$). He also demonstrated that equalized factor price makes sure of gains from trade for the countries participating in trade.

This study derived the price-trade equilibrium of the $2 \times 2 \times 2$ Hicks-Neutral HOV model (we call it the Trefler model). The study found that the Trefler model has only one cone for commodity price, although it has two cones of factor diversification. It is more available to get full relationship among factor prices, commodity price, and trade volumes. The study attained the first result of the price-trade equilibrium and factor price non-equalization when countries have different productivities.

This paper is divided into three sections. Section 2 introduces the price-trade equilibrium of the Trefler Hicks-Neutral HOV Model. Section 3 illustrates gains from trade by the equilibrium. Section 4 examines the equilibrium conditions of many commodities and many factors. The last one is the conclusion.

2. The General Trade Equilibrium When countries have different Productivities

2.1 Trefler Model

We first denote a "standard" $2 \times 2 \times 2$ Trefler model based on Trefler (1993). The major assumption in Trefler model is to express technology differences from the factor input requirements by

$$A^H = \begin{bmatrix} a_{K1}^H & a_{K2}^H \\ a_{L1}^H & a_{L2}^H \end{bmatrix} = \Pi A^F = \begin{bmatrix} \pi_K & 0 \\ 0 & \pi_L \end{bmatrix} A^F \tag{2-1}$$

where Π is a 2×2 diagonal matrix, its element π_k is factor productivity-argument parameter, $k = K$ (capital), L(Labor). A^H is the 2×2 technology matrix. Its element $a_{ik}^H(w/r)$ is the input requirement of factor k needed to product one unit of output i, $i=1,2$, $k=L, K$.

The foreign country's technological matrix is

$$A^F = \Pi^{-1} A^H = \begin{bmatrix} 1/\pi_K & 0 \\ 0 & 1/\pi_L \end{bmatrix} A^H = \begin{bmatrix} a_{K1}^H/\pi_K & a_{K2}^H/\pi_K \\ a_{L1}^H/\pi_L & a_{L2}^H/\pi_L \end{bmatrix} \tag{2-2}$$

The Trefler model can be expressed as

$$A^H X^H = V^H, \qquad (A^H)' W^H = P^H \tag{2-3}$$

$$\Pi^{-1} A^H X^F = V^F, \qquad (\Pi^{-1} A^H)' W^F = P^F \tag{2-4}$$

where V^h is the 2×1 vector of factor endowments with elements K as capital and L as labor; X^h is the 2×1vector of output; W^h is the 2×1 vector of factor prices with elements r as rental and w as wage; P^h is a 2×1vector of commodity prices with elements p_1^h and p_2^h; $h = H, F$ for countries.

The Trefler model is with two diversification cones of factor endowments. For the home country, we express it in algebra as

$$\frac{a_{K1}^H}{a_{L1}^H} > \frac{K^H}{L^H} > \frac{a_{K1}^H}{a_{L2}^H} \tag{2-5}$$

For the foreign country, it is

$$\frac{a_{K1}^H \pi_L}{a_{L1}^H \pi_K} > \frac{K^F}{L^F} > \frac{a_{K1}^H \pi_L}{a_{L2}^H \pi_K} \tag{2-6}$$

A unique feature for the Trefler model is that it is with a single cone of commodity price, although technologies are different. Its cost ratio ranks, which show the rays of commodity price cone in algebra, are

$$\frac{a_{K1}^H}{a_{K2}^H} = \frac{a_{K1}^F}{a_{K2}^F}\frac{a_{K1}^H \pi_k}{a_{K2}^H \pi_k} \; > \; \frac{P_1^*}{P_2^*} > \frac{a_{L1}^H}{a_{L2}^H} = \frac{a_{L1}^F}{a_{L2}^F} = \frac{a_{L1}^H \pi_L}{a_{L2}^H \pi_L} \tag{2-7}$$

Under most circumstances, the models of countries with technology difference across countries are with two commodity price cones. The feature of the single price cone reduces the difficultness of analyses of price-trade equilibrium. It provides a chance to get a price-trade equilibrium comparatively easy.

