

Evaluating the Factor-Content Approach to Measuring the Effect of Trade on Wage Inequality

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Abstract

This paper addresses two questions: (i) can factor content of trade be used to measure the effect of trade on wage inequality in a *given year*, with tastes and technology constant; and (ii) can it be used to measure the contribution of trade to the *change* in wage inequality *between two years*, with tastes and technology allowed to change? Deardorff and Staiger (1988) had shown that the answer to the first question can be given in the affirmative provided all production functions and the utility function are Cobb-Douglas. I demonstrate, as does Deardorff (2000) independently, that the affirmative answer can be extended to the case when all production functions and the utility function take the CES form with identical elasticity of substitution. I further demonstrate that we can answer the second question in the affirmative under the same conditions as the first. I then examine critically the assumptions underlying these conclusions. They include identical elasticities of substitution across all production functions and the utility function, absence of increasing returns and non-competing imports, homotheticity of demand, and no endogenous response of factor supplies to trade. I conclude that, taken as a whole, these assumptions are sufficiently strong to leave many analysts, including myself, skeptical of the estimates based the factor-content approach.

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1. Introduction

Traditionally, factor content calculations have been applied exclusively to testing the factor-proportions theory. Recently, however, Borjas, Freeman and Katz (BFK) (1992), Katz and Murphy (1992), Wood (1994) and Baldwin and Cain (1997) have gone on to apply these calculations to the estimation of the effect of trade on wage inequality. These authors identify skilled and unskilled labor contents of net imports as additions to the existing supplies of the respective factors and, using a constant elasticity of substitution, convert them into a change in the skilled-to-unskilled wage.

While the theoretical basis of the application of factor-content calculations to the factor-proportions theory had been laid out clearly in Vanek's (1968) seminal work and extended further in the subsequent important work of Leamer (1980), the theoretical basis of their use in measuring the effect of trade on wage inequality has been a source of some controversy. BFK, who originally applied these calculations to the study of the effect of trade on wage inequality, themselves relied on a partial-equilibrium, labor-market model. Looking for a rationale for their procedure in general-equilibrium, trade theorists, on the other hand, have reached conflicting conclusions.

Thus, Bhagwati (1991) initially raised objections to the use of the factor content of trade for purposes of calculating the effect of trade on wage inequality. Subsequently, Bhagwati and Dehejia (1994) provided two counter-examples in which factor-content calculations fail to predict the change in wage inequality correctly even qualitatively. Leamer (1995) also disapproved of these calculations in strong terms. In Leamer (2000), he reiterates this position. On the other hand, Krugman (2000) defends factor-content calculations as being "entirely justified" and Deardorff (2000) reaches the conclusion "Yes" in response to the question "Is the factor content of trade of any use?"

The purpose of this paper is to subject the factor-content approach to measuring the effect of

trade on wage inequality to a comprehensive analysis. In broad terms, the paper makes two contributions. First, it offers several new results on the relationship between factor content of trade and wage inequality. Second, to better understand the sources of the controversy among various authors, it subjects the assumptions underlying the approach to a careful scrutiny.

The results and critique in this paper are best summarized by reference to two key questions that empirical studies on factor-content and wage inequality have attempted to answer:¹

- (i) Can factor content of trade be used to measure the effect of trade on wage inequality in a *given year*, with tastes and technology constant.
- (ii) Can factor content of trade be used to measure the contribution of trade to the *change* in wage inequality *between two years*, with tastes and technology allowed to change?

In a paper that pre-dates the actual application of factor-content calculations to wage inequality, Deardorff and Staiger (1988) had shown the answer to the first of these questions to be in the affirmative, provided we assume that all production functions and the utility function are Cobb-Douglas. I demonstrate in the present paper, as does Deardorff (2000) independently, that this result can be extended to the case when all production functions and the utility function take the CES form,

¹It may be noted that these are very special questions. For example, they do not relate directly to *trade policies*. Answers to them do not depend on whether a given change in trade flows (and hence its factor content of trade) resulted from a change in trade policies at home or abroad. A richer set of questions is posed in Bhagwati (1997), who casts the analysis directly in terms of trade policies at home and abroad and changes in technology and factor endowments. Also see Deardorff and Hakura (1994) in this context.

with an *identical* elasticity of substitution.

The consensus view with respect to question (ii), at least prior to the first draft of this paper, was that the change in factor-content of trade cannot be used to determine the effect of trade on the change in wage inequality between two years, with tastes and technology allowed to change. I demonstrate this to be untrue, however. I am able to show that the same assumptions that allow us to answer the first question in the affirmative, also allow us to answer the second question in the affirmative.

The critique of the factor-content approach is largely a critique of the restrictive assumptions it requires. To begin with, the requirement that all production functions and the utility function take the CES form with an identical elasticity of substitution is very strong. Recall that the empirical literature on factor-intensity reversals [Minhas (1960)] had made the point that the differences between the elasticities of substitution across sectors are sufficiently large to make the reversals a realistic possibility. Subsequent empirical work has confirmed these findings, with some even questioning the CES form of production functions. There is also evidence questioning the validity of the assumption that preferences are homothetic [Hunter (1991), Panagariya, Shah and Mishra (1997)].

Some readers of Krugman (2000) may express puzzlement with this critique, since his defense of the factor-content approach is based on a model with fully general production functions and a general, homothetic utility function. Nowhere does he impose even the CES form, let alone an identical elasticity of substitution across various functions. But the limitation of his approach--and its generalization to the many-commodities case by Deardorff (2000)--is that it applies strictly to *infinitesimally small changes*. If one considers finite changes in trade flows, as one must in any

empirical exercise, the CES form and identical elasticity of substitution are required to justify the factor-content approach.

Even assuming CES functions with identical elasticities, the factor-content approach breaks down if some of the assumptions, made implicitly by Deardorff and Staiger, are relaxed. Thus, as Leamer (2000) notes and Deardorff (2000) elaborates, if the trading equilibrium, for which calculations are to be performed, is characterized by the presence of non-competing imports, factor-content approach can be applied only by reverting back to the Cobb-Douglas case. I further demonstrate in this paper that the presence of increasing returns renders the approach invalid even in the Cobb-Douglas case. I also show that if factor supplies themselves respond to the changes in factor prices, for example, through migration or skill formation, we cannot glean the effect of trade on factor prices from factor content of trade.

Additional objections to the factor-content approach arise if we relax some of the more explicit assumptions, made to establish a positive answer to the above two questions. The examples in Bhagwati and Dehejia (1994) demonstrate that, if we step out of homothetic-tastes assumption, not required to establish the Stolper-Samuelson theorem which is at the heart of factor-content calculations, even the positive *correlation* between the relative supply of unskilled labor and wage inequality breaks down. That is to say, under nonhomotheticity of tastes, factor-content calculations can lead to *qualitatively* wrong answers.

Given the validity of the factor-content approach under a specific set of assumptions on the one hand, but the highly restrictive nature of these assumptions on the other, should we accept the calculations based on it as Krugman (2000) and Deardorff (2000) do or reject them as Bhagwati and Dehejia (1994) and Leamer (2000) do? There is no unambiguous answer to this question; in the

ultimate, each researcher must draw his or her own conclusion, based on the relative weights he or she assigns to the limitations of the approach and the necessity of a *quantitative* estimate of the effect of trade on wage inequality. Personally, I take a skeptical view of the approach: the assumptions required to implement it are much too strong to inspire confidence in the estimates it generates. We must explore further the alternative option of gleaning the effect of trade on wages inequality directly from prices.²

The remainder of the paper is organized as follows. In Section 2, I formally introduce the two questions around which the paper is organized and outline the model underlying BFK's original calculations. In Section 3, I identify two propositions relating to each of the questions within a general equilibrium model. A novel geometric technique is used to arrive at these propositions. In Sections 4, I discuss the limitations of the propositions and hence the calculations based on the factor-content approach. I conclude the paper in Section 5.

