

# Interacting factor endowments and trade costs: a multi-country, multi-good approach to trade theory

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## Abstract

Classic trade questions are reconsidered by generalizing a factor-proportions model to multiple countries, multiple goods or multi-stage production, and country-specific trade costs. The focus is on the *interaction* between a country's relative endowment and its trade cost in determining its production specialization, trade volume, factor prices, and welfare. We begin with a symmetric three-good case, comparing trade to autarky. Trade costs play a particularly interesting role for countries with endowments near the world average. Then we consider trade in a two-good case and allow one good to fragment into two stages. Production specialization and the volume of trade are higher with fragmentation for most countries but interestingly, for a large block of countries, these variables fall following fragmentation. Countries with moderate trade costs engage in market-oriented assembly, while those with lower trade costs engage in export-platform production. These two cases correspond to the concepts of horizontal and vertical affiliate production in the literature on multinational enterprises. Increases in specialization and the volume of trade accelerate as trade costs go to zero with and without fragmentation.

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Trade theory tends to be dominated by two-country models while empirical research inevitably confronts multi-country data. Theoretical analyses which do assume multiple countries often rely on product differentiation (Armington or monopolistic-competition), free trade, and possibly factor-price equalization to obtain results. Often the models are not solved for world general equilibrium, especially outside of the factor-price-equalization set.

While rich insights have certainly been gained from the two-country approach, some inherent limitations of two-ness rule out many interesting and important questions. A couple of examples for factor-proportions models are as follows. First, consider a country with the average world endowment. In a two-country model, the other country has the same endowment by definition and so a country with the average world endowment is predicted not to trade, which is surely counter empirical. Second, suppose that there are three goods to be produced. With two countries, one country must produce at least two of the goods, so some specialization patterns are ruled out. Both countries cannot be specialized even if they have extreme endowment ratios. Third, consider trade costs. In a two-country world, there is no meaningful sense in which one country has low trade costs and the other high trade costs. We could never ask how two countries with the same factor proportions but different trade costs differ in their production and trade patterns. A fourth example comes from the theory of multinational firms. A two-country model will generally not support horizontal and vertical firms simultaneously.

These limitations are the motivation for this paper. The purpose of the paper is to reconsider a set of classic trade questions where there are multiple countries which differ in relative endowments and trade costs. Our basic set up is a two-dimensional space of countries, differing in relative factor endowments and in trade costs, and we characterize the production

and trade of every country in this two dimensional space. We begin by deriving the pattern of production specialization, trade, and factor prices in a three-good, two-factor context, comparing trade to autarky for all countries. The model is also an excellent vehicle for considering multi-stage production and outsourcing, topics of current interest. Our second exercise is thus to begin with trade in a two-good model, and then allow the production of one good (X) to fragment into two stages, components (C) and assembly (A) and assess how countries with different factor endowments and trade costs react to this new opportunity.

Several results can be highlighted. For the three-good model:

(1) A country's trade volume depends on its trade costs and factor endowments. For high trade cost countries, trade volume is increasing in the extent to which factor endowments differ from the average world average endowment. For low trade-cost countries this is not true. A low trade-cost country with the average world endowment may specialize and trade a great deal.

(2) Gains from trade and the effects of trade on relative factor prices are increasing in the difference between a country's factor endowment and the world average endowment. Combined with the previous point, this implies a non-monotonic relationship between trade volumes and gains from trade. A low trade-cost country with the average world endowment will specialize and trade a great deal, but gain very little.

Turning to outsourcing:

(3) Separation of component (C) and assembly (A) production occurs under two distinct circumstances. One group of countries imports C and undertakes A for local consumption only. Another group imports C, performs A locally, and exports the final product. The model thus encompasses both market oriented and export platform outsourcing, and identifies country characteristics in which each occurs.

(4) A set of countries with relative factor abundance close to the factor intensity of integrated X production lose from fragmentation, a result anticipated by Jones and Kierzkowski (2001).

(5) Many countries respond to fragmentation by specializing and trading *less*. For these countries trade in the final assembled product is replaced by trade in C, so their volume of trade falls.

(6) Lower trade costs increase trade volumes and specialization, and the relationship

between trade costs and trade volumes is non-linear for the world as a whole (though not for all countries) even *without* vertical specialization. Fragmentation further increases trade volumes in line with the findings of Yi (2003)<sup>1</sup>.

## 1. Related literature

Our paper relates to an extensive range of existing literature, both theoretical and empirical. An early multi-country approach to factor-proportions trade is found in Leamer (1984) with more recent developments in a series of papers by Davis and Weinstein which move away from free trade and factor-price equalization (the empirical implications of trade frictions with many countries and goods are derived in Davis and Weinstein 2003).

Analyses of fragmentation are given in Jones (2000) and the articles in the edited volume of Arndt and Kierzkowski (2001). Venables (1999), Hanson (1998), and Venables and Limao (2002) considers aspects relevant here and the latter two papers in particular introduce a multi-country framework and country or region-specific trade costs. We build upon much of this research, adding new features including solving for world general equilibrium and developing the systematic relationship between the country-specific characteristics of endowments and trade costs and the resultant patterns of specialization and trade.

An important contribution of the present paper is to encompass both market serving and export platform motives for fragmentation. This issue appears primarily in the literature on multinational firms where it is referred to as the distinction between horizontal and vertical investment. The horizontal model was developed in Markusen (1984) and the vertical model in

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<sup>1</sup>In Yi's (2003) important paper, he shows that standard two-country models without vertical specialization/fragmentation cannot produce a non-linear relationship between trade volume (as a share of income) and lower trade costs. We show that this can indeed occur in our multi-country model with country-specific trade costs.

Helpman (1984) and Helpman and Krugman (1985). An integrated approach is given in Markusen (2002), but all of these analyses have the two-country limitation given above, and Helpman-Krugman in particular rely on zero trade costs and factor-price equalization.

Turning to the empirical literature, the growth of trade in intermediates and vertical specialization are analyzed by a number of authors including Hummels, Rapoport and Yi (1998), Yeats (1998), Dickens (1999), Ng and Yeats (1999), Hummels, Ishii and Yi (2001), and Hanson, Mataloni and Slaughter (2001, 2002). Yi's (2003) paper presents an insightful integration of theory and empirical analysis, but the theory sticks with a two-country case (and thus countries cannot differ in trade costs). We hope that our paper can contribute to this empirical literature by suggesting new underlying theoretical relationships with empirical implications.

## 2. The multi-country model

As noted above, we will work in a world in which there are many countries. The description of each country draws on standard trade theory ingredients. Each country has fixed endowments of two factors,  $L$  and  $K$ . Production has constant returns to scale and is perfectly competitive. The unit cost functions for good  $i$  is  $b_i(w, r)$ , the same in all countries, where  $w$  and  $r$  are factor prices.

