A Dual Definition for the Factor Content of Trade and its Effect on Factor Rewards in US Manufacturing Sector

Agelos Delis[1] Theofanis P Mamuneas[2]

University of Nottingham University of Cyprus

Abstract

In this paper, first we introduce a dual definition of the Factor Content of Trade (FCT) using the concept of the equivalent autarky equilibrium. A FCT vector is calculated by estimating a symmetric normalized quadratic revenue function for the US manufacturing sector for the period 1965 to 1991. The FCT for capital is positive, while the FCT for skilled and unskilled labor are both negative, suggesting that the Leontief Paradox was not present for the period of investigation. Capital is revealed by trade to be relatively more abundant compared to either type of labor, while skilled labor is relatively more abundant than unskilled labor. Then using the quadratic approximation lemma, the growth rate of the factor rewards is related to the growth rate of FCT, the growth rate of endowments and technological change. We find that technological change is the most important determinant in explaining wage inequality between skilled and unskilled workers in US manufacturing between 1967 and 1991.

Keywords: International trade, relative wages, Factor Content of Trade, skilled and unskilled labour, Leontief Paradox, revenue function.

JEL classification: F11, F16 and J31.

[1]GEP, School of Economics, University of Nottingham, University Park, Nottingham, NG7 2RD, UK (email: agelos.delis@nottingham.ac.uk)

[2]Department of Economics, University of Cyprus, Nicosia, CY 1678, Cyprus (email: mamuneas@ucy.ac.cy)

1 Introduction

The possible relationship between international trade and wage inequality in developed countries has been a very important and regularly debated topic for both academics and politicians the last decade. Unskilled workers in many developed countries and especially in US have seen a significant decline in their relative wages, while at the same time international trade increased considerably. Some have argued that the increase of international trade is likely to explain this decline of relative wages. Trade economists have approached this question using the Heckscher-Ohlin model, from two different but equivalent angles. The first is based on the traditional Stolper-Samuelson theorem, where changes in product prices cause changes in factor rewards (Leamer, 1998 and 1994; Baldwin and Cain, 1997; and Harrigan and Balaban, 1999); and the second is based on the Factor Content of Trade (FCT) theorem of Vanek (1968) and the work of Deardorff and Staiger (1988), where changes in the volume of net exports are transformed (via an input-output matrix) into changes in relative factor rewards (Borjas et al., 1992; Katz and Murphy, 1992; and Wood, 1995).

The FCT approach has been heavily criticized on the ground that it lacks a solid theoretical foundation and especially that FCT is not related with factor prices. For instance, Panagariya (2000), Leamer and Levinsohn (1995) and Leamer (2000) argue that FCT calculates quantities of indirectly exported and imported factors via international trade but according to the Stolper-Samuelson theorem, it is product prices and not factor quantities, which are related with factor prices. Yet, by introducing the concept of the Equivalent Autarkic Equilibrium (EAE), Deardorff and Staiger (1988) provide the theoretical foundation and show under which assumptions the FCT and relative wages are related (see also, Deardorff, 2000; and Krugman, 2000).

In this paper, in contrast to all previous FCT studies which rely on the use of input-output matrices to calculate the FCT (see Borjas et al., 1992; Katz and Murphy, 1992; Wood, 1995), we calculate the FCT by directly estimating the endowments required to achieve the EAE. This is accomplished by estimating a revenue function similar to Harrigan and Balaban (1999). We assume the revenue function to be of the Symmetric Normalized Quadratic functional form, which is more attractive because it has the important property of flexibility when convexity and concavity are imposed. We find that the *FCT* for capital is positive, the *FCT* for skilled labor is negative but quite close to zero, while the *FCT* of unskilled labor is negative and big in magnitude. Hence, there is no Leontief Paradox in the US for the period 1965-1991 in our framework.

Then, by using the quadratic approximation lemma (Diewert 1976, 2002) we are able to decompose the growth rate of factor rewards of trade equilibria to the growth rate of *FCT*, the growth rate of endowments and technological change. We find that the growth rate of the reward for both types of labor gained from *FCT Effect*, while the reward to capital had loses. The endowment effect is positive for the growth of the wages of unskilled workers and negative for the wages of skilled workers and the reward to capital. Lastly, technological change had a positive effect in all factor rewards with capital experiencing the highest gains and unskilled labor the least ones. Finally, it seems that technological change is the most important determinant for the decline in relative factor rewards for unskilled workers in the US from 1967 to 1991. This is in accordance with most studies of both approaches with the exception of Wood (1995) and Leamer (1998).

The rest of the paper is organized into six sections. Section 2 develops the theoretical model and provides a dual definition of the factor content of trade. Section 3 contains a discussion of the empirical specification and estimation of the revenue function. Section 4 presents the *FCT* for each factor and discusses the Leontief Paradox. In Section 5 we decompose the growth rate of factor rewards into a *FCT Effect*, an Endowment Effect and a Technology Effect and present the results based on this decomposition. Finally, the last section concludes the paper.

2 The Model

In this section we develop a general equilibrium model for a trading economy using duality. The production side of the economy is described by a revenue function while the consumption side by an expenditure function. The use of duality, and more specifically the implementation of a revenue function, is preferred because it complies with the standard assumptions made in international trade theory that product prices and endowments are given while factor prices and outputs are the endogenous variables to be determined.

Let $F(y, v, t) = 0$ be a transformation function for an economy with a linearly homogeneous technology, which produces $y = (y_1, ...y_n)$ goods with the use of $v = (v_1, ...v_m)$ inputs $(n \leq m)$ in a perfect competitive environment where t is a time index that captures technological change. Then, at given international prices $p = (p_1, ...p_n)$ and domestic inputs v, there exists a competitive production equilibrium. In such equilibrium we can think of the economy as one that maximizes the value of total output subject to the technological and endowment constraints. In other words there is a revenue or Gross Domestic Product (GDP) function such that:

$$R(p, v, t) = \max_{y} \{py : F(y, v, t) = 0\} \tag{1}$$

The revenue function has the usual properties, i.e., it is increasing, linearly homogeneous and concave in v and non-decreasing, linearly homogeneous and convex in p. In addition if $R(p, v, t)$ is differentiable then from Hotteling's Lemma (Diewert 1974) the equilibrium output and factor rewards are:

$$y(p, v, t) = R_p(p, v, t) \tag{2}$$

$$w(p, v, t) = R_v(p, v, t) \tag{3}$$

where R_p and R_v are the vectors of first partial derivative of the revenue function with respect to product prices and endowments, respectively.

On the consumption side the economy's preferences defined over the n goods are represented by an expenditure function, which is continuous and twice differentiable on prices:

$$E(p,u) = \min_{x} \{px : \ u(x) \geq u\} \tag{4}$$

where u is the level of utility and $x = (x_1, ...x_n)$ is the consumption bundle. The expenditure function is non-decreasing, linear homogenous and concave in prices and increasing in u. From Shepherd's Lemma (Diewert 1974) the consumption vector of the economy is:

$$x(p,u) = E_p(p,u) \tag{5}$$

where E_p is the vector of first partial derivative of the expenditure function with respect to product prices.

The trade equilibrium is defined as

$$R(p,v,t) = E(p,u) \tag{6a}$$

$$T = R_p(p,v,t) - E_p(p,u) \tag{6b}$$

that is the total value of production should be equal to the total expenditure for the economy, which implies trade balance and the difference between production and consumption gives the economy's vector of net exports, T.

Consider now a hypothetical equilibrium, the equivalent autarky equilibrium introduced by Deardorff and Staiger (1988), where production equals consumption, at the same product prices and at the same utility level as in the trading equilibrium. This equilibrium can be achieved by changing the initial endowment of the economy such that the economy is producing what it desires to consume, having no incentive to trade with other countries. Hence, the vector of net exports is going to be a vector of zeros and trade is by definition balanced

$$R(p, v^e, t) = E(p, u) \tag{7a}$$

$$R_p(p, v^e, t) = E_p(p, u) \tag{7b}$$

where v^e is the equivalent autarky equilibrium endowments vector and p, u the price vector and utility level respectively as in the trade equilibrium.

In Figure 1, following Krugman (2000), we depict the trading and equivalent autarky equilibria. In the Trade Equilibrium, the economy is producing where the production possibilities frontier DE is tangent to the relative product prices line AB, at P, while the economy is consuming at C where the relative product prices line is tangent to the indifference curve U^o. The economy is exporting $Y_1 - X_1$ units of good 1 and imports $X_2 - Y_2$ units of good 2. The equivalent autarky equilibrium is depicted at C. There, the economy is endowed with the necessary inputs that allow the production of its consumption bundle at the trade relative product prices AB. At the EAE, the production possibilities frontier is FG, both consumption and production takes place at C and therefore the trade volume is zero. Note that at the trading equilibrium P and at the EAE C preferences are the same and because product prices are also unchanged the vector of consumption is unaltered. Under the assumption of balanced trade, GDP and the economy's total expenditure would be identical in both equilibria.