2. The Questions Identified

There are two key questions underlying the factor-content calculations:

Question I: Using the factor content of trade, can we legitimately infer the quantitative impact of trade on skilled-to-unskilled-wage ratio *in a single year, holding tastes and technology constant*?³ For instance, letting the observed skilled-to-unskilled wage ratio in

²Some progress in this direction has been made. Thus, see the recent work of Harrigan (1998) and Kumar (1998).

³Though, here and elsewhere, I refer only to factor content of trade, we usually need to know the proportionate change in the endowment ratio brought about by factor content of trade to calculate

1980 be 2, can we derive from factor content of trade the counter-factual relative wage if the country had chosen to be an autarky in that year?

Question II: Using the change in factor content of trade, can we legitimately measure the contribution of trade to the *change* in relative factor prices *between two years*, with tastes and technology allowed to change? For instance, assuming skilled-to-unskilled wage rose by 10% between 1980 and 1985, can we infer the contribution of trade to this rise from the change in factor content of trade between the two years, even if tastes and technology may have changed during this period?

In a paper predating the present debate, Deardorff and Staiger (1988) had shown that an affirmative answer to Question I can obtain provided we make the assumption that all production functions and the utility function are Cobb-Douglas. I will demonstrate below, as does Deardorff (2000) independently, that the affirmative answer extends to the constant-elasticity-of-substitution (CES) case provided we make the further assumption that all production functions and the utility function have the *same* elasticity of substitution.⁴

As regards Question II, at least prior to the first draft of this paper, the consensus has been

the proportionate change in the relative wage. As such, in addition to the factor content of trade, we also need to know the existing factor endowments.

⁴Strictly speaking, additional restrictions have to be imposed to validate this result. Thus, as Leamer (2000) notes, it requires complete diversification in production. I will show in section 4 that it also requires the assumption of constant returns everywhere and no endogenous response of factor endowments to trade.

that the answer to it is in the negative. As noted in the introduction, I will demonstrate that, surprisingly, the same assumptions that allow us to answer Question I in the affirmative also allow us to answer Question II in the affirmative. Thus, even if technology, tastes and endowments shift between the two years, the answer to Question II is in the affirmative provided production functions and the utility function have the CES form with the same elasticity of substitution in each year and other assumptions (see footnote 4) for the affirmative answer to Question I are satisfied.

Let me begin by illustrating the key idea behind the calculation of the change in wage inequality, attributable to trade, within general equilibrium. In Figure 1, let us consider the observed change in wage inequality between two years, say, 1980 and 1985. Represent the economy's production possibilities frontiers in the two years by $E_{80}F_{80}$ and $E_{85}F_{85}$, respectively. The shift in the production frontier may be due to a change in technology, endowments, or both. Let T_{80} and T_{85} represent trading equilibria in the two years. Suppose skilled-to-unskilled wage ratio, which measures wage inequality, is 10% higher at T_{85} than at T_{80} . Our goal is to determine what proportion of this rise in wage inequality can be attributed to increased trade (Question II).

One way to answer this question is to first determine relative factor prices at autarky equilibria shown by A_{80} and A_{85} in Figure 1. The change in factor prices between these autarky equilibria represents the increase in wage inequality that would have taken place in the absence of trade. Assuming this change to be 8% and recalling that the observed change (in the presence of trade) was 10%, we can conclude that trade accounted for a 2% increase in wage inequality. This represents $(2/10) \cdot 100 = 20\%$ of the actual, total increase in inequality.

To see how the necessary calculations can be done using information on the existing factor endowments and factor content of trade, we must introduce some notation. Denote skilled wage by

s, unskilled wage by w and their ratio s/w by ω . We will think of ω as a measure of wage inequality.

The larger is ω , the greater is wage inequality. I distinguish variables at a trading equilibrium by superscript T. Denoting the observed relative skilled wage in natural logs by $\ln \omega_{80}^T$ and $\ln \omega_{85}^T$ and using the approximation $\ln(1+\alpha) \approx \alpha$, the proportionate increase in wage inequality observed between 1980 and 1985 can be written as⁵

$$(1a) \quad \frac{\Delta \omega^T}{\omega_{80}^T} = \ln \omega_{85}^T - \ln \omega_{80}^T$$

Correspondingly, using superscript A to distinguish the autarky equilibrium, the increase in wage

inequality under hypothetical autarky equilibrium may be written

$$(1b) \quad \frac{\Delta \omega^A}{\omega_{80}^A} = \ln \omega_{85}^A - \ln \omega_{80}^A$$

Subtracting (1b) from (1a), we obtain the proportionate change in wage inequality purely "due to trade" in the sense that it is entirely the result of the country being in a trading rather than autarky equilibrium in the two years under consideration.⁶

⁵Letting $\Delta \omega^T \equiv \omega_{85}^T - \omega_{80}^T$, we have $\ln \omega_{85}^T - \ln \omega_{80}^T = \ln(\omega_{85}^T/\omega_{80}^T) = \ln[(\omega_{80}^T + \Delta \omega^T)/\omega_{80}^T] = \ln[1 + (\Delta \omega^T/\omega_{80}^T)] \approx \Delta \omega^T/\omega_{80}^T$.

⁶As noted in footnote 1, this is a very special question. The answer to it does not depend, for example, on whether trade barriers in 1985 were held at the same level as in 1980. Any changes in trade policies in the intervening years do not have any bearing on the question either.

$$(1c) \quad \frac{\Delta \omega^T}{\omega_{80}^T} - \frac{\Delta \omega^A}{\omega_{80}^A} = (\ln \omega_{85}^T - \ln \omega_{80}^T) - (\ln \omega_{85}^A - \ln \omega_{80}^A)$$

$$= (\ln \omega_{85}^T - \ln \omega_{85}^A) - (\ln \omega_{80}^T - \ln \omega_{80}^A)$$

The last equality in (1c) makes clear that if factor content can be used to infer the effect of trade on wage inequality in a *given* year, with tastes and technology constant (Question I), it can also be used to infer the contribution of trade to wage inequality *over time*, with tastes and technology allowed to change (Question II).

The issue then is how do we translate the factor content of trade into a factor-price effect (Question I). In this section, I discuss the approach taken by BFK, which effectively assumes a one-sector economy. BFK assume the following relationship between factor endowments and factor prices⁷

$$(2) \quad \frac{S}{L} = b \left(\frac{s}{w} \right)^{-\sigma}$$

where S and L denote the endowments of skilled and unskilled labor, respectively, contained in *consumption*, b is a constant and σ can be viewed as the aggregate elasticity of substitution between the two types of labor. Under autarky, the endowments in consumption coincide with those in production which, in turn, are the observed endowment. At a trading equilibrium, the observed endowment of a factor must be adjusted by its content in net imports to obtain the endowment in consumption. The equation says that a 1% increase in the relative supply of skilled labor contained

⁷BFK do not explicitly state this relationship but it is clearly central to their calculations.

in consumption can be fully absorbed in the economy provided relative skilled wage declines by $1/\sigma$ percent.