We have chosen to develop the model with three produced goods. The reason is that three goods gives a much richer pattern of trades than does a two-good model. Both the pattern of trade and the number of goods produced, traded, or non-traded, will vary across countries.<sup>2</sup> The three-good framework also sets the stage for our analysis of fragmentation, which we model

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<sup>2</sup> A larger numbers of goods produce great complexity. We have also experimented with a continuum of goods, and make occasional reference to this case in the remainder of the paper.

as increasing the number of traded activities from two to three. With three goods and two factors production is indeterminate in countries that have zero trade costs, but such countries lie only on a line in our two-dimensional space of countries.<sup>3</sup>

The three goods are denoted  $X_1$ ,  $X_2$  and  $X_3$ , and all consumers have identical homothetic preferences over these goods. World prices of goods are  $p_i$ . Trade is subject to iceberg trade costs, which we will assume in this paper are the same for all goods to/from a particular country. Thus, if a country with trade costs  $t \geq 1$  (where  $t = 1$  is free trade), imports good  $X_i$ , the internal price will be  $tp_i$ . Conversely, if it exports the good the price will be  $p_i/t$  as domestic producers only receive a fraction of the world price. Notice that we assume that these trade costs are incurred on both exports and imports, and that a particular country has the same values  $t$  on its trade with all destinations. It is this that allows us to talk of a clearly defined ‘world price’; it is as if there is a central market place to which countries export and from which they import. Of course, this is a fiction, but it is also a great simplification, meaning that we do not have to work with a full matrix of trade costs between all pairs of countries. It corresponds with reality to the extent that trade costs are just border costs. For example, if trade costs are simply port handling costs, then they apply to all imports regardless of source and exports regardless of destination. Similarly, if the barriers are non-preferential import tariffs or export taxes then they are consistent with our model, although we ignore revenue that any such tariff barriers might earn.

The equilibrium location of production satisfies a set of inequality relationships. Each good  $X_i$  will be produced in a country only if its unit cost is less than or equal to the import price;

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<sup>3</sup> Computationally, this indeterminacy is resolved by imposing a very small trade cost of 0.025%.

and export opportunities mean that the lower bound on unit cost is the export price, so

$$p_i t \geq b_i(w, r) \geq p_i / t, \quad i = 1, 2, 3 \quad (1)$$

If the unit cost is strictly within this inequality then the country is self-sufficient in the good, while it may export the good if the unit cost is at the lower end, and import it at the upper end.

Our strategy for describing the equilibrium has two parts. The first is numerical. We use GAMS to solve for the multi-country equilibrium and details of the code used and dimensionality of the problem are given in appendix 1. We present results from these simulations in a series of figures which describe what countries – differentiated by factor endowments and by trade costs – produce; what they trade; and values of their factor prices and real incomes. These figures indicate the existence of different regimes, in which countries are specialized in different activities. The second part of our strategy is to analytically characterize these regimes, showing how they depend on key parameters of the model.

## 2.1 A symmetric three-good case

We start by presenting results for a symmetric three-good case, and make the following assumptions:

I) Consumer preferences are Cobb-Douglas with expenditure equally divided between the three goods.

II)  $X_1$ ,  $X_2$ , and  $X_3$  production are Cobb-Douglas with symmetric factor shares, with  $X_1$  the most capital intensive:  $X_1$  has labor and capital shares of 0.30 and 0.70 respectively,  $X_2$  has shares 0.50 and 0.50, and  $X_3$  has shares 0.70 and 0.30.

III) Countries are uniformly distributed over a two-dimensional parameter space. One

dimension is factor endowments, which range from  $L = 0.1$  to  $L = 0.9$ , with countries scaled such that capital endowments are  $K = 1 - L$ . The second dimension is trade costs, ranging from free trade to a value of  $t = 1.37$ . Computationally, the two dimensional space is represented by a matrix of 31 x 41 countries, with countries in column 21 having the world average endowment ratio.

We solve for world general equilibrium for all countries simultaneously. Note the difference between our approach and that of the commonly used “world Edgeworth box”, which presents solutions of a set of two-country models, each with a different division of the world endowment between two countries.

Figures 1 and 2 give the structure of production and trade specialization over this matrix of countries. The horizontal axis is labor abundance, measured by  $L \in [0.1, 0.9]$ , and the vertical is trade costs,  $t \in [1, 1.37]$ . A particular country is a point in the figure. The bottom row of the figure, countries with zero trade costs, is characterized by multiple cones of (partial) diversification bounded by regions of complete specialization, as is familiar from Leamer’s work. Moving through one cone of diversification, the structure of production changes according to Rybczynski effects until the edge of the cone of diversification is reached. Countries with higher trade costs, (ie moving upwards in the figures), become less specialized, thus labor abundant countries range from producing good 3 only, to producing goods 2 and 3 and, if their trade costs are sufficiently high, producing all three goods. Countries with the world average endowment ratio either produce just good 2 (if their trade costs are low) or all three goods.

Figure 2 gives the trade regimes in world general equilibrium. The shaded regions are

countries which have one non-traded good. For countries with low trade costs, all goods are traded. For countries with moderate trade costs, there are alternating regions of all goods traded versus one good non-traded. At high trade costs countries with close to the world average endowments are autarkic, while countries with extreme endowment ratios export the good intensive in their abundant factor. Volumes of trade (the sum of exports and imports as a share of production) are shown in Figure 3 which, for better viewing, has the *high-trade-cost* countries are in the nearest row. Trade volumes are lower for countries with high trade costs, and are greatest for countries which are specialized. In our example there are three groups of countries with maximal trade volumes, the number equaling the number of goods. Increasing the number of goods increases the number of diversification cones, regions of specialization and the trade volume peaks of Figure 3. The key point to note is however that the relationship between trade volume and relative endowments is non-monotonic for low trade-cost countries. It is only at higher trade costs, when the central countries do not trade, that we see a monotonic difference between a country's trade volume and the deviation of its endowment ratio from the world average.

The “intersection” of Figures 1 and 2 produces a pattern of both production and trade specialization that divides the world up into eighteen regimes, many of which are mirror images of each other. The full characterization of these regimes is presented in appendix 2 and in Figure A1. These regimes reduce to four generic types of production/trade structure. First, there are sets of countries that are *specialized* in production of a single good which is exported, while other goods are imported. Second, there are countries that produce two goods, one of which is exported and the other not traded; the third good is imported (*partial specialization*). Third,

there are ‘*Heckscher-Ohlin*’ economies in which two goods are both produced and traded, while the third good is either imported or produced and not traded. Comparative statics in this region depend crucially on what is traded – it is possible that the two goods that are both produced and traded are *both* exported, while imports are of a good that is not produced domestically. Finally, there is *autarky*. Each of these cases gives somewhat different comparative statics and we discuss them in turn.