Since consumption is the same in both equilibria then from (6b) and (7b) we have

$$R_p(p, v^e, t) = R_p(p, v, t) - T \tag{8}$$

and therefore we can explicitly solve from (8) for the EAE endowments vector v^e by knowing the net exports and the revenue function of the economy. Assuming that the implicit function theorem holds, $|R_{pv}(p, v^e, t)| \neq 0$,[1] we can solve for the EAE endowment vector $v^e(p, v, t; T)$ which is going to depend on the trade equilibrium prices, initial endowment, technology and the net export vector. Then, the factor content of trade is defined as the difference between the actual endowments in a trading equilibrium and the endowments at the equivalent autarky equilibrium,

$$f = v - v^e(p, v, t; T) \tag{9}$$

In the literature, the usual definition of FCT is just the product of an input requirement matrix, Γ, times the trade vector T (see for example Deardorff and Staiger, 1988). Harrigan (2001) has shown that if there is non-jointness in output quantities, the input requirement matrix Γ is equal to R_{pv}^{-1} and therefore the factor content of trade will be equal to $R_{pv}^{-1}T$. It is not difficult to show that our definition of FCT is identical to $R_{pv}^{-1}T$ under the non-jointness assumption. Under this assumption a revenue function can be written as $R(p, v, t) = r(p, t)v$, then the vector of outputs is $R_p = r_p v$, where r_p is the vector of partial derivatives of $r(p, t)$ with respect to product prices and $R_{pv} = r_p$ which is independent of the endowment vector. From (8) we have that $T = R_p(p, v, t) - R_p(p, v^e, t) = r_p v - r_p v^e = r_p(v - v^e) = R_{pv} f$, and therefore $f = R_{pv}^{-1}T$. Therefore our definition of FCT given by (9) is equivalent to the usual definition appearing in the literature under the assumption of non-jointness, however is a generalization to wider technologies even in

[1]The determinant of matrix R_{pv} is different from zero, where R_{pv} is the matrix of the second partial derivatives of the revenue function with respect to product prices and endowments.

cases where jointness in output quantity is present.

3 Econometric Specification and Estimation

The revenue function is assumed to have the symmetric normalized quadratic functional form as discussed in Kohli (1991, 1993):

$$\begin{aligned} R(p,v,t) = & \frac{1}{2}\left(\sum_{j=1}^{M}\psi_j v_j\right)\left(\sum_{i=1}^{N}\sum_{h=1}^{N} a_{ih}p_i p_h\right)\left(\sum_{i=1}^{N}\theta_i p_i\right)^{-1} \\ & + \sum_{i=1}^{N}\sum_{j=1}^{M}(c_{ij}p_i v_j) + \frac{1}{2}\left(\sum_{i=1}^{N}\theta_i p_i\right)\left(\sum_{j=1}^{M}\sum_{\ell=1}^{M} b_{j\ell}v_j v_\ell\right)\left(\sum_{j=1}^{M}\psi_j v_j\right)^{-1} \\ & + \left(\sum_{j=1}^{M}\psi_j v_j\right)\left(\sum_{i=1}^{N} d_i p_i\right)t + \left(\sum_{i=1}^{N}\theta_i p_i\right)\left(\sum_{j=1}^{M} e_j v_j\right)t \\ & + \left(\sum_{i=1}^{N}\theta_i p_i\right)\left(\sum_{j=1}^{M}\psi_j v_j\right)\left(\frac{1}{2}h_{tt}t^2 + h_t t\right) \end{aligned} \qquad (10)$$

where p and v are the product prices and input endowment vectors respectively and t is an index of exogenous technological change. There are $N(N-1) + M(M-1) + (N \times M) + 2$ unknown parameters a_{ih}, $b_{j\ell}$, c_{ij}, d_i, e_j, h_t and h_{tt}, where $i, h = 1, ...N$ and $j, \ell = 1, ..M$. There are also $N + M$ predetermined parameters θ_i and ψ_j. In particular, θ_i and ψ_j are set equal to the share value of each product and input respectively at the base year. Symmetry conditions are imposed $a_{ih} = a_{hi}$; $b_{j\ell} = b_{\ell j}$ and the assumptions of linear homogeneity in p and v require some additional restrictions:

$$\sum_{i=1}^{N}\theta_i = \sum_{j=1}^{M}\psi_j = 1, \text{ and } \sum_{h=1}^{N} a_{ih} = \sum_{\ell=1}^{M} b_{j\ell} = \sum_{i=1}^{N} d_i = \sum_{j=1}^{M} e_j = 0 \qquad (11)$$

This functional form is attractive because it is a flexible functional form that retains its flexibility under the imposition of convexity and concavity in prices and endowments respectively. The necessary and sufficient condition for global concavity in inputs is that the matrix $B = [b_{j\ell}]$ is negative semi-definite and for global convexity that the matrix $A = [a_{ih}]$ is positive semi-definite. If these are not satisfied then they are imposed following Diewert and Wales (1987) without removing the flexibility properties of the revenue function.

Based on (10) the reward of the jth factor becomes:

$$\begin{aligned} w_j \;=\; & \frac{1}{2}\psi_j \left(\sum_{i=1}^{N}\sum_{h=1}^{N} a_{ih}p_i p_h\right)\left(\sum_{i=1}^{N}\theta_i p_i\right)^{-1} + \left(\sum_{i=1}^{N}\theta_i p_i\right)\left(\sum_{\ell=1}^{M} b_{j\ell}v_\ell\right)\left(\sum_{j=1}^{M}\psi_j v_j\right)^{-1} \\ & -\frac{1}{2}\psi_j\left(\sum_{i=1}^{N}\theta_i p_i\right)\left(\sum_{j=1}^{M}\sum_{\ell=1}^{M} b_{j\ell}v_j v_\ell\right)\left(\sum_{j=1}^{M}\psi_j v_j\right)^{-2} + \sum_{i=1}^{N} c_{ij}p_i + \psi_j\left(\sum_{i=1}^{N} d_i p_i\right)t \\ & + e_j\left(\sum_{i=1}^{N}\theta_i p_i\right)t + \psi_j\left(\sum_{i=1}^{N}\theta_i p_i\right)h_t t + \frac{1}{2}\psi_j\left(\sum_{i=1}^{N}\theta_i p_i\right)h_{tt}t^2 \end{aligned} \quad (12)$$

Similarly the output supply of the ith good becomes:

$$\begin{aligned} y_i \;=\; & \frac{1}{2}\theta_i \left(\sum_{j=1}^{M}\sum_{\ell=1}^{M} b_{j\ell}v_j v_\ell\right)\left(\sum_{j=1}^{M}\psi_j v_j\right)^{-1} + \left(\sum_{j=1}^{M}\psi_j v_j\right)\left(\sum_{h=1}^{N} a_{ih}p_h\right)\left(\sum_{i=1}^{N}\theta_i p_i\right)^{-1} \\ & -\frac{1}{2}\theta_i\left(\sum_{j=1}^{M}\psi_j v_j\right)\left(\sum_{i=1}^{N}\sum_{h=1}^{N} a_{ih}p_i p_h\right)\left(\sum_{i=1}^{N}\theta_i p_i\right)^{-2} + \sum_{j=1}^{M} c_{ij}v_j + d_i\left(\sum_{j=1}^{M}\psi_j v_j\right)t \\ & + \theta_i\left(\sum_{j=1}^{M} e_j v_j\right)t + \theta_i\left(\sum_{j=1}^{M}\psi_j v_j\right)h_t t + \frac{1}{2}\theta_i\left(\sum_{j=1}^{M}\psi_j v_j\right)h_{tt}t^2 \end{aligned} \quad (13)$$

The estimating model is the equation sets (12) and (13) together with the parameter restrictions (11). The errors related to equations (12) and (13) are assumed to be identically, and independently distributed with zero expected value and a positive definite covariance matrix. These equations are jointly estimated by the iterative three stages least square estimator applied to data for the US manufacturing sector over the period from 1965 to 1991, using as instruments one year lagged values for p and v. There are six equations, three relating to outputs and three relating to factor rewards. The goods are exportable, importable and non-tradeable and the three factors of production are capital, skilled and unskilled labor. We use data for the value and price of capital and aggregate labor from Dale Jorgenson's 35 KLEM data set. In order to decompose labor into skilled and unskilled we have used the NBER Mare -Winship Data. Trade data were obtained from the Centre for International Data at the University of California Davis. Finally, data for the output deflators are used from the Bureau of Economic Analysis[2].

Table 2 shows the estimated parameters and the R^2 for the system of the six equations. The revenue function is linearly homogeneous in prices and inputs, but initially convexity in prices and concavity in inputs were not satisfied. Following the method proposed by Diewert and Wales (1987) we impose convexity for product prices and concavity for input quantities. The hypothesis of convexity and concavity cannot be rejected at a 5% level of significance (Wald test statistic(4)=32.7). The joint null hypothesis of non-jointness in output quantities is rejected at a 5% level of significance (Wald test statistic(2)=29.1), which is in accordance with the more general technology used above. In addition, the hypothesis of non technological change is rejected (Wald test statistic(6)=534).