Substituting $\omega \equiv s/w$ and $k \equiv S/L$ and taking log on each side, we can rewrite equation (2) as

$$(2') \quad \ln \omega = \frac{1}{\sigma} [\ln b - \ln k]$$

Assuming (2') holds at the trading as well as autarky equilibrium in a given year, with tastes and

technology constant, by subtraction, we obtain

$$(3) \quad \ln \omega_t^T - \ln \omega_t^A = \frac{1}{\sigma_t} [\ln k_t^A - \ln k_t^T] \quad t = 80, 85.$$

Here k_t^A is the skilled-to-unskilled labor ratio in year t in consumption under autarky which

coincides with the observed endowment ratio. Ratio k_t^T , on the other hand, is the ratio in consumption at the trading equilibrium and is given by

$$(4) \quad k_t^T \equiv \frac{S_t^A + \Delta S_t}{L_t^A + \Delta L_t}$$

where ΔS_t and ΔL_t represent skilled- and unskilled-labor contents of net imports of all goods combined in year t .⁸ Alternatively, ΔS_t and ΔL_t can be viewed as additions to the existing endowments of skilled and unskilled labor brought about by trade. Making use of these definitions

⁸Exports, to be viewed as negative imports, make a negative contribution to ΔL_t and ΔS_t .

and using, once again, the approximation $\ln(1+\alpha) \approx \alpha$, we can rewrite (3) as

$$(3') \quad \ln \omega_t^T - \ln \omega_t^A = - \frac{1}{\sigma_t} \left[\frac{\Delta S_t}{S_t^A} - \frac{\Delta L_t}{L_t^A} \right] \equiv - \frac{1}{\sigma_t} \frac{\Delta k_t}{k_t^A}$$

Thus, the proportionate effect of trade on the relative wage equals the proportionate change in

relative factor endowments resulting from trade divided by the elasticity of substitution. A 1% fall in skilled-to-unskilled-labor endowment ratio through trade raises wage inequality by $1/\sigma_t$ percent.

Subtracting equation (3') for $t = 80$ from that for $t = 85$ and making use of (1c), we obtain

$$(5) \quad \frac{\Delta \omega_{80}^T}{\omega_{80}} - \frac{\Delta \omega_{80}^A}{\omega_{80}} = - \left[\frac{1}{\sigma_{85}} \frac{\Delta k_{85}}{k_{85}^A} - \frac{1}{\sigma_{80}} \frac{\Delta k_{80}}{k_{80}^A} \right]$$

Given the values of σ_{85} and σ_{80} , this equation allows us to assess the contribution of trade to wage

inequality between two years, with tastes and technology allowed to change. If we further assume that the elasticity of substitution does not change between the two years, setting $\sigma_{80} = \sigma_{85} \equiv \sigma$, we can simplify (5) further to

$$(5') \quad \frac{\Delta \omega_{80}^T}{\omega_{80}} - \frac{\Delta \omega_{80}^A}{\omega_{80}} = - \frac{1}{\sigma} \left[\frac{\Delta k_{85}}{k_{85}^A} - \frac{\Delta k_{80}}{k_{80}^A} \right]$$

This is the key equation employed by BFK. According to it, if we assume that the elasticity of

substitution does not change over time, the contribution of trade to wage inequality can be inferred from the difference between trade-induced proportionate changes in skilled-to-unskilled endowment ratios in the two years.

The above analysis relies on two crucial assumptions: (i) factor content of net imports is equivalent to an increase in the factor content of consumption, and (ii) as shown in equation (2), there is a constant economy-wide elasticity of substitution between skilled and unskilled labor. Are these assumptions justified? BFK do not answer these questions. In principle, equation (2) could be justified via a one-good model in which σ represents the (constant) elasticity of substitution between skilled and unskilled labor along the isoquant. But since there is no basis for trade in such a model, this justification is inherently contradictory. We must necessarily address the question in a model with two or more goods.

3 Justifying the Factor Content Approach in General Equilibrium

I perform two tasks in this section. First, using a novel diagrammatic techniques, I discuss and derive the conditions under which affirmative answers can be given to Questions I and II. Second, I demonstrate that the affirmative answer is robust to the introduction of trade deficit, intermediate inputs and nontraded goods.

Question I

Assume a world with two-good, two-factors and two-regions. Call the factors skilled and unskilled labor, goods 1 and 2 and regions North and South. Let good 1, exported by North, be skilled-labor intensive. Focus on North's economy which is in a trading equilibrium characterized by a tariff with tariff proceeds redistributed to consumers in a lump sum fashion.⁹ The case of complete free trade can be derived as a special case. Suppose we calculate the amount of unskilled and skilled labor contained in North's imports and exports.

⁹It is not necessary to assume that tariff revenue be redistributed to consumers.

Unless otherwise noted, we will now focus on an equilibrium in a single year, with tastes and technology constant. Therefore, the notation will be simplified by dropping the time subscript. Thus, for example, total quantities of unskilled and skilled labor contained in net imports of the two goods will be denoted by ΔL and ΔS , respectively.¹⁰ Because we assume balanced trade and North exports the skilled-labor-intensive good, we will see that ΔL is positive and ΔS negative. The following two steps are needed to justify the translation of these factor contents into factor-price effects.¹¹

Step 1: Deardorff-Staiger Equivalence Theorem: A trading equilibrium is equivalent to an autarky equilibrium with endowments of unskilled and skilled labor augmented by total factor content of net imports of all goods combined.

Step 2: Aggregate Elasticity of Substitution: Under autarky, the general-equilibrium elasticity of substitution between unskilled and skilled labor is constant. This is equivalent to having relationship (2).

Step 1 allows us to represent the trading equilibrium as an autarky equilibrium with factor endowments adjusted by factor content of trade. Given step 2, we can substitute the information on factor content of trade in equation (3) to compute the change in the relative factor price if the economy moves to autarky.

An algebraic proof of step 1 is available in Deardorff and Staiger (1988). Here I offer a

¹⁰Since good 1 is exported, it makes a negative contribution to ΔL and ΔS .

¹¹Alternative justifications may exist as well.

diagrammatic proof.¹² In Figure 2, measure good 1 on the horizontal axis and good 2 on the vertical axis. Let curve EF represent North's production possibilities frontier. Line QQ' represents the domestic price and QC the terms of trade. North produces at point Q and consumes at C. The corresponding quantities produced are X_1 and X_2 and those consumed C_1 and C_2 . The region exports TQ of skilled-labor-intensive good and imports TC of unskilled-labor-intensive good.

Figure 3 maps this equilibrium into input space and transforms trade flows into imports and exports of factors. Measuring skilled labor along the vertical axis and unskilled labor along the horizontal axis, let point E represent the economy's endowments of the two factors. Associated with the equilibrium in Figure 2 is a set of factor prices which allows us to determine factor intensities in the two goods. Let ray OA_i ($i = 1, 2$) represent the equilibrium skilled-to-unskilled labor ratio, S_i/L_i , in good i . Completing the parallelogram EX_1OX_2 , we obtain the vector OX_i which represent quantities of the two factors used in the production of good i .

Next, let us represent the factors needed to produce quantities consumed, shown by C_1 and C_2 in Figure 2, by vectors OC_1 and OC_2 in Figure 3. Adding these vectors, we obtain point C which represents North's factor content of consumption in the trading equilibrium. The difference between vectors OE and OC gives North's factor content of trade. To show this, Observe that AE and X_1C_1 are parallel and equal. Therefore, if we complete right triangle EAF, EF and AF represents the skilled- and unskilled labor content of exports, respectively. Analogously, completing right-triangle

¹²I develop a new technique for this purpose in Figure 3 below. As shown in Panagariya (1999), this techniques can be readily employed to prove various factor-content propositions relating to factor-proportions theory.

ACB, CB and AB represent skilled- and unskilled-labor content of imports. It is then immediate that the content of skilled labor in net imports, BC-EF, equals MF-EF or -EM. Similarly, the content of unskilled labor in net imports, AB-AF, equals FB or MC. Thus, through trade in goods, North exports EM of skilled labor and imports MC of unskilled labor.

It is now easy to see that the equilibrium reached through trade from endowment point E is identical to that reached under autarky from endowment point C. Figure 3 already shows that if endowments are given by point C and factor prices are such as to support factor intensities OA_1 and OA_2 , outputs will be C_1 and C_2 . By construction, the goods- price ratio, supporting factor prices consistent with OA_1 and OA_2 , is given by the slope of line QC in Figure 2. Given constant returns to scale, average costs also equal marginal costs. Moreover, since there are no factor-market distortions, the average-cost pricing conditions ensure the equality of the domestic price to the marginal rate of transformation. The production possibilities frontier associated with endowment C in Figure 3 must be tangent to domestic price line at point C in Figure 2.