***Specialization:*** In regions in which countries are specialized in production of one good – say good  $j$  – factor prices are determined by two equations. One says that unit costs equal unit export receipts, and the other says that the factor intensity of the sector equals the relative abundance of factors;

$$b_j(w, r) = p_j/t, \quad \frac{\partial b_j/\partial w}{\partial b_j/\partial r} = L/K \quad (2)$$

In this case the level of factor prices depends on trade costs (first equation), but the factor price ratio does not. This price ratio is determined by technology and the country’s factor abundance, as can be seen by differentiating the second equation and using the definition of the elasticity of substitution,  $\sigma_j$ , to give

$$\hat{L} - \hat{K} = \sigma_j(\hat{r} - \hat{w}). \quad (3)$$

where  $\sigma_j = 1$  in our Cobb-Douglas example. Thus, in regions of specialization, a country may have low wages either because it is labor abundant or because it has high trade costs. In the latter case it also has low  $r$ , while in the former  $r$  is relatively high.

***Partial Specialization:*** The second type of regime is where only one good is produced

and traded, but a second good is produced and non-traded. Equations (2) above are then modified by the fact that employment in traded sectors equals the economy's factor endowment net of factor usage in the non-traded sector, this changing the right hand side of equation (2). Comparative statics are then complex, as moving around either endowment space or trade cost space may change the volume of non-traded output.

**'Heckscher-Ohlin' economies:** Economies in which there are two goods that are both produced and traded (the same goods) have factor prices determined by the equality of price (world price trade cost adjusted) to unit costs. For example, consider region 4 of Figure A1 in which relatively capital abundant countries produce and export good  $X_1$  and produce and import  $X_2$ . The following conditions hold:

$$p_1/t = b_1(w, r), \quad p_2 t = b_2(w, r). \quad (4)$$

Factor prices in this region do not depend on endowments, but do depend on trade costs.<sup>4</sup>

Moving around the region, changes in trade costs give Stolper - Samuelson effects according to

$$\hat{r} = -\hat{t} \left[ \frac{\lambda_1 + \lambda_2}{\lambda_2 - \lambda_1} \right], \quad \hat{w} = \hat{t} \left[ \frac{2 - \lambda_1 - \lambda_2}{\lambda_2 - \lambda_1} \right], \quad \lambda_2 > \lambda_1, \quad (5)$$

where the labor share in costs is  $\lambda_j$ . As usual, factor prices move in opposite directions according to relative factor intensities, and the terms in brackets are greater than unity, so there are magnification effects. Higher trade cost countries in this region therefore have higher real wages and lower returns to capital than do low trade cost countries. There is a mirror image region, containing relatively labor abundant countries that produce and export good  $X_3$  and produce and

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<sup>4</sup> The fundamental property is 'factor price insensitivity' see Leamer and Levinsohn (1995).

import  $X_2$ . Since  $\lambda_3 > \lambda_2$ , high trade cost countries in this region have lower real wages and higher returns to capital than do low trade cost countries. Rybczynski effects are dual.

For some countries, it is two export goods that set prices, for example region 6 of Figure A1, in which countries produce and export goods 1 and 2 and import good 3, so

$$p_1/t = b_1(w, r), \quad p_2/t = b_2(w, r), \quad \hat{t} = -\hat{r} = -\hat{w} \quad (6)$$

Higher trade cost countries in this region have lower prices of *both* factors, with relative factor prices unchanged. Higher trade costs also mean a higher price of the imported good, so real factor prices are reduced. The logic underlying the argument is exactly that of Stolper-Samuelson; factor prices are determined by the equality of unit costs to the prices of goods that are both produced and traded. However, the conclusion is quite different, because in this case it is two export goods that are produced and traded, rather than an export and an import competing good.

The patterns of trade and production that we have outlined describe what different countries do in equilibrium. They also tell us about the comparative statics of a single small country. That is, if a single country accumulates factors or reduces its trade costs at unchanged world prices, then it moves through and between the regions we have outlined, with the associated factor price and income changes.

Finally, we turn to comparing the trading equilibrium with autarky. Figures 4 and 5 give factor price changes from autarky and the gains from trade respectively, and are again viewed with the highest trade cost countries nearest. Looking at factor prices, precise effects vary across regions, but there is no non-monotonicity: trade raises or leaves unchanged the relative price of a country's abundant factor and lowers or leaves unchanged the relative price of the

scarce factor.

Figure 5 shows gains from trade: each country's welfare with trade as a proportion of its autarky welfare. Results are intuitive: gains are greater the lower a country's trade costs and the greater the difference between its endowment ratio and the world average (and hence the difference between its autarky prices and world prices with trade).

Notice that even countries with the world average endowment gain from trade. Our symmetric model is calibrated such that, if we only had a set (row) of countries with zero trade costs, world prices would be  $p_1 = p_2 = p_3$ . The central country would be specialized in  $X_2$  but at the same time would be indifferent between trade and autarky, diversifying to produce all three goods. Now add a small positive trade cost for all countries and continue to assume that all prices are equal. The central country would then choose autarky. An increase in the relative price of good 2 is needed to induce exports of good 2 from the central country(ies) to meet the demands from countries that are net exporters of goods 1 and 3:  $p_2 > p_1 = p_3$ .

Combining Figures 3 and 5 we see that there is not a close correlation between a country's trade volume and its gains from trade, especially for low-trade-cost countries. In particular, the central low-cost countries trade a lot, but gain very little. With reference to the previous paragraph, the prices needed to induce exporters of good 2 from the central countries are not very different from those countries' autarky prices, and so their gains are small. This casts doubt on attempts such as that of Frankel and Romer (1999) to empirically quantify gains from trade on the basis of trade volumes.

### 3. Fragmentation

We now turn to using this analytical structure to investigate the effects of the fragmentation of production. If one good can fragment into two separate stages of production, then what is the new pattern of trade and specialisation in the world economy, and what is the pattern of real income change? We start from an initial position with two final goods (X and Y), then allow the possibility that production in the X sector can be ‘fragmented’ into two separate elements, components, C, and assembly, A. The unit cost function for good X can therefore be separated into two sub-cost functions, and written

$$b_X(w, r) = B(b_A(w, r), b_C(w, r)) \quad (7)$$

for all values of factor prices  $w, r$ . Writing the unit cost function in this way implies that there is no direct technical efficiency loss (or gain) in fragmentation. However, a cost saving arises if it is cheaper to import components than to produce them at local factor prices. The world price of components is denoted  $p_C$  and they are subject to trade costs at rate  $t_C$ . Throughout this section, we either assume that trade costs for components are prohibitive so that fragmentation cannot arise, or that  $t_C = t$ , the common value of all other trade costs for a particular country.

As before, the equilibrium location of production satisfies a set of inequality relationships. Unit costs of each good (X, Y, C),<sup>5</sup> lie in the interval

$$p_z t \geq b_z(w, r) \geq p_z / t, \quad z = C, X, Y. \quad (8)$$

If the unit cost is strictly within this inequality then the country is self-sufficient in the good, while it may export the good if the unit cost is at the lower end, and import it at the upper end.