The trade vector of the home country by the HOV theorem is

$$T^H = X^H - s^H(X^F + X^H) \tag{2-8}$$

where $T^H$is the 2×1 trade vector; s^H is the home country's share of GNP to world GNP.

The factor content of trade of the home country is,

$$F^H = A^H T^H = V^H - s^H(V^H + \Pi V^F) = V^H - s^H(V^H + V^{FH}) = V^H - sV^{WH} \tag{2-9}$$

where V^{WH} is the world effective factor endowments measured by refereing to the home country's technolog, s^H is the home country's share of GNP. Vector V^{WH} can be further expressed as

$$V^{WH} = V^H + V^{FH} = \begin{bmatrix} K^{WH} \\ L^{WH} \end{bmatrix} = \begin{bmatrix} K^H + \pi_K K^F \\ L^H + \pi_L L^F \end{bmatrix} \tag{2-10}$$

By assuming

$$V^{FH} = \Pi V^F \tag{2-11}$$

$$W^{FH} = \Pi^{-1} W^F \tag{2-12}$$

we can rewrite (2-3) and (2-4) as

$$A^H X^H = V^H, \qquad\qquad (A^H)' W^H = P^H \tag{2-13}$$

$$A^H X^F = V^{FH}, \qquad\qquad (A^H)' W^{FH} = P^F \tag{2-14}$$

It is a same-technologies version of the Trefler model. Trefler had demonstrated that both "factor price equalization hypothesis and HOV theorem hold" for this version.

The price-trade equilibrium solution of the Heckscher-Ohlin model (Guo, 2015) is

$$W^{H*} = \begin{bmatrix} \frac{L^W}{K^W} \\ 1 \end{bmatrix} = \begin{bmatrix} \frac{L^H + L^F}{K^H + K^F} \\ 1 \end{bmatrix} \tag{2-15}$$

$$P^* = (A^H)' \begin{bmatrix} \frac{L^W}{K^W} \\ 1 \end{bmatrix} \tag{2-16}$$

$$s^H = \frac{1}{2}\left(\frac{K^H}{K^W} + \frac{L^H}{L^W}\right) \quad , \qquad s^F = 1 - s^H \tag{2-17}$$

It holds for the Trefler model. Applying it on the model (2-13) and (2-14) yields

$$W^{H*} = \begin{bmatrix} \frac{L^{WH}}{K^{WH}} \\ 1 \end{bmatrix} = \begin{bmatrix} \frac{L^H + \pi_L L^F}{K^H + \pi_K K^F} \\ 1 \end{bmatrix} \tag{2-18}$$

$$P^* = (A^H)' \, W^{H*} \tag{2-19}$$

$$W^{F*} = \Pi W^{H*} \tag{2-20}$$

$$F_K^h = \frac{1}{2} \frac{K^h L^{WH} - K^{WH} L^h}{K^{WH}} \qquad (h = H, F) \tag{2-21}$$

$$F_L^h = -\frac{1}{2} \frac{K^h L^{WH} - K^{WH} L^h}{L^{EW}} \qquad (h = H, F) \tag{2-22}$$

$$T_1^h = x_1^h - s^h x_1^W, \qquad T_2^h = x_2^h - s^h x_2^W \;, \qquad (h = H, F) \tag{2-23}$$

$$s^H = \frac{1}{2}\left(\frac{K^H}{K^{WH}} + \frac{L^H}{L^{WH}}\right) \quad , \qquad s^F = 1 - s^H \tag{2-24}$$

Walras' equilibrium allows dropping one market clear condition. We take $w^{H*} = 1$. It just serves as benchmark price referred both by all of the other factors in domestic or in international and by world common commodity prices.

We notice that the relative factor prices of two countries after factor price localization are under the following relationship,

$$r^F = \pi_K r^H \tag{2-25}$$

$$w^F = \pi_L w^H \tag{2-26}$$

This is just assumed by Trefler (1993).

The world equilibrium prices (one set of commodity price and two sets of local factor prices) are the function of the world effective factor endowments.