Figure 4 shows this last point explicitly. Given EF as the production possibilities frontier and allowing the economy to trade along the terms-of-trade line QC, consumption takes place at C, with domestic price represented by EE' . Furthermore, as just explained, basket C can be produced domestically at price EE' , provided we adjust factor endowments by the quantities contained in imports and exports in the trading equilibrium. That is to say, if we draw the production possibilities frontier associated with the factor-endowment vector obtained by adding the vector contained in trade to the initial one, it will correspond to a curve such as GH in Figure 4. The key feature of GH is that the marginal rate of transformation along it at point C equals the slope of EE' . Thus, the trading equilibrium is shown to be exactly equivalent to the autarky equilibrium obtained by

adjusting factor endowments by the quantities contained in trade.¹³

Given this equivalence, we know that a movement from the trading equilibrium to autarky is identical to an increase in factor endowments by the factor content of net imports, maintaining autarky. We know from the two-sector model that, under autarky, the changes in factor endowments lead to changes in outputs which, in turn, impact goods prices and, ultimately, factor prices. Thus, a relationship between factor content of trade and the autarky equilibrium necessarily exists. The issue is whether this relationship has the simple form shown in equation (2), thus, yielding us Step 2.

To examine this issue, let us first introduce an algebraic expression for σ when the changes in S and L are small. This expression was derived originally by Jones (1965). Let the elasticity of substitution between skilled and unskilled labor in sector i be σ_i and that between goods 1 and 2 in consumption be σ_d . At the initial autarky equilibrium, denote $\lambda_{Li} \equiv L_i/L$, $\lambda_{Si} \equiv S_i/S$, $\theta_{Li} \equiv wL_i/p_iX_i$, $\theta_{Si} \equiv sS_i/p_iX_i$ and define

$$\lambda \equiv \lambda_{S1} - \lambda_{L1}, \quad \theta \equiv \theta_{S1} - \theta_{S2}$$

$$\Delta S \equiv \sigma_1 \lambda_{S1} \theta_{L1} + \sigma_2 \lambda_{S2} \theta_{L2}, \quad \Delta L \equiv \sigma_1 \lambda_{L1} \theta_{S1} + \sigma_2 \lambda_{L2} \theta_{S2}, \quad \text{and} \quad \sigma_s \equiv (\Delta S + \Delta L) / (\lambda \theta).$$

The Expression for σ_s is the elasticity of substitution between X_1 and X_2 along the general-equilibrium supply curve or, equivalently to production possibilities frontier. Given our assumption that good 1 is skilled-labor-intensive, λ , θ and, hence, σ_s are positive.

Using a circumflex (\wedge) over a variable to denote a small, proportionate change in that variable, Jones (1965) shows that the effect of a small change in relative factor endowments on

¹³The construction in Figure 3 is easily extended to allow for more than two goods.

relative factor prices under autarky is given by

$$(6) \quad \hat{s} - \hat{w} = -\frac{1}{\lambda\theta} \cdot \frac{1}{\sigma_s + \sigma_d} (\hat{S} - \hat{L})$$

Defining

$$(7) \quad \sigma_A = \theta \cdot \lambda (\sigma_d + \sigma_s),$$

we can see that σ_A plays the same role in equation (6) as σ in equation (2). The value of the expression on the right-hand side depends on all endogenous variables and, thus, varies with the initial equilibrium around which comparative statics are performed. In general, without knowledge of equilibrium values of all endogenous variables, we cannot determine the economy-wide elasticity of substitution.

There is, however, one highly special case in which a constant value of σ_A does obtain.

Thus, the following lemma holds:

Lemma 1: If all production functions and the utility function exhibit the same constant elasticity of substitution (CES), the economy-wide, aggregate elasticity of substitution between unskilled and skilled labor coincides with this elasticity.

The proof of this lemma is straightforward. Setting $\sigma_1 = \sigma_2 \equiv \sigma$, we have $\Delta_S + \Delta_L = \sigma[\lambda_{S1}(1 - \theta_{S1}) + \lambda_{S2}(1 - \theta_{S2}) + \lambda_{L1}\theta_{S1} + \lambda_{L2}\theta_{S2}] = \sigma(1 - \theta_{S1}\lambda + \theta_{S2}\lambda) = \sigma(1 - \lambda\theta)$. This, in turn, implies $\sigma_s = \sigma(1 - \lambda\theta)/\lambda\theta$. Substituting this value of σ_s and $\sigma_d = \sigma$ into (7), we obtain $\sigma_A = \sigma$. In this special case, (6) reduces to (3). Deardorff (2000) independently proves a very similar result within a multi-good,

multi-factor model.¹⁴ Indeed, it is a trivial matter to use Deardorff's construction to extend the above lemma to the multi-good, multi-factor case. Therefore, henceforth, I will assume that Lemma 1 holds for the multi-good, multi-factor case. Note that, under the conditions stated in this lemma, we can use an estimate of the sectoral elasticity of substitution between skilled and unskilled labor to measure σ . More importantly, the lemma allows us to state the following proposition.

Proposition 1: Assuming trade does not lead to endogenous changes in technology, tastes and endowments, the economy is fully diversified, constant returns prevail everywhere, and production functions and the utility function exhibit the same constant elasticity of substitution, for a given trading equilibrium, we can translate each 1 percent reduction in the relative endowment of skilled labor induced by factor content of trade into $1/\sigma$ percent increase in the relative return to skilled labor.

Lemma 1 establishes the validity of equation (2) and, hence, equation (3'), which is equivalent to Proposition 1.

Question II

What can we say about measuring the contribution of trade to the *change* in wage inequality observed between two points in time, with tastes and technology allowed to change? The following result holds:

Proposition 2: Suppose we observe trading equilibria in two different years with each satisfying the conditions stated in Proposition 1. Tastes, technology, and factor endowments

¹⁴Deardorff (2000) works with the share of a factor in total expenditure and shows that this share declines by $1/\sigma$ percent due to a 1 percent increase in the supply of the factor.

may differ between the two equilibria but not the elasticity of substitution. It is then possible to infer the percentage change in wage inequality due to trade from the difference between percentage changes in factor endowments induced by trade in the two years. For each 1% difference between percentage increases in the relative skilled-labor endowment, contributed by trade in the two years, wage inequality changes by $1/\sigma$ percent.

Once again, given Lemma 1, we have relationship (2) which allows us to establish equation (5), which, given identical elasticities of substitution in the two years, leads to (5'). Thus, Proposition 2 is shown to hold true.

Extensions to Nontraded Goods, Intermediate Inputs and Trade Deficit

I will argue in the next section that the strong assumptions we have made seriously undermine the ability of these propositions to serve as justifications for factor-content calculations. Presently I show, however, that the propositions do stand up to three modifications. First, the presence of nontraded goods does not negate their validity. Using a construction similar to that in Figure 3, it is easy to verify that the Deardorff-Staiger equivalence is unscratched by the addition of nontraded goods. We also know that if all production functions and the utility function are CES and share the same elasticity of substitution, equation (2) continues to hold true. Given the equivalence and (2), we have equations (3') and (5').

Second, the propositions are also robust to trade deficits. We know that Step 2 is independent of what causes factor endowments to change. Therefore, the only issue is whether Step 1 remains valid in the presence of trade deficits. To see that it does, suppose there are no trade barriers and think of QQ' in Figure 2 as the international price (ignore dotted line QC altogether). This line also represents North's income. If trade is balanced, consumption will take place

somewhere along QQ' . But suppose the region is running a deficit so that its expenditure, measured by EE' , exceeds its income, QQ' . The region produces at Q and consumes at C with QT representing exports and TC imports. We have already seen in Figure 2 that equilibrium C can be represented as an autarky equilibrium provided we add net imports of each factor through trade to the existing supply of the factor. Thus, the Deardorff-Staiger equivalence is validated and so also Propositions 1 and 2.