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<sup>5</sup>Assembly “services” cannot be exported, except embodied in final good X.

For assembly activity, equations (7) and (8) need to be used together. For example, consider a country that uses imported components and exports its output. Its factor prices must satisfy

$$p_X/t = B(b_A(w, r), p_C t). \quad (9)$$

Notice that assembly potentially faces a double effect of trade costs; trade costs raise the price of imported components and reduce the returns from exported final output. In the full general equilibrium the location of production is determined by these inequalities, and goods and factor prices are determined by market clearing in the usual way.

For numerical analysis we assume that the fragments  $C$  and  $A$  are Cobb–Douglas, and that  $C$  and  $A$  combine in a Cobb-Douglas function to produce  $X$ . Restrictions on factor shares come from equation (7), and it will be assumed that  $X$  is capital intensive relative to  $Y$ , and  $C$  capital intensive relative to  $A$  (these assumptions simply being a labeling of activities and factors). However, there remain two possible rankings of the factor intensities of the four activities, as shown below where activities are ranked from least to most labor intensive:

Case 1:	$C$	$X$	$Y$	$A$
Case 2:	$C$	$X$	$A$	$Y$

In this analysis we concentrate on results for case 1, in which assembly and components become respectively the most and least labor intensive activities. Results for case 2 are qualitatively similar so we will not analyze it in detail. To be specific, we set labor shares  $\lambda$  and the share of components in  $X$  production,  $\beta$ , as follows:

$$\text{Case 1:} \quad \lambda_C = 0.20 \quad \lambda_X = 0.43 \quad \lambda_Y = 0.57 \quad \lambda_A = 0.66 \quad \beta = 0.5.$$

Notice that we have constructed the factor shares in  $X$  and  $Y$  to be symmetric ( $\lambda_X = 0.43$ ,  $\lambda_Y = 0.57$ ) but this symmetry is lost after fragmentation, where we require  $\beta\lambda_C + (1 - \beta)\lambda_A = \lambda_X$ .

### 3.1 Patterns of production

The structure of production without fragmentation is illustrated in Figure 6, and with fragmentation in Figure 7. Figure 6 is the two-good analogue of figure 1. There is a single cone of diversification, in which countries produce both  $X$  and  $Y$ . Countries with the world average endowment ratio do not trade. Outside the cone of diversification countries are specialized in one good, with the boundaries between diversification and specialization moving to more extreme endowment ratios as trade costs increase.

The effect of fragmentation is given in Figure 7, and initially appears complex. However, it can be understood with reference to our earlier three-good example, together with the fact that assembly and component production are not symmetric. The asymmetry arises for two reasons. One is the fundamental difference between components and assembly; assembly can take place only if supplied by components, and  $A$  activity may be subject to double trade costs. The other reason is simply to do with our parameter values; the factor intensity of component production is more ‘extreme’ than the factor intensity of assembly,  $\lambda_C = 0.20$ ,  $\lambda_A = 0.66$ .

Comparing Figure 7 with Figure 1, and putting to one side for the moment the different shapes of the regions, there is only one qualitative difference, the presence of a group of capital abundant medium-high trade cost countries that undertake  $C$  and  $A$ , the most and the least capital intensive activities, while not producing any good  $Y$ . The reason is clear; the presence of trade costs on components creates a premium on component production and assembly taking place in the same country. What about the different shapes of the regions and the asymmetry of the diagram? This follows from the asymmetry of  $C$  and  $A$  activity, together with the fact that there are efficiency gains from fragmentation;  $p_X/p_Y = 1$  in the initial symmetric two good case, but is

less than unity once fragmentation has taken place.

### 3.2 Trade: vertical and horizontal specialization

Figure 8 presents information on trade patterns, concentrating on trade in *C* and *A* (trade in assembled or “final” *X*). The pattern of trade in *C* and *A* is qualitatively similar to that we saw in figure 2, looking just at trade in goods 1 and 3, with patterns of exports and imports depending on factor abundance and trade costs. However, to understand the pattern of outsourcing that is occurring, it is best to link the information on Fig 8 to concepts developed in the literature on multinational firms. We therefore focus on four regions that are marked on the Figure;

- MO(h): countries for which assembly = local market sales; some or all components are imported.
- MO(p): countries for which assembly = local market sales; some components are exported.
- EP(p): countries that export assembled *X* produced with imported components.
- EP(h): countries that import assembled *X* and export components.

‘MO’, short for market-oriented, describes the fact that all countries in these regions are meeting local demand for good *X* entirely from local assembly; they neither import nor export the good. This is similar to the notion of horizontal or local market-oriented investments used in the literature on foreign direct investment. For example, suppose that we were to assume that firms undertaking local assembly from imported components are affiliates of foreign components producers. A country exporting the components is then a parent, denoted (p) in Figure 8, and a country assembling from imported components is a host, denoted (h) in the Figure. Although there is no necessary bilateral link between a parent and host as in two-country models, this

notation draws out the relationship between our approach and that of the multinational literature. Thus, countries in region MO(h) are labor abundant and relatively high trade cost, and in equilibrium import component products just to undertake assembly production for the local market.

‘EP’ denotes export-platform production, by which we mean assembly of imported components for re-export as finished X. This correspond to the notion of vertical or export-platform investments in the foreign direct investment literature. If again we were to suppose that assemblers are affiliates of component producers, then countries in the region EP(p) have parent firms shipping components to affiliates in countries EP(h) for assembly and re-export (in addition to meeting local demands).<sup>6</sup>

Several important points emerge from Figure 8. The first is that the same basic model generates both market-oriented and export-platform activity, occurring simultaneously but for different sets of countries. The division of countries into those engaging in market-oriented activity and those engaging in export-platform depends primarily on trade costs, while specialization in components or in assembly is determined primarily by factor endowments.

These results are interesting for the multinationals’ literature which has focused on country characteristics as determinants of whether or not activity is market-oriented or export-platform, although it frequently identifies trade costs as an inducement to market-oriented activity and a deterrent to export-platform activity. Our results break the two-country restrictions of the

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<sup>6</sup> Of course, exact bilateral pairings are not determined in this model, since goods are all traded on a world market. The regions EP(p) and EP(h) correspond to what Hummels Rapoport and Yi (1998), Hummels Ishii and Yi (2001) and Yi (2003) term “vertical specialization”: a country exports an intermediate and re-imports it as a finished good (EP(p)) or imports an intermediate and re-exports it as a finished good (EP(h)).

existing literature, and show how both country relative endowments and country trade costs determine whether one is a parent or a host, and whether the activity is market-oriented or export-platform.