From the factor content of trade (2-21), we see that when $\frac{K^H}{L^H} > \frac{K^{WH}}{L^{WH}}$, then $F_K^H > 0$. This is just the content of the "effective" Heckscher-Ohlin theorem. This also the HOV thoerm.

The localized factor price (2-21) displays that the relative factor price (rent/wage) in the home country, in reversely, is proportional to their world effective factor endowments. It does not relate to benchmark technologies. Moreover, it does not relate to commodity prices. It is endogenously determined by the exogenous effective factor endowments.

3. Autarky Price and Comparative Advantage

> "Proofs of the static gains from trade fall into the unrefutable category yet these are some of the most important results in all of economics". (Leamer and Levinsohn, 1995, p.1342)

Guo (2015) provided a computable autarky price by the logic that "autarky" factor endowments determined its "autarky" price. It sourced from the logic that world factor endowments determine world price in the Heckscher-Ohlin model. He also provided a mathematical proof for autarky price by using the IWE diagram.

The autarky prices of two countries can be expressed

$$r^{ha} = \frac{L^h}{K^h} \qquad (h = H, F) \qquad (3\text{-}1)$$

$$w^{ha} = 1 \qquad (h = H, F) \qquad (3\text{-}2)$$

$$p_1^{ha} = a_{k1}\frac{L^h}{K^h} + a_{L1} \qquad (h = H, F) \qquad (3\text{-}3)$$

$$p_2^{ha} = a_{k2}\frac{L^h}{K^h} + a_{L2} \qquad (h = H, F) \qquad (3\text{-}4)$$

where superscript ha indicates the autarky price of country h.

Gains from trade are measured by

$$-W^{ha\prime}F^h > 0 \qquad (h = H, F) \qquad (3\text{-}5)$$

$$-P^{ha\prime}T^h > 0 \qquad (h = H, F) \qquad (3\text{-}6)$$

We add the negative sign in inequalities above since we expressed trade by net export, T^h . In most other literatures, they express trade by net import.

Appendix A provides the proof of gains from trade by inequality (3-5). It implies that localized-equalized factor prices at equilibrium make sure that countries participating in the trade gains from trade.

The result of gains from trade is another good side effect of the equilibrium of trade. It is one important property of the equilibrium and the factor price non-equalization.

When $\pi_K < 1$ and $\pi_L < 1$, the home country is with Adam Smith's absolute advantage in the productions of both commodities. This study demonstrates that even when one country is with absolute advantages in technologies in productions of both commodities, the two countries still have benefits to do trade by the factor endowment differences and by technology differences. Both countries gain from trade.

We now summarize the result of this study to a theorem.

The theorem – Comparative Advantage By Different Productivities

Suppose that two countries are engaged in free trade, having an identical homothetic taste but different productivities and same or different factor endowments by the Trefler model. When the common commodities price formulated, factor prices (w^H, r^H) and (w^F, r^F) of the two countries are localized. The world effective factor endowments determine the common commodity price and the localized factor prices, which always make sure that the two countries gain from trade.

Proof

We have derived the equilibrium price (2-14) through (2-16). It is unique for a giving world effective factor endowments. Appendix A demonstrated the gains from trade by the equilibrium price. The prices at the equilibrium are functions of world effective factor endowments. This theorem is supported by two important principles of international economics. The first one is that it makes sure gains from trade. This is a necessary requirement of international trade theory for the solution. The second is that the world price and local factor price remain the same when the allocation of the effective factor endowments of two countries changes.

End Proof

The equilibrium shows the unification of the trade direction, the Non-FPE theorem, and gains from trade. They confirmed each other.

4. Many Commodities and Factors

For higher dimension (many-factor, many-commodity, and may-country) model, Guo (2018) provided a solution for the Heckscher-Ohlin model. It demonstrates that general equilibriums are available for the cases of un-even technology matrix. A higher dimension Trefler model can be converted into the model like equations (2-14) through (2-16), which is a same-technology Heckscher-Ohlin model mathematically. The general equilibrium in the higher dimension Heckscher-Ohlin model can be generalized to the higher dimension Trefler model without difficulties. We concern if the Trefler model still is one commodity price cone in the cases of many commodity and many factors. We use a three-factor and three-commodity model to illustrate that it is still at one price cone.