In Table 3 we report the estimated price and endowment elasticities for all goods and factors. All own price elasticities of output are positive and well below unity, suggesting that the output supplies are inelastic. In addition, an increase in the price of exportable reduces the quantity produced for both importable and non-tradable goods. While an increase on importable's price increases the output of non-tradable goods. More capital leads to a drop in the output of both the importable and the non-tradable, while it increases the output for the exportable. Changes in skilled labor are positively related to changes in the output of all three aggregate goods. While an increase in unskilled labor will result in more output produced for the two tradable goods and less for the non-tradable. We also see that technological change increases the production of the exportable good and reduces the production of the two other goods.

[2] In appendix A we provide a detailed construction and sources of the data.

The reward to all three factors gains from an increase in exportable's price. While an increase in importable's price leads to a decrease in capital's reward, but a rise in the wages of both types of labor. An increase in non-tradable's price reduces the reward to both capital and unskilled labor, while it increases the reward to skilled labor. All own inverse factor price elasticities are negative as expected and inelastic with the only exception of capital's own elasticity (-1.14%). Additionally, capital is a gross-substitute with skilled and unskilled labor while skilled and unskilled labor are gross-complements. Finally, technological change appears to enhance the reward to both capital and skilled labor, but reduce the reward to unskilled labor.

4 Factor Content of Trade

The estimated parameters of the revenue function are used in order to calculate the FCT for each input. In particular, solving equation (8) for v^e and then using equation (9), allow us to obtain the factor content of trade, f_j, for each input for the period 1965 to 1991. The FCT for all three factors are plotted in Figure 2. We observe that FCT of capital, f_K, is positive and generally increasing throughout our sample period. The FCT of both skilled, f_S, and unskilled, f_U, labor is negative and declining till 1986 and then increased till 1991, with the FCT of skilled labor having a relatively smaller magnitude[3]. Hence, the US economy was exporting the services of capital and importing the services of both types of labor for all the years between 1965 to 1991. The net exports of capital services in 1965 were 16.34 billion USD[4], reached a maximum of 62 billion USD in 1986 and fell to 54.30 billion USD in 1991. While the net imports of skilled labor services rose from 9.89 billion USD in the first year of the period to 44.04 billion in 1986 and then were reduced to 32.50

[3]Similar results are found by Bowen et al (1987) for capital and unskilled labor. For some categories of skilled labor Bowen et al (1987) find an opposite sign. However Bowen et al (1987) use an input-output matrix to calculate the FCT, and employ a different definition of skilled labor from this study.

[4]All net trade services of factors are measured in constant 1970 prices and it is assumed that the economy is in a balanced trade equilibrium (see more in the Appendix A).

billion USD in 1991. Similarly, the net imports of unskilled labor increased from 20.45 billion in 1965 to 96.88 billion in 1986 and then decreased to 68.48 billion USD in the last year of the sample.

It is evident that for the period 1965-1991 in our analysis of the three aggregate goods and three aggregate inputs there is no Leontief Paradox in the US economy, since the FCT for capital is positive and the FCT for both types of labor is negative. The partition of labor into skilled and unskilled, is consistent with some of the early explanations in the literature about the Leontief Paradox (Kenen, 1965; Baldwin, 1971 and Winston, 1979) and could be a possible explanation for the absence of the Leontief Paradox.

Our result is also consistent with the analysis of Leamer (1980). The FCT that we calculate is by definition the factor content of net trade. Leamer also showed that in a multi-factor, multi-product H-O-V environment, a country is revealed by trade to be relatively abundant in a particular factor compared to any other factor, if the FCT of this factor is positive and the FCT of the other is negative. Hence, capital is revealed by trade to be relatively abundant compared to either type of labor in the US economy for the period 1965-1991. In addition, Leamer (1980) showed under which condition a country with negative FCT for two inputs is revealed by trade to be relatively abundant in one of them. In such a case, US is revealed by trade to be relatively more abundant in skilled labor if the ratio of the FCT of skilled labor to the FCT of unskilled labor is smaller than the ratio of skilled labor to unskilled labor used in the production. In our case, we find that the share of skilled labor imported is less than the share of unskilled labor imported and trade reveals that skilled labor is relatively abundant to unskilled labor in the US economy between 1965 to 1991.

For all of the years in the sample period more unskilled and skilled labor would have been employed in a hypothetical EAE relative to capital, but more unskilled labor would have been employed relative to skilled labor. Therefore in the US manufacturing sector there is a clear ordering of factor abundance revealed by trade. Capital is the most abundant factor relative to both types of labor, while skilled labor is relatively more abundant when compared with unskilled labor between 1965 to 1991.

5 Factor Rewards Decomposition

So far we have discussed the definition of the Equivalent Autarky Equilibrium, the estimation of the revenue function for US and the calculation of the FCT using duality in the case of jointness in output quantities. In this section our goal is to establish a general relationship between changes in factor prices in one side and changes of endowments, FCT and technology in the other. For this reason we first show how the difference between the factor rewards in the two equilibria can be approximated.

In Figure 3 we portray two Trade Equilibria *(TE)* and also their respective EAE at time periods t and s. For each *TE,* P^t and P^s, the factor rewards are given by $w_t = R_v\left(p_t, v_t, t\right)$ and $w_s = R_v\left(p_s, v_s, s\right)$, respectively. Recall that from equation (8) we can obtain the endowments vector at the two *EAE,* C^t and C^s. Hence, the factor rewards at the EAE are given by $w_t^e = R_v\left(p_t, v_t^e, t\right)$ and $w_s^e = R_v\left(p_s, v_s^e, s\right)$, respectively. Our objective is to find the effect of FCT changes on changes of rewards over time. Instead of comparing directly the factor rewards between equilibria P^t and P^s, we go through the equivalent autarky equilibria C^t and C^s. In other words, the difference in factor rewards between periods t and s is given by the difference between the *TE* and EAE for period t minus the the difference between *TE* and EAE for period s plus the difference between the EAE in t and s. This enables us to link factor reward changes with changes in endowments, FCT and technology.

By using the quadratic approximation lemma (Diewert, 1976, 2002) the *TE* factor rewards

$w_t = R_v\left(p_t, v_t, t\right)$ at period t, evaluated at the EAE endowments v_t^e are

$$w_t = R_v(p_t, v_t^e, t) + \frac{1}{2}(R_{vv} + R_{vv}^e)\left(v_t - v_t^e\right) = w_t^e + \overline{R}_{vv} f_t \tag{14}$$

where the matrix $\overline{R}_{vv} = \frac{1}{2}(R_{vv} + R_{vv}^e)$ has a typical entry $\overline{r}_{v_j v_\ell}$ that is the mean effect of a change in the lth endowment on the reward of the jth factor evaluated at the trade and equivalent autarky equilibrium at period t. Totally differentiating (14) with respect to time t, we get:

$$\frac{dw_t}{dt} = \frac{dw_t^e}{dt} + \overline{R}_{vv}\frac{df_t}{dt} \tag{15}$$

Therefore (15) relates the change in factor rewards at the trade equilibrium with the change of factor rewards at the EAE plus the changes of factor content of trade.[5]

Consider now the rewards at the equivalent autarky equilibrium and note that the equilibrium price would be a function of endowments and exogenous technical change that is $p_t = p(v_t^e, t)$ and hence the factor rewards at EAE can be written as

$$w_t^e = R_v\left(p\left(v_t^e, t\right), v_t^e, t\right) = R_v^e \tag{16}$$

Totally differentiating (16) with the respect to t we get:

$$\frac{dw_t^e}{dt} = \left(R_{vp}^e \frac{\partial p_t}{\partial v_t^e} + R_{vv}^e\right)\frac{dv_t^e}{dt} + R_{vp}^e \frac{\partial p_t}{\partial t} + R_{vt}^e \tag{17}$$

Substituting (17) in (15), noting that from the definition of factor content of trade $\frac{dv_t^e}{dt} = \frac{dv_t}{dt} - \frac{df_t}{dt}$

[5] Notice that when there is non-jointness in output quantities, $R_{vv} = 0$, and therefore $w_t = w_t^e$and $\frac{dw_t}{dt} = \frac{dw_t^e}{dt}$.

and collecting terms we have that

$$\frac{dw_t}{dt} = \left(-R^e_{vp} \frac{\partial p_t}{\partial v^e_t} - R^e_{vv} + \overline{R}_{vv} \right) \frac{df_t}{dt} + \left(R^e_{vp} \frac{\partial p_t}{\partial v^e_t} + R^e_{vv} \right) \frac{dv_t}{dt} + R^e_{vp} \frac{\partial p_t}{\partial t} + R^e_{vt} \tag{18}$$

Expression (18) relates the changes of the observed rewards at trade equilibrium to the changes of FCT of all factors, f_t, endowments, v_t and exogenous technical change, t. It is a generalization of Deardorff and Staiger (1988) and also of Leamer (1998). If we assume no technological change and that the endowments remain constant, the change in factor rewards will be just a function of the change of the *FCT*. In addition, if there is non-jointness in output quantities or R_{pv} is locally independent of v, factor rewards and consequently their changes between the trade and the equivalent autarky equilibrium will be identical. Then the change of factor rewards will collapse to $\frac{dw_t}{dt} = -R_{vp} \frac{\partial p_t}{\partial v^e_t} \frac{df_t}{dt}$ similar as in Deardorff and Stager (1988).