Finally, the propositions are also robust to the introduction of intermediate inputs. To show this, we simply need to note that, given technology, we can calculate both direct and indirect (embodied in intermediate inputs) requirements of skilled and unskilled labor in the production of each good. If we then interpret the OA_i in Figure 3 as factor intensities defined by direct and indirect input usage, the remainder of the analysis remains unchanged.

4 Limitations of General-Equilibrium Formulation

It is tempting to conclude from Propositions 1 and 2 that factor content calculations can after all be legitimized in general equilibrium. I will argue in this section, however, that in view of the strong assumptions required to arrive at them, this is an unwarranted conclusion. Several limitations are relevant.

Empirical Validity of the Equality of Elasticities of Substitution

Some may argue that the assumption that all production functions and the utility function be of CES form and have the same elasticity of substitution is not especially restrictive. Some may also assert (incorrectly) that these assumptions are routinely employed in computable general equilibrium

models.¹⁵ Such complacency is not supported by empirical evidence, however. From the literature spawned by the Leontief (1954) paradox, trade theorists have known for long that factor-intensity reversals are a real possibility. For CES production functions the reversals, in turn, arise when they exhibit differences in elasticities of substitution. Thus, we have known since the seminal contribution by Arrow, Chenery, Minhas and Solow (1961) and the careful study by Minhas (1960) that elasticities of substitution in production do vary across sectors.

As for demand, not only the requirement that the elasticity of substitution characterizing it be the same as that characterizing production functions is without *any* basis, empirical studies have shown nonhomotheticity to be a key characteristic of it. Thus, studies by Hunter (1991) and Hunter and Markusen (1989) present evidence supporting nonhomotheticity. My own recent joint paper, Panagariya, Shah and Mishra (1997), which exploits the highly disaggregated data on imports covered by the Multi-Fiber Agreement (MFA) and estimates parameters of a utility function, strongly suggests the presence of nonhomotheticity in the United States demand for MFA products.

Beyond the Special-Parameters Case

Because empirical evidence brings into question the assumptions underlying propositions 1 and 2, we must ask how the latter are affected if we relax these assumptions.

First take Proposition 2 which requires that the elasticity of substitution be the same over time. If the elasticity shifts in reality, however, it is possible for BFK's calculations to yield a qualitatively incorrect result. Thus, suppose trade raised skilled-to-unskilled labor-endowment ratio

¹⁵Though the CES form is routinely employed, the elasticities of substitution are allowed to vary across sectors and between supply and demand.

by 2% in 1980 and 3% in 1985 and that the elasticity of substitution rose from 1 to 2 between the same years. Applying $\sigma = 1$ to both years, equation (5') predicts a 1% rise in wage inequality between the two years on account of trade. Applying $\sigma = 2$ to both years yields a .5% rise in wage inequality due to trade. But if we apply $\sigma = 1$ in 1980 and $\sigma = 2$ in 1985, using equation (5), we obtain a .5% *decline* in wage inequality on account of trade. Thus, in general, a larger reduction in the relative endowment of skilled labor does not imply a larger increase in wage inequality; shifts in the elasticity of substitution matter.

It may be argued that as long as we apply the correct elasticity of substitution--i.e., rely on equation (5) rather than (5')--, the above problem can be avoided. This is obviously true if all other assumptions of Proposition 2 are satisfied. The issue then is what happens if we consider more general utility and/or production functions. The answer is provided by Bhagwati and Dehejia (1994) who show by counter example that the changes in factor content of trade and factor prices fail to correlate in the way hypothesized by BFK and Proposition 2 in the general case.

To see why, in Figure 5, suppose the production and consumption points in 1980 are Q^0 and C^0 , respectively. Suppose further that the only source of difference between 1980 and 1985 is a trade deficit which moves expenditure outward to EE' . Because the deficit is assumed not to have an impact on goods prices, in the 2x2 model, this change is associated with no change whatsoever in factor prices. Yet, leaving aside solely the homothetic-tastes case in which consumption moves to C' , factor-content approach will attribute some change in wage inequality to trade. If consumption moves to a point north-west of C' such as C^1 , factor-content approach will lead to the conclusion (incorrectly) that trade contributed positively to wage inequality between 1980 and 1985. This is because skilled-to-unskilled-labor endowment ratio under autarky is the same in the two years but

that under trade is lower in 1985 than 1980. Analogously, if consumption moves south-east of C in 1985 to, say, C^2 , factor-content calculations will predict (again incorrectly) a negative contribution of trade to wage inequality.

What can we say about Proposition 1? From Figure 1, it would seem that for a given year, with tastes and technology constant, factor content calculations are *guaranteed* to give a *qualitatively* correct answer. It turns out, however, that in the presence of a trade deficit which was very large during 1980s, if preferences exhibit nonhomotheticity, even for a given year, with tastes and technology constant, factor-content calculations can lead to qualitatively wrong answer.

In Figure 6, under autarky, the economy produces and consumes at A. The opening to trade, which is accompanied by a trade deficit, leads to a movement of the production point to Q and consumption point to C. The deficit allows the country to be a net importer of both goods. Because C shows a higher skilled-to-unskilled goods ratio than Q, it is associated with a higher skilled-to-unskilled endowment ratio in production than the latter. Therefore, factor-content calculations will predict that trade leads to a fall in the relative skilled wage though in reality, as indicated by the movement from A to Q, the relative skilled wage has risen.

What accounts for the failure of factor content of trade to give even qualitatively the right answer in this example? It is easy to verify that the breakdown of the Deardorff-Staiger equivalence is not the answer. Adding net imports of factors to native factors does reproduce each of the two equilibria as autarky equilibria. The failure arises at the next stage: Step 2. It can be verified that the *ex post*, reduced-form value of σ as we move from C^0 to C^1 or C^2 in Figure 5 is infinity so that the change in endowments has no effect whatsoever on factor prices. Similarly, the *ex post*, reduced

form elasticity of substitution for the movement from A to C in Figure 6 is *negative*!¹⁶

Increasing Returns

It is easy to see that the Deardorff-Staiger equivalence is also likely to break down in the presence of increasing returns. For example, suppose sector 1 is subject to scale economies that are output generated as in Panagariya (1980, 1981). Then we know that even at constant goods prices, relative factor prices depend on factor endowments. In particular, in Figure 2, letting point C be the trading equilibrium, the endowment vector that generates this point as an autarky equilibrium will produce different relative factor prices than those prevailing at the trading equilibrium. Moreover, with input requirements per unit of output varying with the scale of output, the measurement of factor content of trade itself becomes a tricky affair. In general, there is no presumption that differences between factor endowments in the trading equilibrium and those needed to reproduce C as an autarky equilibrium will bear a predictable relationship to the factor content of trade, however measured, at the former equilibrium.

Noncompeting Imports

Leamer (2000) has noted that the Deardorff-Staiger equivalence theorem--Step 1 for establishing Propositions 1 and 2--implicitly assumes that the economy is fully diversified and that the presence of noncompeting imports invalidates it. His point is readily illustrated with the help of the diagrammatic technique used in the previous section. For simplicity, once again, I focus on the free-trade case.

¹⁶A similar explanation applies to the counter-intuitive examples relating factor content of trade and wages in Baldwin and Cain (1997).

In Figure 2, suppose the international price line (which also serves as the domestic price line under the present free-trade case) is sufficiently steep to make the production of good 2 unprofitable in North. The region specializes completely in the production good 1, importing the entire quantity of good 2 consumed. In terms of factor markets, as shown in Figure 7, this translates into a factor intensity of good 1 that coincides with the endowment ray OE. The factor price ratio is then given by the slope of good 1's isoquant (not drawn) at point E. Given this factor price ratio, we can determine the least-cost factor-intensity ratio for good 2 as shown by OA_2 . Of course, by assumption, at the given goods and factor prices, it is unprofitable to produce this good.