### 3.3 Trade volumes, factor prices, and welfare.

Figure 9 presents qualitative information on changes in trade volumes and welfare following fragmentation. Points with no shading or hatching are countries for which both trade volume and welfare increase. It is interesting to note that there are many countries for which trade volume falls following fragmentation. The reason is clear. Consider a country with labor endowment approximately equal to 0.67 in Figure 9 and medium-low trade costs. In the initial situation, its volume of trade measure (VOT, taken to be the ratio of the sum of imports and exports to income) was unity, as it was importing all its consumption of X (Figure 6). With fragmentation, its consumption of X is met from local assembly, so it is importing just components not finished products, and pays for this with smaller exports of Y. Its trade volume therefore falls. Fragmentation allows a country to import just that part of a good in which it does not have a comparative advantage, instead of importing the whole good.

The regions of falling trade volume are largely (although not entirely) contained within the 'MO' regions of Figure 8. These are regions where fragmentation means that instead of importing or exporting complete X products, countries import or export components, with assembly of X undertaken locally. This is trade reducing. In line with the multinationals' literature, this market-oriented activity substitutes for trade while the export-platform activity we identify in Figure 8 is a complement to trade.

Figure 9 also indicates that there are a set of countries that lose from fragmentation. There are two forces at work. One is that there is an overall world efficiency gain. The world economy has some opportunities open to it that were not previously present, so cannot do worse (there are no distortions). The other force is that the terms of trade have changed. As noted above, the price of good X has now fallen relative to the price of Y, as fragmentation of X allows it to be produced more efficiently. Countries with labor endowment of less than 0.5 were initially exporters of X, and those with labor endowment greater than 0.5 were importers. The welfare implications are clear from Figure 9, in which we see a range of countries – large initial exporters of X but not countries with ‘extreme’ endowments – experiencing welfare loss. These countries were ideally suited to integrated X production initially, and lose due to the term-of-trade deterioration even if they adjust to a new pattern of specialization.

Figures 10a, 10b, and 10c present quantitative information corresponding to the qualitative information in Figures 8 and 9. For clarity, results have to be viewed with the high-trade-cost countries in the foreground (the nearest row is the top row of the previous diagrams) and, for Figs 10a and 10b, only for countries with trade costs below the median. The top panel, Figure 10a presents the change in the volume of trade as a share of GDP following fragmentation. This Figure illustrates the asymmetries introduced, and shows the dual role of trade costs and endowments in determining trade volume. The largest trade volumes are for countries specialized in assembly. Their imports of components are 100% of GDP (components and assembly are of equal value) and imports of Y are 50% of GDP. Thus imports and exports are 150% of GDP and total trade is three times GDP. Countries specialized in components export 100% of GDP and import 50% in X and 50% in Y, so their trade is two times GDP. A comparison of Figures 10a

and 9 gives a feel for the shaded areas of Figure 9 where trade volume decreases following fragmentation.

Figure 10b gives the welfare effects of allowing fragmentation. There are large real income gains for countries with extreme factor endowments, which can now specialize in an activity which provides a better match for their endowments. This effect is greatest for very capital abundant countries, since the factor intensity of C is more extreme than the factor intensity of A in our example. As noted in our discussion of Figure 9, there is a small set of moderately capital abundant countries that lose from fragmentation due to the terms-of-trade effect, but these losses are quantitatively very small.

Changes in factor prices are not so easily interpreted, so we present both the pre- and post-fragmentation  $w/r$  ratios for the zero-trade-cost countries in Figure 10c. A log scale is used for factor price ratios for clarity, but we are really only interested in the qualitative results. In the absence of fragmentation (line WRN), the results follow directly from the pattern of production (Fig. 6) There is a cone of diversification and factor-price equalization set (FPE) of countries in the center with  $w/r$  ratios diverging toward either fringe. As we saw on Fig 7, fragmentation creates two cones of diversification and associated FPE sets. The larger FPE set on the left of Figure 10c is the set of countries specializing in C and Y while the smaller set on the right are the countries specializing in Y and A. Although the left-hand FPE set largely overlaps the pre-fragmentation FPE set, it is interesting to note that the factor prices in these sets are not the same. Countries are now producing different things and at different world prices. For the fringe countries, on the other hand, we do see the intuitive result that fragmentation raises the relative price of the country's abundant factor.

#### 4. Comparative statics: globalisation in a multi-country world

The patterns identified in the preceding section provide a synthesis of the different ways in which countries participate in the world economy, integrating theories of trade, market-oriented investment and export-platform investment. The question we now seek to address is: as trade costs fall in the world economy, what happens to countries' trade and specialization, to the volume of trade and to countries' and individuals' real income levels?

The effect on production/trade regimes can be briefly discussed with reference to Figure 8 without presenting an additional diagram. Proportionately reducing trade costs for all countries has the effect of stretching all MO and EP regions upwards, as countries that previously had high trade costs now face lower ones. In addition to these direct effects there is a reduction in the world price of X relative to Y, as it is fragmented X production that gains most from lower trade costs. The important point to note is that falling trade costs causes a range of capital abundant countries to close down X assembly, instead importing X from labor abundant countries. At the same time a range of labor abundant countries switch from appearing 'import substituting' (assembling X goods just for local consumption: MO(h)) to becoming export oriented (exporting assembled X goods: EP(h)).

This change is associated with dramatic increases in the degree of specialization and the volume of world trade relative to income. Figure 11 has on the horizontal axis a measure of world trade costs and measures trade volume as a proportion of world GDP on the vertical axis. The trade cost is a scaling factor, whereby all countries have their trade costs scaled up and down by this multiple; 1 is the central case value where each country has the trade costs in Figures 1-10.<sup>7</sup>

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<sup>7</sup> Thus, comparing points 0.5, 1, and 1.5 a country with initial  $t - 1 = 0.1$  has costs, 0.05, 0.1, 0.15

The uppermost of the positively sloped lines is the volume of trade measures with (VOTY) and without (VOTN) fragmentation. We see that in both cases there is a convex relationship, with larger proportionate cuts in trade costs increasing the volume of trade at an increasing rate. Permitting fragmentation increases trade volumes, and the proportionate increase is greater the lower are trade costs, as indicated by the line marked RATIO, which gives the ratio of the volume of trade without fragmentation to that with.

The role of fragmentation in creating trade is similar to that pointed out by Yi (2003) and others. A comparison of our result and that of Yi (2003) is not straightforward, as they derived from different models. Indeed, trade expansion at the *extensive* margin (more things traded, more countries trading) as well as at the *intensive* margin (more volume of trade in the same stuff by the same countries) is important in both papers. In our model without fragmentation, trade does expand at the extensive margin with a proportional lowering of all countries' trade costs as more countries are drawn out of autarky and into world trade: more countries trade in addition to more trade by existing traders.