However, decomposition in (18) depends on the demand side of the economy and in particular on $\frac{\partial p}{\partial v^e}$ and $\frac{\partial p}{\partial t}$. From (7$b$), the matrix of first partial derivatives of product prices with respect to *EAE* endowments is $\frac{\partial p}{\partial v^e} = -\left(R_{pp} - E_{pp}\right)^{-1} R_{pv}$ and the vector of first partial derivatives of product prices with respect to time is $\frac{\partial p}{\partial t} = -\left(R_{pp} - E_{pp}\right)^{-1} R_{pt}$. Therefore equation (18) depends on the second derivatives of the expenditure function with respect to prices. Instead of making any assumptions for the second derivatives of the expenditure function, in the empirical part of this section, we estimate directly $\frac{\partial p}{\partial v^e}$ and $\frac{\partial p}{\partial t}$ by using a Seemingly Unrelated Regression Estimator and assuming that the relationship between the growth rate of prices, the growth rate of *EAE* endowments and technological change is given by,

$$\widehat{p_i} = a_{it} + \sum_j \beta_{ij} \widehat{v^e_j}, \tag{19}$$

where a $\widehat{\ }$ over a variable means growth rate, $a_{it} = \frac{\partial p_t}{\partial t} / p_i$ is the effect of technical change on price and $\beta_{ij} = \frac{\partial p_i}{\partial v_j^e} / \frac{v_j^e}{p_i}$ is the elasticity of price with respect to EAE endowments.

Using equation (19) and (18) we can write the reward to the ℓth factor in growth form as

$$\begin{aligned} \widehat{w}_{\ell t} \;\; = \;\; & -\sum_j \left(\sum_i \varepsilon^e_{\ell i} \beta_{ij} + \eta^e_{\ell j} - \overline{\eta}_{\ell j} \right) \frac{w^e_{\ell t}}{w_{\ell t}} \frac{f_{jt}}{v^e_{jt}} \widehat{f_{jt}} \\ & + \sum_j \left(\sum_i \varepsilon^e_{\ell i} \beta_{ij} + \eta^e_{\ell j} \right) \frac{w^e_{\ell t}}{w_{\ell t}} \frac{v_{jt}}{v^e_{jt}} \widehat{v}_{jt} \\ & + \left(\sum_i \varepsilon^e_{\ell i} a_{it} + \eta^e_{\ell t} \right) \frac{w^e_{\ell t}}{w_{\ell t}}, \end{aligned} \tag{20}$$

where $\varepsilon^e_{\ell i}, \eta^e_{\ell j}, \eta^e_{\ell t}$ are the elasticity of the factor reward with respect to price, endowments and time respectively and $\overline{\eta}_{\ell j}$ is the weighted mean elasticity of the factor rewards with respect to endowments between the *TE* and *EAE* (see appendix B for details). Equation (20) decomposes the growth rate of factor rewards into three terms. The first term is the change of the factor content of trade, the second term is the effect of the change of endowments and the last term the technological change effect.

Table 4 reports all factor reward elasticities evaluated at *EAE* and Table 5 the parameter estimates from the price equations (19). These elasticities are used to calculated the decomposition given by equation (20). From Table 4 it is clear that an increase in the price of the exportable leads to a rise in the reward for capital and unskilled labor and a decline for skilled labor's reward. An increase in the price of the importable or non-tradable goods increases the rewards of capital and skilled labor while it reduces the rewards of unskilled labor respectively. All own inverse factor price elasticities are negative as expected. Capital is a gross-substitute with skilled and unskilled labor, while skilled and unskilled labor are gross-complements. Technological change increases the reward to capital and skilled labor and reduce the reward to unskilled labor. The parameter estimates of Table 5 show that the an increase in the EAE endowments of capital and unskilled labor reduces the equilibrium price of all goods while that of skilled labor works on the opposite direction. Finally the effect of technology increases the equilibrium price of exportable, importable and non-traded goods.

In Table 6 the factor rewards decomposition of US manufacturing is presented for the period 1967-1991. For this period, the factor rewards of capital, skilled and unskilled labor have increased, on average, by 2.4%, 7% and 6% respectively. The pattern that emerges is that the reward changes differ according to the type of factor. In the case of capital and skilled labor this can be mostly attributed to the effect of technological change while in the case of unskilled labor to the factor content of trade and endowments changes. For both types of labor the *FCT Effect* has a positive impact on the growth of their factor rewards. On average for the period 1967-1991, the *FCT Effect* is 2.5% and 3.3% for skilled and unskilled labor respectively, while the *FCT Effect* on the growth of the reward of capital is negative, -1.8%.[6]

The *Endowments Effect* is negative for both capital and skilled labor's rewards, -13.35% and -1.27% respectively, and positive for the growth rate of unskilled labor reward, 2.10%. Capital is the factor with the highest growth in its endowments, followed by skilled labor and naturally this growth had affected adversely the reward for each of these two factor. On the opposite side, unskilled labor endowments have declined over the period of investigation and such decline in the supply of unskilled labor has caused, ceteris paribus, an increase on the reward of unskilled labor.

The last column of Table 6 presents the *Technology Effect.* This effect is positive on average for the growth rate of factor rewards for all three inputs. The technological effect on the growth of capital reward is the highest in magnitude, an average of 17.52%, followed by skilled labor's growth, 5.68%. For the same period the *Technology Effect* on the growth of unskilled labor reward is only 0.50%.

[6] Note that the overall sign and magnitude of the *FCT Effect* for each factor reward depends on all inverse factor price elasticities, equilibrium product price elasticities and the *FCT* growth of all factors and therefore the direction of the effect is ambiguous.

Furthermore, in Table 6, we report the average growth rate of factor rewards and their decomposition for the periods 1967-1981 and 1982-1991. From the second column it is clear that the growth rate of the reward to all factors has decreased significantly from the first to the second sub-period. But the ranking of the growth rates among the three factors remains unchanged, skilled labour experiences the highest growth and capital the lowest in both sub-periods. Looking at the decomposition, the *FCT Effect* for capital and skilled labor rewards increases over time, while it decreases for unskilled labor. It is important to stress that in the second sub-period the *FCT Effect* is the highest for capital and the lowest for unskilled labor. This could be seen as evidence that for the period 1982-1991 international trade has benefited the most the growth of capital reward and the least the one of unskilled labor. The *Endowment Effect* decreases over time for all three factors and is one of the reasons of the lower growth rates of factor rewards in the last sub-period. Similarly, the *Technology Effect* decreases for all three factors of production between the two sub-periods. But while it remains positive for the reward to capital and skilled labor, it becomes negative for unskilled labor in the last sub-period. This seems to suggest not only that technical change favours the rewards to capital and skilled labor, but that it causes a decline in absolute terms for the growth of unskilled labor reward.

It is clear from Table 6 that the difference between the rewards of capital and the two types of labor has narrowed, but that the wage inequality between the two types of workers has increased at a rate of slightly above 1% on average for every year. This seems to be attributed to technological change that has favoured considerably much more skilled labor relative to unskilled labor. This can be easily seen by looking at the factor rewards decomposition in Table 6. For the period 1967-1991 the *FCT Effect* is higher for the unskilled labor and so does the *Endowment Effect*, in fact this effect is negative for skilled labor. As for the *Technology Effect* it is positive for both types of labor over the whole sample period, but skilled labor's magnitude is much higher relative to unskilled labor's.

Consequently, the observed increasing wage inequality between skilled and unskilled workers seems to be due to the *Technology Effect*[7]. Hence, the widening on relative wages between skilled and unskilled workers seems to be the result of technological change that is biased towards skilled labor.

6 Conclusion

In this paper, we provide a dual definition for the factor content of trade based on the equivalent autarky equilibrium introduced by Deardorff and Staiger (1988). This new definition of FCT allows for a more general technology that permits the existence of jointness in output quantities. By estimating a symmetric normalized quadratic revenue function we calculate the FCT of capital, skilled and unskilled labor for the US manufacturing sector for the period 1965 to 1991. Moreover by applying the quadratic approximation lemma to the difference of factor rewards between the trading equilibrium and EAE, we are able to link the observed growth of factor rewards to the growth of FCT, endowments and technological change for 1967-1991.