Given OA_1 and OA_2 , suppose the bundles of factors needed to produce in North the quantities of the two goods consumed by it are represented by points C_1 and C_2 . Adding these bundles, we obtain bundle C. The difference between E and C then gives the factor content of trade. The issue is whether we can reproduce the initial trading equilibrium by adjusting the country's endowment to point C. The answer is in the negative. At the given factor and goods prices, it is unprofitable to produce good 2 so that even though it is *feasible* to produce bundles C_1 and C_2 domestically, in a competitive equilibrium, they will not be produced. For both goods to be produced, goods and factor prices must adjust which means that the Deardorff-Staiger equivalence no longer holds.

Deardorff (2000) suggests a way out of this jam by combining the adjustment in factor endowments by factor content with a Hicks-neutral technical change in non-competing imports. Thus, in Figure 7, suppose we allow a Hicks-neutral technical progress in sector 2 just enough to make this good profitable to produce at the given goods and factor prices. Suppose further that the factor bundle needed to produce C_2 is now given by C_2' . Adding bundles C_1 and C_2' , we obtain C'

as the endowment bundle necessary to produce the consumption basket using the improved technology. The difference between E and C' is, of course, the factor content of trade once the technical progress is taken into account. The Deardorff-Staiger equivalence is once again established. In principle, the change in relative factor prices due to a switch from the observed trading equilibrium to autarky can be calculated by (i) reducing the endowment of each factor by its content in net imports measured at the technological coefficients that permits their production and (ii) a technical regress in noncompeting imports just enough to bring technology to its original level. Hicks neutral technical change in a closed economy with Cobb-Douglas preferences has no effect on *relative* factor prices due to an exactly equivalent offsetting price change [e.g., see Krugman (2000)]. Therefore, (ii) can be avoided altogether if preferences are assumed to have that structure.¹⁷ But since Step 2 to justify factor-content calculations requires identical elasticities of substitution in consumption and production, taking this course requires the imposition of Cobb-Douglas structure on both consumption and production.

Despite its elegance, it is not clear how this restoration of the Deardorff-Staiger equivalence can help in empirical calculations of the effects of trade on factor prices. For noncompeting imports, we do not observe the technology of production in the country under investigation. It is equally problematic to figure the extent of Hick-neutral technical change that will make the production of these goods profitable. One possibility is to use the technology in countries where noncompeting imports are produced. But theory does not provide any basis for that either. Given noncompeting imports, factor prices are likely to differ across countries. In that case, even the factor intensity of

¹⁷See Deardorff (2000) in this connection.

good 2 abroad will differ from the one that will prevail in the country under investigation (OA_2 in Figure 7). Moreover, in practice, differences in productivities also cause factor prices and factor intensities to differ across countries.¹⁸

Trade-Induced Technical Change

Proposition 1 (and, therefore, Proposition 2) breaks down if trade itself causes technology or factor endowments to shift. Question I focuses on where the economy would have been had there been no opportunity to trade. If trade happens to lead to technical progress, the autarky equilibrium cannot be constructed by assuming technology to be that available in the observed equilibrium.¹⁹ In terms of Figure 4, in the absence of trade, the production possibilities frontier would have been inside EF with precise location of the autarky equilibrium depending on the nature of technical regress one assumes.

In principle, to calculate the effect of trade on factor prices, we must first compute the effect of factor content of trade at constant technology along the lines of Proposition 1 and then correct it

¹⁸Wood (1994) uses factor intensities of non-competing imports in the foreign country after adjusting them for differences in factor prices. But he does not adjust the factor intensities for differences in productivity.

¹⁹There is some evidence linking trade and technical progress. For example, Coe and Helpman (1995) hypothesize that productivity growth in a country is faster the greater the imports of technical knowledge embedded in its imports. They test the hypothesis on the 21 OECD countries and Israel and find a positive and statistically significant effect of the index of technology imports (as embodied in goods imports) on productivity growth.

for technical progress that accompanies trade. Interestingly, if preferences are Cobb-Douglas and technical progress is Hicks-neutral, the latter has no effect on relative factor prices. The effect of Hicks-neutral technical progress in a good is exactly offset by an equivalent rise in its price. Therefore, in the special case when all functions are Cobb-Douglas and induced technical change is Hicks-neutral, factor content calculations remain valid as far as relative factor prices are concerned. If the functions are CES, even assuming identical elasticities of substitution everywhere and Hicks-neutral technical progress, relative factor prices are affected beyond the effect yielded by factor content calculations. The direction of the change depends on both the sector in which technical progress takes place and on whether the elasticity of substitution is larger or smaller than unity. Similarly, if induced technical progress is biased in favor of one or the other factor, it will change factor prices beyond what factor content calculations may predict.

This analysis shows that the adjustment Wood (1994) makes to factor content of trade to account for trade-induced technical change is without basis even within the CES case with identical elasticities of substitution everywhere. As just explained, if this elasticity is unity (the Cobb-Douglas case), no adjustment beyond factor-content calculations is required. And in the more general case, it is not the factor content of trade that should be adjusted. Instead, we should directly compute the effect of the technical change. Oddly, if we accept Wood's (1994, 1995) contention that trade-induced technical change has been concentrated in the labor-intensive sector, assuming the elasticity of substitution to be larger than unity, his adjustment is in the wrong direction. For in this case, the technical change leads to a *fall* in the relative wage of skilled labor. Wood's calculations, by contrast, *raise* the relative skilled wage on account of the technical change.

Trade-Induced Changes in Factor Endowments and Tastes

Trade can also change the mix of factor endowments via skill acquisition as well as immigration. For instance, suppose by itself trade increases skilled wage. This could, in turn, increase the relative supply of skilled labor by causing more individuals to seek education and by changing the mix of immigration in favor of skilled labor. By leaving out the effect of these changes in factor prices, factor-content calculations will overstate the effect of trade on wage inequality.

This point has an important implication for factor-content calculations in the presence of immigration. When trade and immigration are both present and interact with each other, one cannot separate the effects of one from the other. In this respect, BFK are right to calculate the effects of trade and immigration jointly and not to separate them. They, nevertheless, slip into error when they state,

In summary, changes in labor skill endowments induced by trade flows can explain a substantial fraction (15-25 percent) of the 1980-85 increase in the college/high school differential and a smaller proportion of the 1980-88 increase. Immigration flows did not significantly alter the nation's relative supplies of high school and college equivalents during the 1980s and are unlikely to have had much impact on the college/high school earnings ratio.

As just argued, even if immigration does not directly change the economy's relative factor endowments, it can do so indirectly through (induced) changes in goods trade. In general, the effect of immigration cannot be determined by applying (2) to changes resulting directly from the inflow of factors without taking into account the accompanying effect on trade and the factor content of such trade.

Factor-content calculations will also be invalidated if trade leads to a change in tastes. The

direction of bias will depend on the direction of the shift in tastes. If the shift is towards the import good, the effect on wage inequality will be lower than what factor content calculations will predict. The shift in tastes works essentially the same way as nonhomotheticity since the latter leads to a change in consumption ratios, *ex post*, at given relative prices.

Limitations of Krugman's Analysis

It remains to be explained why, despite the limitations discussed above, Krugman (2000) reaches the conclusion that the factor-content procedure is "entirely justifiable." To answer, note that Krugman's analysis involves two steps. Using the 2x2 model and limiting himself to small changes under autarky, he first derives a reduced-form, aggregate elasticity of substitution between skilled and unskilled labor endowments similar to that in Jones (1965). He then shows, as did Deardorff and Staiger (1988), that the outcome at a trading equilibrium is identical to that obtained under autarky with factor endowments adjusted by factor content of trade. These two results together imply that the effect of trade on factor prices can be calculated by applying the aggregate elasticity of substitution to the change in factor endowments implied by the factor content of trade. Deardorff (2000) generalizes Krugman's (2000) result to a many-goods context.

Virtually all objections raised with respect to factor-content procedure are assumed away by Krugman via the choice of model. Thus, he assumes homothetic tastes, complete diversification in production, constant returns and no endogenous effect of trade on technology, tastes and factor-endowments mix. In addition, he confines attention to infinitesimally small changes which allows him to derive *locally* a reduced-form elasticity of substitution between skilled and unskilled labor without having to assume that production functions and the utility function are CES with the same elasticity of substitution.