Suppose that country home's technological matrix is

$$A^H = \begin{bmatrix} a_{11}^H & a_{12}^H & a_{13}^H \\ a_{21}^H & a_{22}^H & a_{23}^H \\ a_{31}^H & a_{32}^H & a_{33}^H \end{bmatrix} \tag{4-1}$$

The foreign country's technological matrix is

$$A^F = \Pi^{-1} A^H = \begin{bmatrix} 1/\pi_1 & 0 & 0 \\ 0 & 1/\pi_2 & 0 \\ 0 & 0 & 1/\pi_3 \end{bmatrix} A^H = \begin{bmatrix} a_{11}^H/\pi_1 & a_{12}^H/\pi_1 & a_{13}^H/\pi_1 \\ a_{21}^H/\pi_2 & a_{22}^H/\pi_2 & a_{23}^H/\pi_2 \\ a_{31}^H/\pi_3 & a_{32}^H/\pi_3 & a_{33}^H/\pi_3 \end{bmatrix} \tag{4-2}$$

For the 3 x 3 x 2 model, the cone of commodity prices is on a tetrahedron shape. The cone of diversification of factor endowments also is a shape of the tetrahedron. Figure 1 shows the tetrahedron of commodity prices. A commodity price vectors lie in the tetrahedron will ensure positive factor prices.

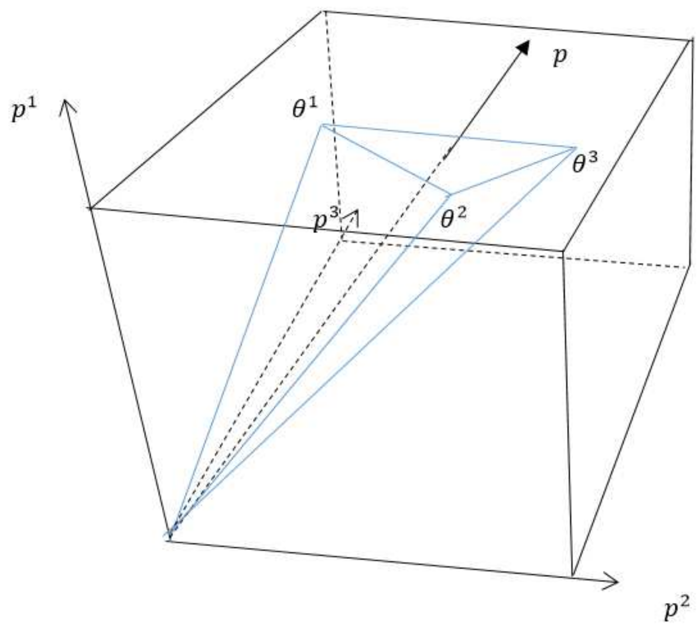

Figure 1 The Cone of Commodity Price by 3 Commodities and 3 Factors

We rewrite the unit cost function of the foreign country, $(A^F)'W = P$, as

$$\begin{bmatrix} a_{11} \\ a_{12} \\ a_{13} \end{bmatrix} w_1 \ /\pi_1 + \begin{bmatrix} a_{21} \\ a_{22} \\ a_{23} \end{bmatrix} w_2 \ /\pi_2 + \begin{bmatrix} a_{31} \\ a_{32} \\ a_{33} \end{bmatrix} w_3 \ /\pi_3 = \begin{bmatrix} p_1 \\ p_2 \\ p_3 \end{bmatrix} \tag{4-3}$$

Each column of $A^{F\prime}(W)$ represnets the optimal unit coefficients from a single factor. Denote

$$\theta^{F1} = 1/\pi_1 \begin{bmatrix} a_{11} \\ a_{12} \\ a_{13} \end{bmatrix}, \theta^{F2} = 1/\pi_2 \begin{bmatrix} a_{21} \\ a_{22} \\ a_{23} \end{bmatrix}, \ \theta^{F3} = 1/\pi_3 \begin{bmatrix} a_{31} \\ a_{32} \\ a_{33} \end{bmatrix} \tag{4-4}$$

Those three vectors are the three rays or ridges that compose the price tetrahedron in Figure 3.