We find that the FCT of capital is positive while the FCT of skilled and unskilled labor are negative. Hence, for the period of investigation, the level of aggregation and under the technological specification of our model, it appears that there is no Leontief Paradox. This suggests that if the economy was at EAE less capital would have been employed relative to skilled and unskilled labor. The positive sign of capital's FCT and the negative sign of the FCT of both types of labor implies that US manufacturing sector was a net exporter of goods that are more capital intensive between 1965 to 1991 and that capital was revealed by trade to be relatively more abundant to the two types of labor. In addition, following Leamer (1980) we show that skilled labor is revealed by trade to be relatively more abundant to unskilled labor, since the ratio of factor content of skilled labor

[7] This result is qualitative similar to Canals (2006), for the period 1980-1999, and Blum (2008), for the 80's, where both found evidence that skilled biased technological change could explain about 58 and 50 percent respectively on the widening of US wage inequality. In another recent paper Bloom etal (2007) also found that trade induced technological change accounts for 38 percent of technological upgrading in US for the period 2000-2005.

to factor content of unskilled labor is smaller than the ratio of skilled to unskilled labor used in the production.

Overall factor rewards between the two types of labor and capital have narrowed but within labor wage inequality has increased. We find that the *FCT Effect* on factor rewards, for the period considered, is positive for the two types of labor and negative for capital. This is probably the result of the more general technology used in the analysis as the decomposition of the *FCT Effect* indicates in Table 6. The *Endowments Effect* is negative for the growth of capital's and skilled labor's reward and positive for unskilled labor. Suggesting that the increasing endowments of capital and skilled labor have suppressed their rewards, ceteris paribus, while the opposite happened for unskilled labor. Technological change has benefited mainly the reward to capital, but also skilled labor's reward to a smaller magnitude. On the contrary, the reward to unskilled labor had almost no gains arising from technological innovation. Finally, the increasing inequality between skilled and unskilled labor's reward seems to be the cause of technological change that was biased in favour of skilled labor's reward.

Appendix A

There are three inputs in our model, capital, v_K, skilled labor, v_S, and unskilled labor,v_U. Data for the value and price of capital and aggregate labor, at a 2-digit SIC87 analysis are obtained from Dale's Jorgenson database for the period 1963-1991[8]. We construct the value added for capital and aggregate labor and also the price of capital and labor. In particular, the price of inputs is a weighted average of their prices in each 2-digit industry with weights the share of each input in every 2-digit industry. We get the quantity of capital and aggregate labor by dividing their value added by their price, respectively.

The division of aggregate labor into skilled and unskilled labor is implemented by using data from the NBER collection of Mare-Winship Data, 1963 1991. We get data on educational levels, weekly wages, status and weeks worked for full time workers in 2-digit SIC industries. We divide workers into skilled and unskilled following Katz and Murphy (1992), a worker is treated as skilled if he or she spent at least twelve years in education. Our sample contains only full time workers, aged 16-45, that have completed their educational grade and are working in the private sector. First, we calculate the total number of weeks worked per year and also the annual wages and salaries for skilled and unskilled workers[9]. Then we divide the annual value of wages and salaries by the corresponding total weeks worked in order to calculate the full time weekly wage for each group respectively. After that we calculate the share of weeks worked for skilled and unskilled workers relative to the total hours worked of all workers. Similarly, we find the shares of wages for each occupational group in the sample. Finally, these shares are multiplied with the total quantity and total wages of aggregate labor, respectively, obtained from Jorgenson's data set in order to get the quantity and wages for skilled and unskilled workers in US.

[8] http://www.economics.harvard.edu/faculty/jorgenson/files/35klem.html

[9] Following Katz, L. and Murphy, K. (1992) we include only full time workers that have worked more than 39 weeks in that year. Also, top code wage and salaries were multiplied by 1.45.

In our model there are three aggregate products, exportable, y_E, importable, y_I, and non tradable, y_N. Initially the products are divided into tradeable and non-tradeables. A 2-digit industry is termed tradable if the ratio of its exports plus imports divided by its revenue is above 10%, otherwise it is termed as non-tradable[10]. Then tradable industries are grouped to exportable and importable depending on whether their net exports are positive or negative, respectively.

For the calculation of value added of the three aggregate products we again use Jorgenson's data set. While data for output deflators are obtained from the Bureau of Economic Analysis at a 2-digit SIC level. Since these are available from 1977 onwards, the values of output deflators for years before 1977 are obtained by interpolation assuming a constant growth rate equal to the growth rate between 1977 and 1978. The aggregation of the three goods is achieved in three stages[11]. First, we calculate the value added for each aggregate good, then an aggregate price is constructed for each of them. This aggregate price is a weighted average of the prices of all 2-digit industries that belong to an aggregate good, with weights the share of each 2-digit industry. The aggregate quantity of output is calculated by dividing the value of each aggregate good by its aggregate price. Similarly, the volume of net exports is calculated by dividing the value of net exports for each aggregate good by its corresponding aggregate price.

The assumption of balanced trade is not satisfied by the data. For that reason, the actual trade volumes for each good are adjusted according to the share of output relative to total revenue in the economy in order to guarantee balanced trade.

[10] Trade data at a 2-digit SIC87 level were obtained online from the Centre for International Data at the University of California Davis.
http://data.econ.ucdavis.edu/international/index.html

[11] Table 1 shows the SIC categories that are included in each aggregate good.

Appendix B

We define R^e_{vp} as the matrix of the second partial derivatives of the revenue function with respect to prices and endowments evaluated at the equivalent autarky equilibrium at period t with a typical entry $\frac{\partial w^e_{\ell t}}{\partial p_{it}}$. Similarly, R_{vv} and R^e_{vv} are the matrices of the second partial derivatives of the revenue function with respect to endowments evaluated at the trade and equivalent autarky equilibrium at period t and have as typical entries $\frac{\partial w_{\ell t}}{\partial v_{jt}}$ and $\frac{\partial w^e_{\ell t}}{\partial v^e_{jt}}$, respectively. While R^e_{vt} is the vector of the second partial derivatives of the revenue function with respect to endowments and time evaluated at the equivalent autarky equilibrium at period t, with a typical entry $\frac{\partial w^e_{\ell t}}{\partial t}$. Using the above definitions we can write equation (18) for the ℓth factor as:

$$\begin{aligned}
\frac{dw_{\ell t}}{dt} \quad = \quad & -\sum_j \left[\sum_i \frac{\partial w^e_{\ell t}}{\partial p_{it}}\frac{\partial p_{it}}{\partial v^e_{jt}} + \frac{\partial w^e_{\ell t}}{\partial v^e_{jt}} - \frac{1}{2}\left(\frac{\partial w_{\ell t}}{\partial v_{jt}} + \frac{\partial w^e_{\ell t}}{\partial v^e_{jt}}\right)\right]\frac{df_{jt}}{dt} \\
& + \sum_j \left(\sum_i \frac{\partial w^e_{\ell t}}{\partial p_{it}}\frac{\partial p_{it}}{\partial v^e_{jt}} + \frac{\partial w^e_{\ell t}}{\partial v^e_{jt}}\right)\frac{dv_{jt}}{dt} \\
& + \sum_i \frac{\partial w^e_{\ell t}}{\partial p_{it}}\frac{\partial p_{it}}{\partial t} + \frac{\partial w^e_{\ell t}}{\partial t} \qquad \text{(B1)}
\end{aligned}$$

We proceed by dividing both sides of $(B1)$ by $\frac{1}{w_{\ell t}}$ in order to obtain the growth rate of factor reward for the lth factor on the left hand side

$$\begin{aligned}
\frac{dw_{\ell t}}{dt}\frac{1}{w_{\ell t}} \quad = \quad & -\sum_j \left[\sum_i \frac{\partial w^e_{\ell t}}{\partial p_{it}}\frac{\partial p_{it}}{\partial v^e_{jt}} + \frac{\partial w^e_{\ell t}}{\partial v^e_{jt}} - \frac{1}{2}\left(\frac{\partial w_{\ell t}}{\partial v_{jt}} + \frac{\partial w^e_{\ell t}}{\partial v^e_{jt}}\right)\right]\frac{df_{jt}}{dt}\frac{1}{w_{\ell t}} \\
& + \sum_j \left(\sum_i \frac{\partial w^e_{\ell t}}{\partial p_{it}}\frac{\partial p_{it}}{\partial v^e_{jt}} + \frac{\partial w^e_{\ell t}}{\partial v^e_{jt}}\right)\frac{dv_{jt}}{dt}\frac{1}{w_{\ell t}} \\
& + \left(\sum_i \frac{\partial w^e_{\ell t}}{\partial p_{it}}\frac{\partial p_{it}}{\partial t} + \frac{\partial w^e_{\ell t}}{\partial t}\right)\frac{1}{w_{\ell t}} \qquad \text{(B2)}
\end{aligned}$$