But our model is richer in that it reveals important difference among countries hidden by the aggregate statistics in Figure 11. This can be seen by focusing on a set of countries which transit through the experience of horizontal then export-platform activity. Figure 12 is analogous to Figure 11, but just reports the trade volumes for countries that, in the central case of Figure 11, were largely engaged in horizontal activity (to be precise, 22 out of 41 countries, those with central-case trade costs of 0.091 and labor endowments in the range 0.20-0.40 and 0.60-0.80). Since all these countries have the same trade costs, their actual costs are shown on the horizontal axis rather than the scaling factor (so 0.091 is their value in Figures 1-10).

The point about this Figure is the cross over of the curves. Thus, for these countries, fragmentation increases specialization and trade when trade costs are relatively high or very low, and decreases it when trade costs are moderately low. The interval in which fragmentation is associated with market-oriented investments is one in which fragmentation reduces trade volumes as noted in Figure 9.

The intuition that trade volume can be less with fragmentation lies in the fact that these countries have somewhat more extreme endowments than ideal for specializing in X or Y, yet not extreme endowments best suited to specializing in C or A. Without fragmentation, they do specialize in X or Y, but with fragmentation those countries generally specialize in C, Y and Y, A respectively. Their volume of trade may be smaller with fragmentation for reasons noted earlier. With moderate trade costs, the capital-abundant countries would like to just export C rather than integrated X, and the labor-abundant countries would like to just import components rather than integrated X. Instead of being forced to import/export all of X, they exercise the option to just import/export that part of X (C) that they are bad/good at.

## 5. Summary and Conclusions

We develop a multi-country model of trade in which countries differ in both factor endowments and trade costs. The ingredients are simple enough to allow intuitions from standard factor endowment trade theory to be applied, yet the setting general enough to allow a richer range of outcomes to occur and a richer range of questions to be addressed.

(1) The first case presented is one with three symmetric final goods. An interesting distinction emerges between low and high-trade costs countries. The pattern of production

specialization and trade for low-trade-cost countries looks familiar from Leamer's work, with sets of partially diversified countries interspersed across endowment ratios between sets of completely specialized countries. The deviation of these countries' endowment ratios from the world average is positively associated with their gains from trade, but not with their trade volume. In contrast, for countries with high trade costs, the deviation of endowments from the world average is positively associated with both trade volumes and the gains from trade. Consequently, there is a positive association between trade volumes and gains from trade for high trade cost countries, but not for low trade cost countries, a finding with important implications for empirical work on the gains from trade.

(2) A second issue to which we apply the model is the effect of allowing one production sector (X) to fragment into two geographically separated production activities (C and A). The effect of fragmentation is to produce a pattern of production that is systematically and intuitively related to the factor intensities of the activities and the factor endowments of the countries. Trade costs are also important, particularly because of the double trade-cost incidence of exporting components and re-importing them.

(3) Introducing fragmentation improves the welfare of most countries and for the world as a whole. However, some countries lose. These are countries that are ideally suited to specializing in integrated X production initially, but less suited to either C or A individually. Fragmentation in the world economy leads to efficiency gains that translates into a fall in the relative price of X. The countries that lose suffer a terms-of-trade deterioration on their initial export good.

(4) Fragmentation enables low trade cost countries to specialize in export activities that match their factor endowments, while higher trade cost countries use fragmentation as a means of

‘import substituting’. Thus, labor abundant countries that have low trade costs import components and export assembled products, while countries with higher trade costs import components and assemble just for the local market. In the latter case fragmentation may actually reduce trade volumes. These cases are analogous to the results in the literature on multinational firms that make the distinction between horizontal (market-oriented) and vertical (export-platform) investments.

(5) Reducing trade costs worldwide moves some countries from one pattern of specialization to another and draws additional countries out of autarky. In particular, final assembly activities move from a set of labor scarce countries to labor abundant ones, with impacts on the real income and factor prices of these countries. The volume of world trade is convex in trade cost reductions, in line with recent experience and empirical findings. As in Yi (2003), trade expands at the extensive margin as more things are traded by existing traders but in our case also due to more countries being drawn out of autarky and into trade. The latter allows us to produce the convexity result even without fragmentation.

(6) Notwithstanding our results that a world wide fall in trade costs increase trade volume and specialization for the world as a whole more with fragmentation than without, there are substantial subsets of countries for which this is not true, at least over certain ranges in trade costs. Countries with moderate trade costs and factor endowments that differ moderately from the world average, may take advantage of fragmentation to “unbundle” their production and trade. As noted in point (3), labor-abundant countries can import just components for local assembly instead of importing finished X (exporting Y), and capital-abundant countries can export just C and assemble at home (importing Y).

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Appendix 1: Inequalities and unknowns in the 3-good general-equilibrium model

Countries differing in relative endowments and trade costs:  $31 \times 41 = 1271$  countries: 29236 inequalities in 29236 complementary non-negative variables:

$i, j$  are countries, where  $i$  indexes the trade cost and  $j$  indexes the endowment  
 $k$  are production activities for good  $X_k$   $k \in \{1, 2, 3\}$

$p_{kij}$ - producer price of $X_k$ in country $ij$	$EX_{kij}$ - exports of $X_k$ from country $ij$
$pc_{kij}$ - consumer price of $X_k$ in country $ij$	$IX_{kij}$ - imports of $X_k$ into country $ij$
$p_k$ - world price of $k$	$XX_{kij}$ - supply of domestic $X$ to home
$p_{uij}$ - price of utility	$U_{ij}$ - utility of consumer in country $ij$

Inequality	Complementary Variable	Number of inequalities and unknowns
------------	------------------------	-------------------------------------

zero profit inequalitiesactivity levels

$c_k(w_{ij}, r_{ij}) \geq p_{kij}$	$X_{kij}$	3813 (i*j*k)
$c_{uij}(pc_{kij}) \geq p_{uij}$	$U_{ij}$	1271 (i*j)
$p_{kij} \geq pc_{kij}$	$XX_{kij}$	3813
$p_{kij} t_i \geq p_k$	$EX_{kij}$	3813
$p_k t_i \geq pc_{kij}$	$IX_{kij}$	3813

market clearing inequalitiesprices

$XX_{kij} + IX_{kij} \geq \frac{\partial c_{uij}}{\partial pc_{kij}} U_{ij}$	$pc_{xij}$	3813
$\sum_i \sum_j EX_{kij} \geq \sum_i \sum_j IX_{kij}$	$p_k$	3
$U_{ij} \geq M_{ij}/p_{uij}$	$p_{uij}$	1271
$X_{kij} \geq XX_{kij} + EX_{kij} - IX_{kij}$	$p_{kij}$	3818

$$L_{ij} \geq \sum_k \frac{\partial c_{kij}}{\partial w_{ij}} X_{kij} \quad w_{ij} \quad 1271$$

$$K_{ij} \geq \sum_k \frac{\partial c_{kij}}{\partial r_{ij}} X_{kij} \quad r_{ij} \quad 1271$$

Income balance inequalities

incomes

$$M_{ij} = w_{ij}L_{ij} + r_{ij}K_{ij} \quad M_{ij} \quad 1271$$

Appendix 2: Production and trade regimes for the 3-good model.