For the home country, each column of $A^{H\prime}(W)$ for a single factor can be expressed respectively as

$$\theta^{H1} = \begin{bmatrix} a_{11} \\ a_{12} \\ a_{13} \end{bmatrix}, \theta^{H2} = \begin{bmatrix} a_{21} \\ a_{22} \\ a_{23} \end{bmatrix}, \ \theta^{H3} = \begin{bmatrix} a_{31} \\ a_{32} \\ a_{33} \end{bmatrix} \tag{4-5}$$

The cone by (3-5) and the cone by (3-6) are the same since θ^{Fi} and θ^{Fi} are at the same line. Generally, the trade equilibrium of many commodity and many factors are available.

Conclusion

This is the first analytical studies to reach the factor price non-equalization by using the simplest case of the $2 \times 2 \times 2$ Trefler model. The study explored a principle that world equivalent factor endowments determine world prices (one set of commodity price and two sets (or many sets) of localized factor prices) when countries have different productivities. It is a generalized Dixit-Norman price property.

The factor price equalization by the same productivity is a special case of the factor price non-equalization by different productivities.

Appendix A

We express the gains from trade for country H as

$$-W^{Ha\prime}F^{H} > 0 \tag{A-1}$$

Adding trade balance condition $W^{*\prime}F^{H} = 0$ on (A-1) yields

$$-(W^{Ha\prime} - W^{*\prime})F^{H} > 0 \tag{A-2}$$

The factor content of trade of the home country in (A-2) is

$$F^{H} = \begin{bmatrix} \frac{1}{2}\frac{K^{H}L^{WH} - L^{WH}L^{H}}{K^{WH}} \\ -\frac{1}{2}\frac{K^{H}L^{WH} - K^{W}L^{WH}}{L^{WH}} \end{bmatrix} \tag{A-3}$$

The equilibrium factor price is

$$W^{*} = \begin{bmatrix} \frac{L^{WH}}{K^{WH}} \\ 1 \end{bmatrix} \tag{A-4}$$

The autarky price is

$$W^{Ha} = \begin{bmatrix} \frac{L^{H}}{K^{H}} \\ 1 \end{bmatrix} \tag{A-5}$$

Substituting (A-3) through (A-5) into (A-2) yields

$$-\begin{bmatrix} \frac{L^{H}}{K^{H}} - \frac{L^{WH}}{K^{WH}} & 0 \end{bmatrix} \begin{bmatrix} \frac{1}{2}\frac{K^{H}L^{WH} - L^{WH}L^{H}}{K^{WH}} \\ -\frac{1}{2}\frac{K^{H}L^{WH} - L^{WH}L^{H}}{L^{WH}} \end{bmatrix} > 0 \tag{A-6}$$

Reduced it to

$$-\left(\frac{L^{H}}{K^{H}} - \frac{L^{WH}}{K^{WH}}\right) \times \frac{1}{2}\frac{K^{H}L^{WH} - L^{WH}L^{H}}{K^{WH}} > 0 \tag{A-7}$$

Rewrite it as

$$-\left(\frac{L^{H}}{K^{H}} - \frac{L^{WH}}{K^{WH}}\right) \times \frac{1}{2}\frac{\frac{L^{WH}}{K^{WH}} - \frac{L^{H}}{K^{H}}}{K^{WH}}(K^{WH})K^{H} > 0 \tag{A-8}$$

We have

$$\left(\frac{L^H}{K^H} - \frac{L^{WH}}{K^{WH}}\right)^2 \times \frac{1}{2} K^H > 0 \tag{A-9}$$

It is true. Therefore, equation (A-1) is valid.
We can prove the gains from trade for the foreign country as $-W^{Fa\prime}F^F > 0$ by the similarly way. We will not repeat it.

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