5. Concluding Remarks

Deardorff and Staiger (1988) demonstrated that if all production functions and the utility function are Cobb-Douglas, factor content of trade can be used to derive the effect of trade on wage inequality in a given year, with tastes and technology constant. In this paper, I have extended this result, as has been done by Deardorff (2000) independently, to the CES case with identical elasticities of substitution everywhere in the economy. I have also demonstrated that, under these same assumptions, we can use the change in factor content of trade to infer the change in wage inequality between two years, with tastes and technology allowed to change.

In the paper, I also provide a systematic discussion of the limitations of the factor-content approach to measuring the effect of trade on wage inequality. First, the assumption of CES form and an identical elasticity of substitution everywhere in the economy is strong and difficult to justify on empirical grounds. Second, in the presence of non-competing imports, the calculations cannot be performed unless one assumes all production functions and the utility function to be Cobb-Douglas. Third, if increasing returns are present, we cannot justify factor-content calculations even in the Cobb-Douglas case. Fourth, if nonhomothetic preferences are admitted, factor-content calculations can lead to even qualitatively the wrong answer. Finally, if tastes, technology or factor endowments themselves respond to the changes in factor prices, induced by trade, the factor-content approach is invalidated.

These limitations are at the heart of the conflicting positions taken by different authors regarding the factor-content approach to measuring wage inequality. As indicated in the introduction, I find the limitations to be sufficiently serious to take a skeptical view of the approach.

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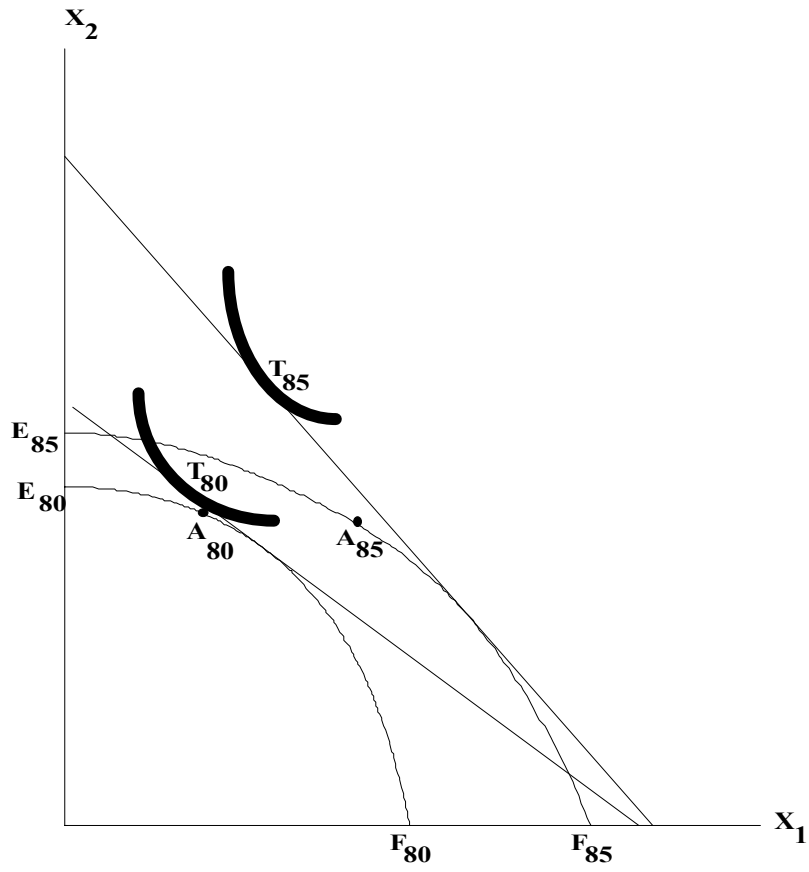


Figure 1: Questions I and II Posed

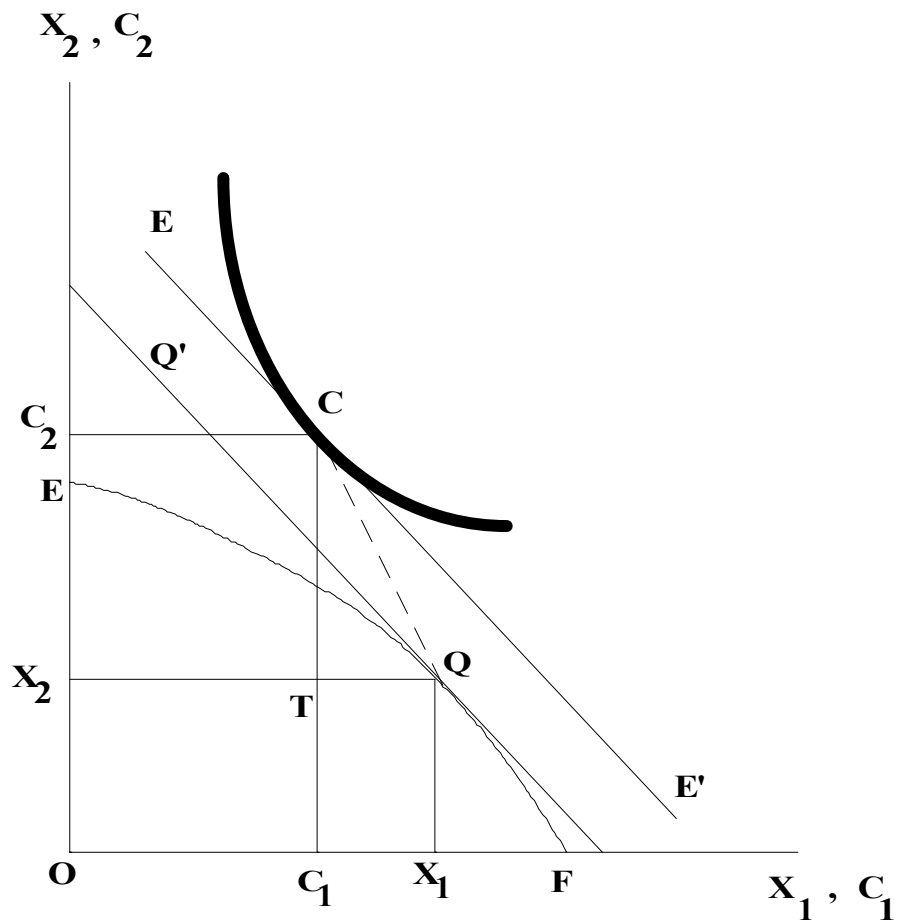


Figure 2: Representing a Tariff-Ridden Trade Equilibrium as an Autarky Equilibrium