Regions refer to Figure A1.

Subscripts  $w, r$ , denote partial derivatives;  $\alpha_i$  denotes share of good in consumers' expenditure.

Region 1: Autarky	produce	trade	Costs	Factor markets
$X_1$	✓	0	$p_1/t < b_1(w, r) < p_1t$	$Y = wL + rK$
$X_2$	✓	0	$p_2/t < b_2(w, r) < p_2t$	$L = \alpha_1 Y b_{1w}/b_1 + \alpha_2 Y b_{2w}/b_2 + \alpha_3 Y b_{3w}/b_3$
$X_3$	✓	0	$p_3/t < b_3(w, r) < p_3t$	$K = \alpha_1 Y b_{1r}/b_1 + \alpha_2 Y b_{2r}/b_2 + \alpha_3 Y b_{3r}/b_3$
R 2: Partial- specialisation	produce	trade	Costs	Factor markets
$X_1$	✓	X	$p_1/t = b_1(w, r)$	$Y = wL + rK$
$X_2$	✓	0	$p_2/t < b_2(w, r) < p_2t$	$L = X_1 b_{1w} + \alpha_2 Y b_{2w}/b_2 + X_3 b_{3w}$
$X_3$	✓	M	$b_3(w, r) = p_3t$	$K = X_1 b_{1r} + \alpha_2 Y b_{2r}/b_2 + X_3 b_{3r}$
R 3: Partial- specialisation	produce	trade	Costs	Factor markets
$X_1$	✓	X	$p_1/t = b_1(w, r)$	$Y = wL + rK$
$X_2$	✓	0	$p_2/t < b_2(w, r) < p_2t$	$L = X_1 b_{1w} + \alpha_2 Y b_{2w}/b_2$
$X_3$		M	$p_3t < b_3(w, r)$	$K = X_1 b_{1r} + \alpha_2 Y b_{2r}/b_2$
R 4: Heckscher -Ohlin	produce	trade	Costs	Factor markets
$X_1$	✓	X	$p_1/t = b_1(w, r)$	$Y = wL + rK$
$X_2$	✓	M	$p_2t = b_2(w, r)$	$L = X_1 b_{1w} + X_2 b_{2w}$
$X_3$		M	$p_3t < b_3(w, r)$	$K = X_1 b_{1r} + X_2 b_{2r}$
R 5: Specialisation	produce	trade	Costs	Factor markets
$X_1$	✓	X	$p_1/t = b_1(w, r)$	$Y = wL + rK$
$X_2$		M	$p_2t < b_2(w, r)$	$L = X_1 b_{1w}$
$X_3$		M	$p_3t < b_3(w, r)$	$K = X_1 b_{1r}$

R6: Heckscher-Ohlin	produce	trade	Costs	Factor markets
$X_1$	✓	X	$p_1/t = b_1(w, r)$	$Y = wL + rK$
$X_2$	✓	X	$p_2/t = b_2(w, r)$	$L = X_1b_{1w} + X_2b_{1w}$
$X_3$		M	$p_3t < b_3(w, r)$	$K = X_1b_{1r} + X_2b_{1r}$
R7: Heckscher-Ohlin	produce	trade	Costs	Factor markets
$X_1$	✓	M	$p_1t = b_1(w, r)$	$Y = wL + rK$
$X_2$	✓	X	$p_2/t = b_2(w, r)$	$L = X_1b_{1w} + X_2b_{1w}$
$X_3$		M	$p_3t < b_3(w, r)$	$K = X_1b_{1r} + X_2b_{1r}$
R8: Heckscher-Ohlin	produce	trade	Costs	Factor markets
$X_1$	✓	0	$p_1/t < b_1(w, r) < p_1t$	$Y = wL + rK$
$X_2$	✓	X	$p_2/t = b_2(w, r)$	$L = \alpha_1 Y b_{1w} / b_1 + X_2 b_{2w} + X_3 b_{3w}$
$X_3$	✓	M	$p_3t = b_3(w, r)$	$K = \alpha_1 Y b_{1r} / b_1 + X_2 b_{2r} + X_3 b_{3r}$
R9: Partial-specialisation	produce	trade	Costs	Factor markets
$X_1$	✓	0	$p_1/t < b_1(w, r) < p_1t$	$Y = wL + rK$
$X_2$	✓	X	$p_2/t = b_2(w, r)$	$L = \alpha_1 Y b_{1w} / b_1 + X_2 b_{2w}$
$X_3$		M	$p_3t < b_3(w, r)$	$K = \alpha_1 Y b_{1r} / b_1 + X_2 b_{2r}$
R10: Specialisation	produce	trade	Costs	Factor markets
$X_1$		M	$p_1t < b_1(w, r)$	$Y = wL + rK$
$X_2$	✓	X	$p_2/t = b_2(w, r)$	$L = X_2 b_{2w}$
$X_3$		M	$p_3t < b_3(w, r)$	$K = X_2 b_{2r}$