Then we multiply and divide by $\frac{v^e_{jt}}{w^e_{\ell t}}$ the first two lines on the RHS of $(B2)$, while we multiply and divide by $w^e_{\ell t}$ the last line on the RHS of $(B2)$

$$\widehat{w_{\ell t}} = \sum_j \left[\sum_i \frac{\partial w^e_{\ell t}}{\partial p_{it}} \frac{p_{it}}{w^e_{\ell t}} \frac{\partial p_{it}}{\partial v^e_{jt}} \frac{v^e_{jt}}{p_{it}} + \frac{\partial w^e_{\ell t}}{\partial v^e_{jt}} \frac{v^e_{jt}}{w^e_{\ell t}} - \frac{1}{2} \left(\frac{\partial w_{\ell t}}{\partial v_{jt}} \frac{v^e_{jt}}{w^e_{\ell t}} + \frac{\partial w^e_{\ell t}}{\partial v^e_{jt}} \frac{v^e_{jt}}{w^e_{\ell t}} \right) \right] \frac{df_{jt}}{dt} \frac{1}{w_{\ell t}} \frac{w^e_{\ell t}}{v^e_{jt}}$$
$$+ \sum_j \left(\sum_i \frac{\partial w^e_{\ell t}}{\partial p_{it}} \frac{p_{it}}{w^e_{\ell t}} \frac{\partial p_{it}}{\partial v^e_{jt}} \frac{v^e_{jt}}{p_{it}} + \frac{\partial w^e_{\ell t}}{\partial v^e_{jt}} \frac{v^e_{jt}}{w^e_{\ell t}} \right) \frac{dv_{jt}}{dt} \frac{1}{w_{\ell t}} \frac{w^e_{\ell t}}{v^e_{jt}}$$
$$+ \left(\sum_i \frac{\partial w^e_{\ell t}}{\partial p_{it}} \frac{p_{it}}{w^e_{\ell t}} \frac{\partial p_{it}}{\partial t} \frac{1}{p_{it}} + \frac{\partial w^e_{\ell t}}{\partial t} \frac{1}{w^e_{\ell t}} \right) \frac{w^e_{\ell t}}{w_{\ell t}} \tag{B3}$$

In order to obtain the growth of factor content of trade and the growth of endowments we multiply and divide by f_{jt} and v_{jt} the first and second line of $(B3)$, respectively. We also multiply and divide by $\frac{v_{jt}}{w_{\ell t}}$ the first term inside the brackets in the first line of $(B3)$

$$\widehat{w_{\ell t}} = -\sum_j \left[\sum_i \frac{\partial w^e_{\ell t}}{\partial p_{it}} \frac{p_{it}}{w^e_{\ell t}} \frac{\partial p_{it}}{\partial v^e_{jt}} \frac{v^e_{jt}}{p_{it}} + \frac{\partial w^e_{\ell t}}{\partial v^e_{jt}} \frac{v^e_{jt}}{w^e_{\ell t}} - \frac{1}{2} \left(\frac{\partial w_{\ell t}}{\partial v_{jt}} \frac{v_{jt}}{w_{\ell t}} \frac{w_{\ell t}}{v_{jt}} \frac{v^e_{jt}}{w^e_{\ell t}} + \frac{\partial w^e_{\ell t}}{\partial v^e_{jt}} \frac{v^e_{jt}}{w^e_{\ell t}} \right) \right] \frac{df_{jt}}{dt} \frac{f_{jt}}{f_{jt}} \frac{1}{w_{\ell t}} \frac{w^e_{\ell t}}{v^e_{jt}}$$
$$+ \sum_j \left(\sum_i \frac{\partial w^e_{\ell t}}{\partial p_{it}} \frac{p_{it}}{w^e_{\ell t}} \frac{\partial p_{it}}{\partial v^e_{jt}} \frac{v^e_{jt}}{p_{it}} + \frac{\partial w^e_{\ell t}}{\partial v^e_{jt}} \frac{v^e_{jt}}{w^e_{\ell t}} \right) \frac{dv_{jt}}{dt} \frac{v_{jt}}{v_{jt}} \frac{1}{w_{\ell t}} \frac{w^e_{\ell t}}{v^e_{jt}}$$
$$+ \left[\sum_i \left(\frac{\partial w^e_{\ell t}}{\partial p_{it}} \frac{p_{it}}{w^e_{\ell t}} \frac{\partial p_{it}}{\partial t} \frac{1}{p_{it}} \right) + \frac{\partial w^e_{\ell t}}{\partial t} \frac{1}{w^e_{\ell t}} \right] \frac{w^e_{\ell t}}{w_{\ell t}} \tag{B4}$$

Finally, recall that $\varepsilon^e_{\ell i}, \eta^e_{\ell j}, \eta^e_{\ell t}$ are the elasticities of the factor reward with respect to price, endowments and time respectively at the equivalent trade equilibrium and $\eta_{\ell j}$ is the elasticity of the factor reward with respect to endowments at the trade equilibrium. While from (19) we know that $\beta_{ij} = \frac{\partial p_{it}}{\partial v^e_{jt}} / \frac{v^e_{jt}}{p_{it}}$ is the elasticity of price with respect to EAE endowments and $a_{it} = \frac{\partial p_{it}}{\partial t} / p_{it}$ is the effect of technical change on price. After collecting terms we reach

$$\widehat{w_{\ell t}} = -\sum_j \left[\sum_i \varepsilon^e_{\ell i} \beta_{ij} + \eta^e_{\ell j} - \frac{1}{2} \left(\eta_{\ell j} \frac{w_{\ell t}}{v_{jt}} \frac{v^e_{jt}}{w^e_{\ell t}} + \eta^e_{\ell j} \right) \right] \frac{w^e_{\ell t}}{w_{\ell t}} \frac{f_{jt}}{v^e_{jt}} \widehat{f_{jt}}$$
$$+ \sum_j \left(\sum_i \varepsilon^e_{\ell i} \beta_{ij} + \eta^e_{\ell j} \right) \frac{w^e_{\ell t}}{w_{\ell t}} \frac{v_{jt}}{v^e_{jt}} \widehat{v_{jt}}$$
$$+ \left(\sum_i \varepsilon^e_{\ell i} a_{it} + \eta^e_{\ell t} \right) \frac{w^e_{\ell t}}{w_{\ell t}} \tag{B5}$$

This is Eq (20) in the main text, where we define $\frac{1}{2}\left(\eta_{\ell j}\frac{w_{\ell t}}{v_{jt}}\frac{v^e_{jt}}{w^e_{\ell t}}+\eta^e_{\ell j}\right)$ to be $\overline{\eta}_{\ell j}$, the weighted mean elasticity of the factor rewards with respect to endowments between the *TE* and *EA*. It involves on the first line on the RHS the growth rate of the *FCT* for all factors that we call it the *FCT Effect*. The expression on the next line incorporates the growth rate of *TE* endowments and is called the *Endowment Effect*. Finally, the expression on the last line is the *Technology Effect*.

References

Baldwin, R., 1971. Determinants of the commodity structure of US trade. American Economic Review 61, 126-146.

Baldwin, R., Cain, G. G., 1997. Shifts in relative wages: the role of trade, technology and factor endowments. National Bureau of Economic Research Working Paper, vol. 5394.

Bloom, N., Draca, M., Van Reenen, J., 2008. Trade Induced Technical Change: The Impact of Chinese Imports on IT and Innovation. mimeo.

Blum B. S., 2008. Trade, Technology, and the Rise of the Service Sector: An Empirical Assessment of the Effects on US Wage Inequality. Journal of International Economics, vol 74, 441-458.

Borjas, G., Freeman, R., Katz, L., 1992. On the labor market effects of immigration and trade, in: Borjas, G., Freeman, R. (Eds.), Immigration and the Work Force, University of Chicago and NBER, Chicago, I.L., pp. 213-244.

Bowen, H., Learner, E., Sveikauskas, L., 1987. Multicounty, multifactor tests of the factor abundance theory. American Economic Review 77, 791-809.

Canals, C., 2006. What Explains the Widening Wage Gap? Outsourcing vs. Technology, La Caixa Working Paper no 1.

Centre for International Data at UC Davis.

Deardorff, A., Staiger, R., 1988. An interpretation of the factor content of trade. Journal of International Economics, vol. 24, 93-107.

Deardorff, A., 2000. Factor prices and factor content of trade revisited: what is the use? Journal of International Economics 50, 73-90.

Diewert, W. E., 1974. Applications of duality theory, in: Intriligator, M., Kendrick, D. (Eds.), Frontiers of Quantitative Economics, vol. 2, North-Holland, Amsterdam, pp. 106-171.

Diewert, W. E., 1976. Exact and superlative index numbers. Journal of Econometrics 4, 114-145.

Diewert, W. E., Wales, T. J., 1987. Flexible functional forms and global curvature conditions. Econometrica 55, 43-68.