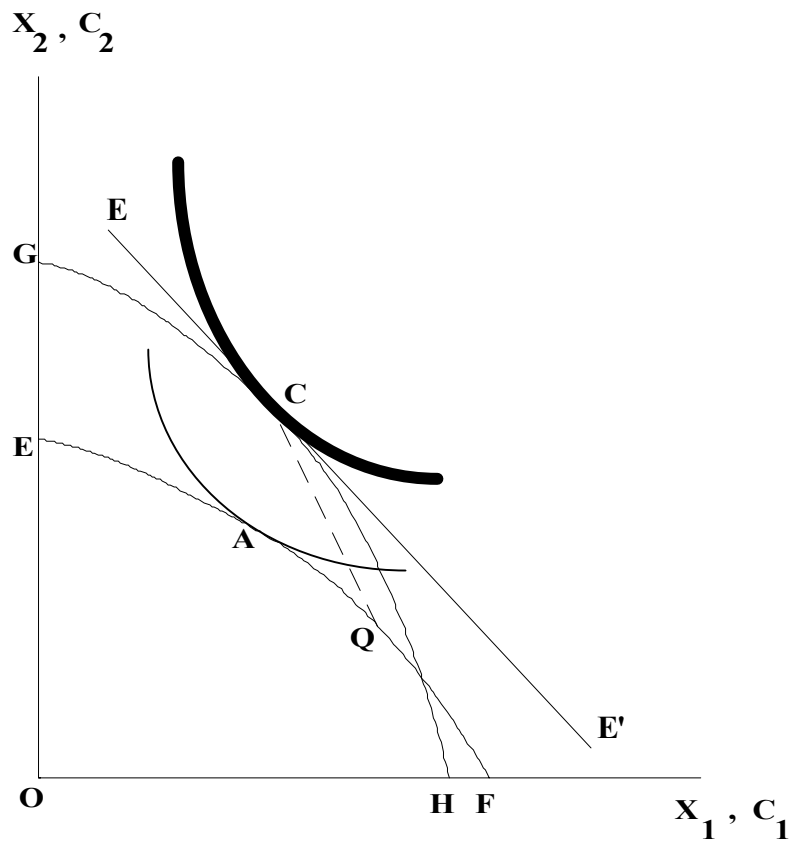


Figure 4: Deardorff-Staiger Equivalence in the Goods Space

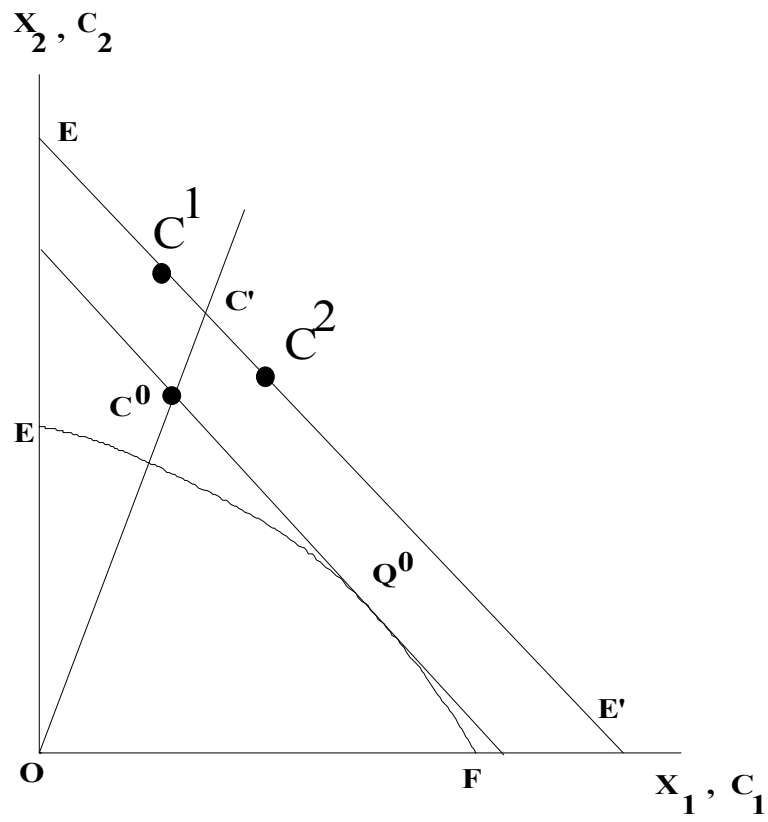


Figure 5: Non-homothetic Tastes and the Factor-Content Approach

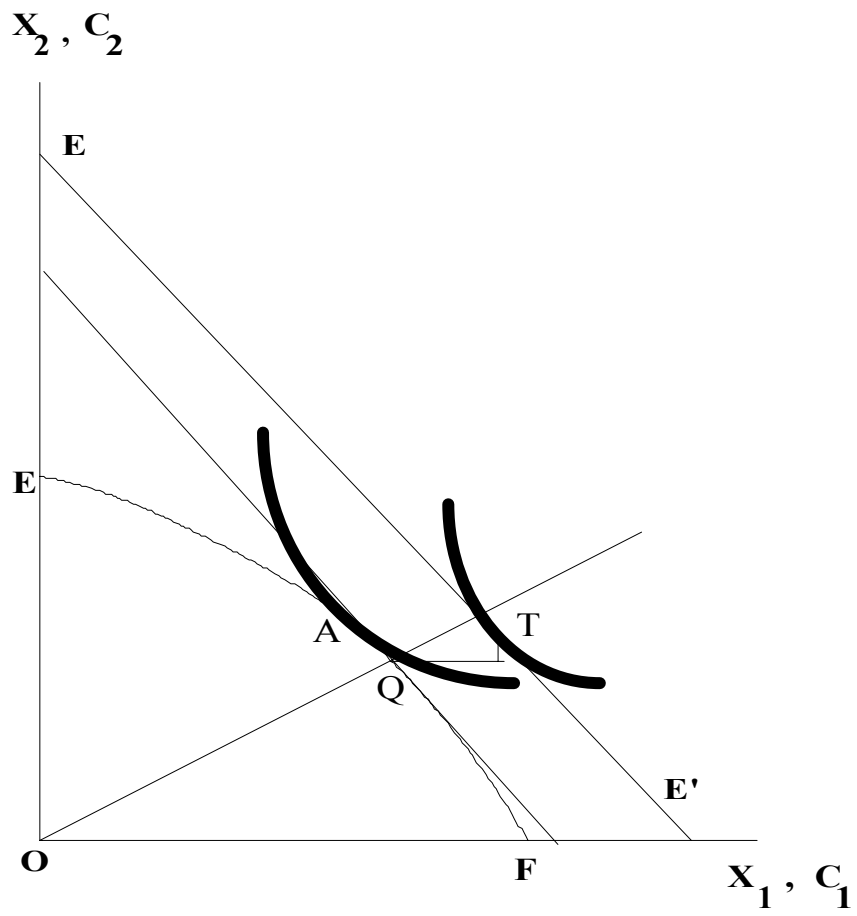


Figure 6: s/w Rises with a Rise in S/L

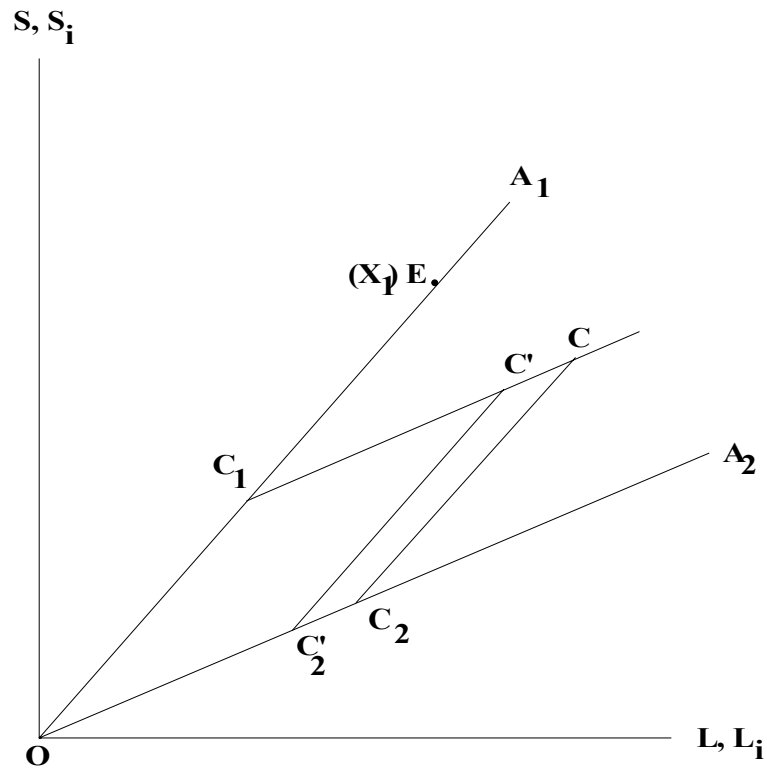


Figure 7: Non-competing Imports and the Factor-Content Approach