Diewert, W. E., 2002. The quadratic approximation lemma and decomposition of superlative indexes. Journal of Economic and Social Measurement 28, 63-88.

Harrigan, J., Balaban R. A., 1999. U.S. wages in general equilibrium: The effects of prices, technology, and factor supplies, 1963-1991. Federal Reserve Bank of New York Staff Report, no. 64.

Harrigan, J., 2001. Specialization and the volume of trade: do the data obey the laws?, in: Harrigan, J., Choi, K. (Eds.), The Handbook of International Trade, Vol. 1, Basil Blackwell, pp. 85-118.

Jorgenson, D. W., Gollop, F. M., Fraumeni, B. M., 1987. Productivity and US Economic Growth. Harvard University Press, Cambridge M.A.

Jorgenson, D. W., 1990. Productivity and economic growth., in: Berndt, E. R., Triplett, J. E. (Eds.), Fifty Years of Economic Measurement: The Jubilee Conference on Research in Income and Wealth, University of Chicago Press, Chicago, I.L.

Jorgenson, D. W.,Stiroh, K. J., 2000. Raising the speed limit: U.S. economic growth in the information age. Brookings Papers on Economic Activity 1, 125-211.

Katz, L., Murphy, K., 1992. Changes in relative wages, 1963-1987: supply and demand factors. Quarterly Journal of Economics 107, 36-78.

Kenen, P., 1965. Nature, capital and trade. Journal of Political Economy 73, 437-460.

Kohli, U., 1991. Technology, Duality, and Foreign Trade: The GNP Function Approach to Modelling Imports and Exports. University of Michigan Press, Ann Arbor, M.I.

Kohli, U., 1993. A symmetric normalised quadratic GNP function and the US demand for imports and supply of exports. International Economic Review 34, 243-255.

Krugman, P., 2000. Technology, trade and factor prices. Journal of International Economics 50, 51-71.

Leamer, E., 1980. The Leontief paradox, reconsidered. Journal of Political Economy 88, 495-503.

Leamer, E., 1994. Trade, wages and revolving door ideas. National Bureau of Economic Research Working Paper, vol. 4716.

Leamer, E., Levinsohn, J., 1995. International trade theory: the evidence, in: Grossman, G., Rogoff, K. (Eds.), Handbook of International Economics, North-Holland, Amsterdam, Vol. 3, pp. 1339-1394.

Leamer, E., 1998. In search of Stolper-Samuelson effects on U.S. wages, in: Collins, S. (Ed.), Imports, Exports and the American Worker, Brookings Institution Press, Washington, D.C., pp. 141-214.

Leamer, E., 2000. What's the use of factor contents? Journal of International Economics 50, 17-49.

NBER's Mare-Winship Data, 1964-1992.

Panagariya, A., 2000. Evaluating the factor-content approach to measuring the effect of trade on wage inequality. Journal of International Economics 50, 91-116.

Vanek, J., 1968. The factor proportions theory: the n-factor cases. Kyklos 21, 749-756.

Winston, G., 1979. On measuring factor proportions in industries with different seasonal and shift patterns or did the Leontief paradox ever existed. Economic Journal 89, 897-904.

Wood, A., 1995. How trade hurt unskilled workers. Journal of Economic Perspectives 9, 57-80.

Zelner, A., 1973. An efficient method for estimating seemingly unrelated regressions and tests for aggregation bias. Journal of the American Statistical Association 68, 317-323.

Table 1: SIC CODES FOR AGGREGATE GOODS

Aggregate Good	**SIC Code Category**
Exportable	Food & Kindred Products (SIC 20)
	Chemicals & Allied Products (SIC 28)
	Industrial & Commerce Machinery & Computer Equipment (SIC 35)
	Electronic & Other Electric Equipment (SIC 36)
	Transportation Equipment (SIC 37)
	Instruments, Photographic, Medical & Optical Goods (SIC 38)
Importable	Textile Mill Products (SIC 22)
	Apparel & Other Finished Products (SIC 23)
	Lumber & Wood Products (SIC 24)
	Paper & Allied Products (SIC 26)
	Petroleum Refining & Related Industries (SIC 29)
	Leather & Leather Products (SIC 31)
	Primary Metal Industries (SIC 33)
	Miscellaneous Manufacturing Industries (SIC 39)
Non-tradable	Tobacco Products (SIC 21)
	Furniture & Fixtures (SIC 25)
	Printing, Publishing & Allied Industries (SIC 27)
	Rubber & Miscellaneous Plastic Products (SIC 30)
	Stone, Clay, Glass & Concrete Products (SIC 32)
	Fabricated Metal Products, Except Machinery (SIC 34)

Table 2: PARAMETER ESTIMATES-REVENUE FUNCTION

Parameter	**Estimate**	**t-stat.**	**Parameter**	**Estimate**	**t-stat.**
a_{EE}	47085.9	0.286	c_{NK}	-2048	-0.851
a_{EI}	-31871.6	-0.394	c_{NS}	61639.2	4.617
a_{EN}	-15214.3	-0.171	c_{NU}	-3075.6	-0.243
a_{II}	21573.3	0.521	b_{KK}	-68690.5	-2.394
a_{IN}	10298.3	0.213	b_{KS}	29583.7	2.294
a_{NN}	4916	0.120	b_{KU}	39106.7	1.779
e_K	2184.5	1.333	b_{SS}	-12741.2	-1.515
e_S	-620.7	-1.003	b_{SU}	-16842.6	-2.523
e_U	-1563.7	-1.224	b_{UU}	-22264.2	-1.303
c_{EK}	64498	2.044	d_E	1557.5	0.607
c_{ES}	-11935.4	-0.420	d_I	-948.9	-0.639
c_{EU}	64737.3	3.018	d_N	-608.6	-0.452
c_{IK}	-13286.6	-0.607	h_t	1146.6	0.808
c_{IS}	72514	3.714	h_{tt}	42.2	0.386
c_{IU}	6805.5	0.428	*Syst.* $\mathbf{R}^2$	0.980	
Hypothesis Testing		**Test Statistic**		$\chi^2_{0.5}$	
No convexity & concavity		Wald(4)=32.7		9.488	
Non-jointness:		Wald(2)=29.1		5.991	
No technological change		Wald(6)=534		12.590	

Table 3: Trade Equilibrium Elasticities
(Mean values, Std. Dev in parenthesis)

	Output Price			Endowment			Techn Change
	Exportable	*Importable*	*Non-tradable*	*Capital*	*Skilled labor*	*Unskilled labor*	
Output Supply	$\varepsilon_{y_i p_E}$	$\varepsilon_{y_i p_I}$	$\varepsilon_{y_i p_N}$	$\varepsilon_{y_i v_K}$	$\varepsilon_{y_i v_S}$	$\varepsilon_{y_i v_U}$	$\varepsilon_{y_i t}$
Exportable	0.326	-0.223	-0.103	0.621	0.048	0.330	0.019
	(0.034)	(0.024)	(0.010)	(0.046)	(0.091)	(0.137)	(0.002)
Importable	-0.528	0.361	0.166	-0.284	1.239	0.044	-0.004
	(0.027)	(0.017)	(0.012)	(0.117)	(0.122)	(0.012)	(0.005)
Non-tradable	-0.253	0.173	0.079	-0.027	1.094	-0.067	-0.001
	(0.025)	(0.016)	(0.009)	(0.043)	(0.016)	(0.040)	(0.004)
Factor Reward	$\varepsilon_{w_j p_E}$	$\varepsilon_{w_j p_I}$	$\varepsilon_{w_j p_N}$	$\varepsilon_{w_j v_K}$	$\varepsilon_{w_j v_S}$	$\varepsilon_{w_j v_U}$	$\varepsilon_{w_j t}$
Capital	1.254	-0.232	-0.022	-1.149	0.678	0.470	0.044
	(0.108)	(0.073)	(0.035)	(0.132)	(0.217)	(0.128)	(0.006)
Skilled labor	0.041	0.516	0.441	0.324	-0.199	-0.1	0.001
	(0.090)	(0.055)	(0.037)	(0.082)	(0.090)	(0.016)	(0.000)
Unskilled labor	1.017	0.061	-0.079	0.759	-0.454	-0.305	-0.017
	(0.031)	(0.010)	(0.021)	(0.100)	(0.163)	(0.064)	(0.002)

Table 4: Equivalent Autarky Equilibrium Elasticities
(Mean values, Std. Dev in parenthesis)

	Output Price			Endowment			Techn Change
	Exportable	*Importable*	*Non-tradable*	*Capital*	*Skilled labor*	*Unskilled labor*	
Factor Reward	$\varepsilon^e_{w_j p_E}$	$\varepsilon^e_{w_j p_I}$	$\varepsilon^e_{w_j p_N}$	$\varepsilon^e_{w_j v_K}$	$\varepsilon^e_{w_j v_S}$	$\varepsilon^e_{w_j v_U}$	$\varepsilon^e_{w_j t}$
Capital	0.841	0.042	0.115	-0.397	0.062	0.334	0.019
	(0.030)	(0.018)	(0.012)	(0.051)	(0.043)	(0.045)	(0.001)
Skilled labor	-0.056	0.569	0.487	0.039	-0.008	-0.030	0.002
	(0.058)	(0.040)	(0.023)	(0.029)	(0.009)	(0.020)	(0.001)
Unskilled labor	1.997	-0.329	-0.668	0.831	-0.150	-0.681	-0.049
	(0.698)	(0.279)	(0.420)	(0.407)	(0.139)	(0.295)	(0.017)

Table 5: Parameter Estimates -Price Growth Equations

Parameter	Estimate	t-stat	Parameter	Estimate	t-stat
a_{ET}	0.069	6.607	β_{IS}	0.446	2.260
β_{EK}	-0.208	-1.743	β_{IU}	-0.308	-1.473
β_{ES}	0.288	2.108	a_{NT}	0.071	6.670
β_{EU}	-0.274	-1.889	β_{NK}	-0.191	-1.562
a_{IT}	0.076	5.011	β_{NS}	0.269	1.919
β_{IK}	-0.227	-1.312	β_{NU}	-0.238	-1.601
Syst. $\mathbf{R}^2$		0.99			

Table 6: Factor Rewards Decomposition
(Annual growth rates %)

Period	Growth of Factor Reward	FCT Effect	Endowment Effect	Tech Change Effect
		Capital		
1967-1991	2.38	-1.79	-13.35	17.52
1967-1981	3.63	-4.84	-10.01	18.48
1982-1991	0.53	2.79	-18.34	16.08
		Skilled Labor		
1967-1991	6.95	2.54	-1.27	5.68
1967-1981	9.17	2.75	-0.11	6.53
1982-1991	3.62	2.23	-3.00	4.39
		Unskilled Labor		
1967-1991	5.93	3.33	2.10	0.50
1967-1981	8.44	4.47	2.46	1.51
1982-1991	2.16	1.62	1.57	-1.03

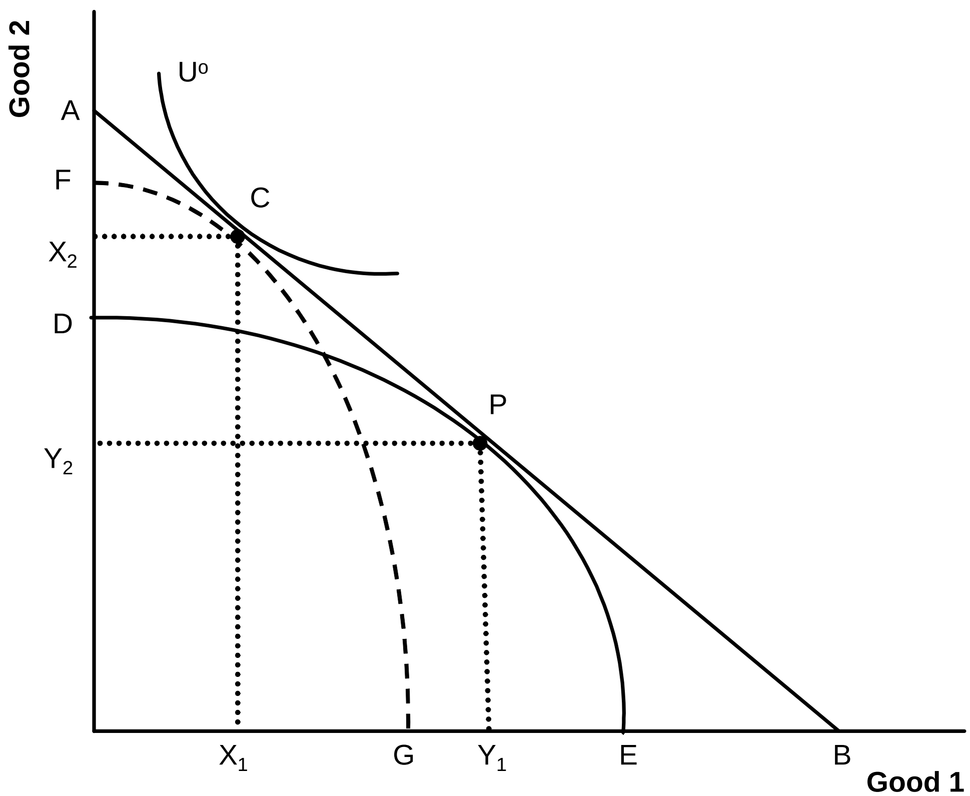


Figure 1: Equivalent Autarky Equilibrium

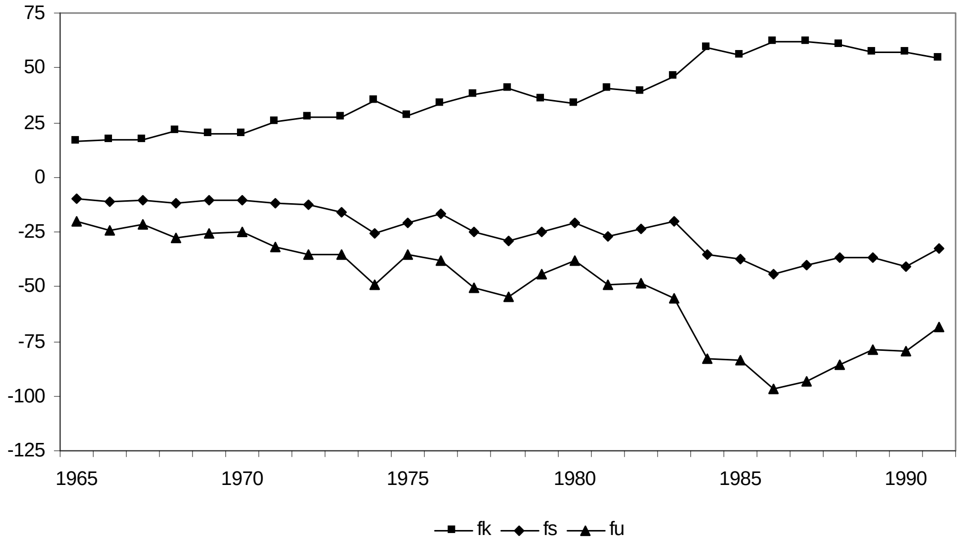
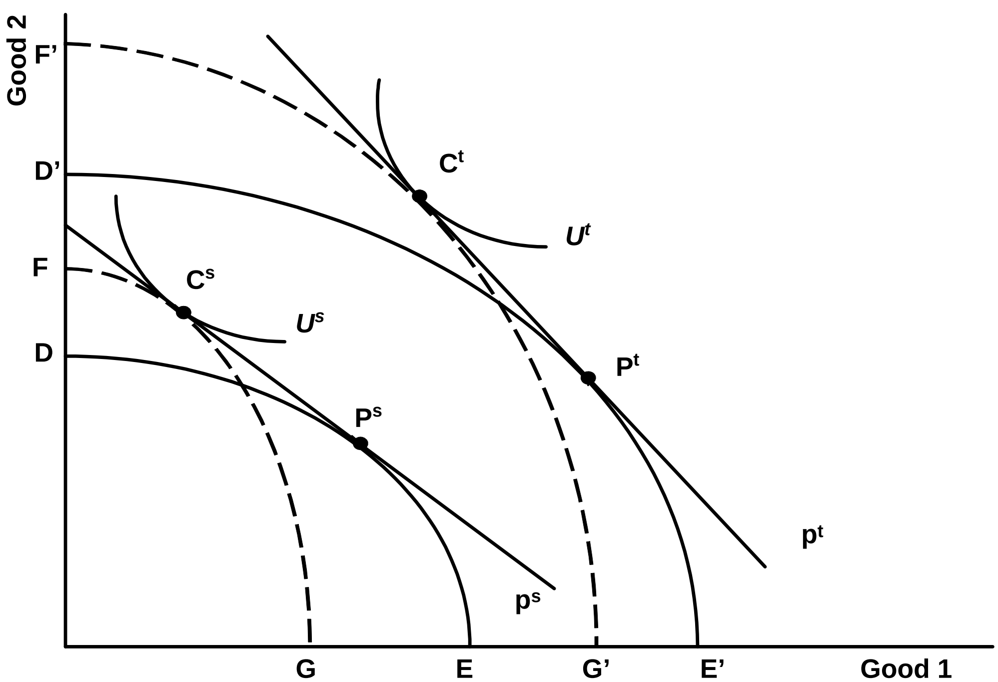


Figure 2: The Factor Content of Capital (f_k), Factor Content of Skilled Labour (f_s) and Factor Content of Skilled Labour (f_u) in billions of 1970 USD.

2 periods



3.pdf

Figure 3: Trade and Equivalent Autarky Equilibria over time.