Figure 1: Regions of production specialization in the three-good model

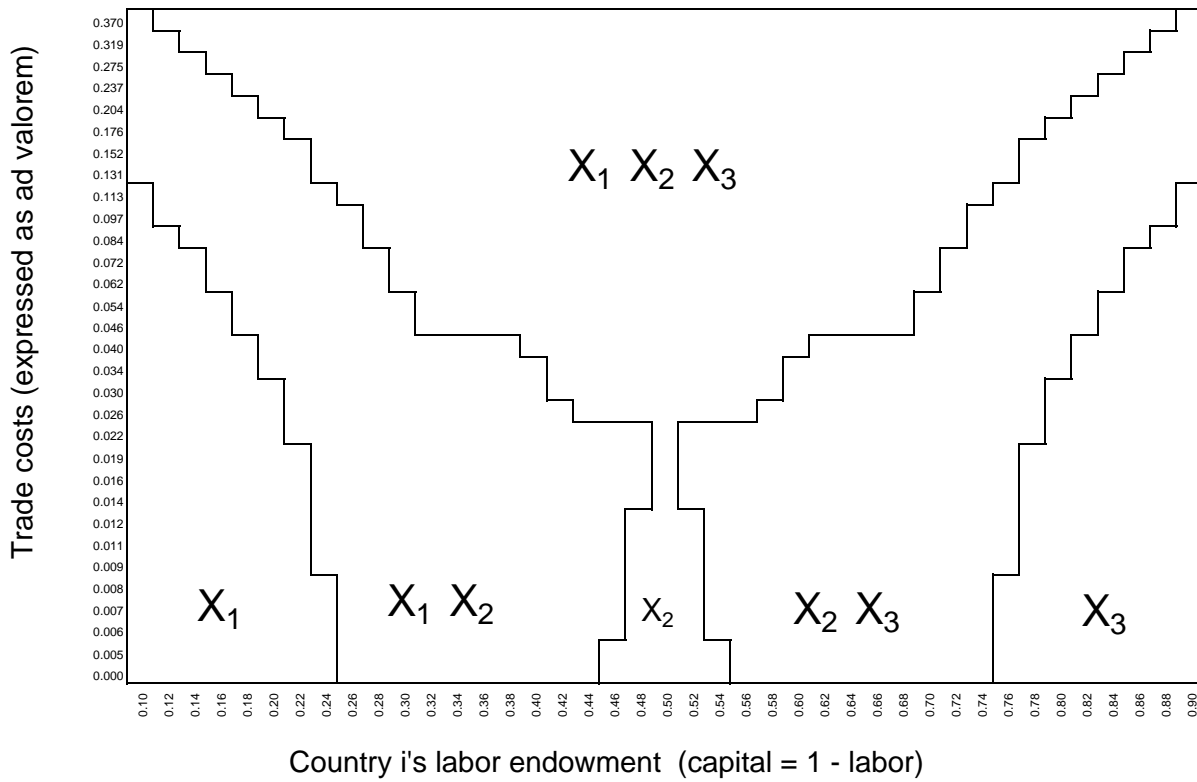


Figure 2: Regions of trade specialization in the three-good model

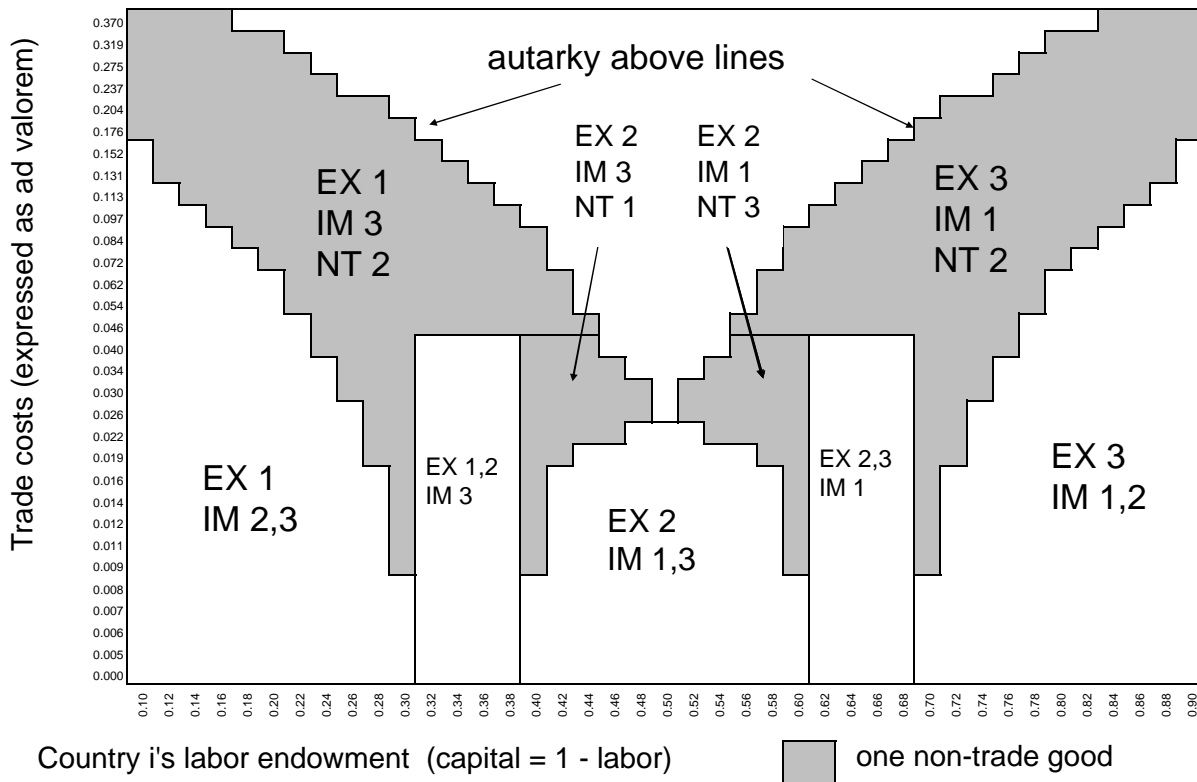


Figure 3: Volume of trade as a share of income

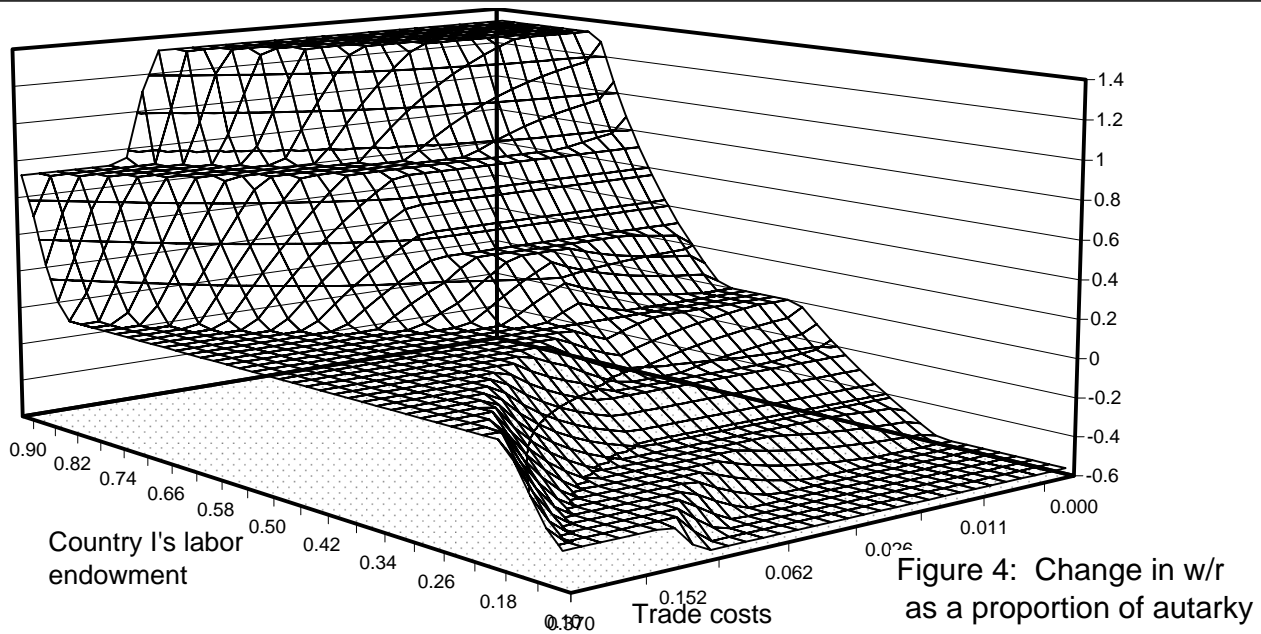
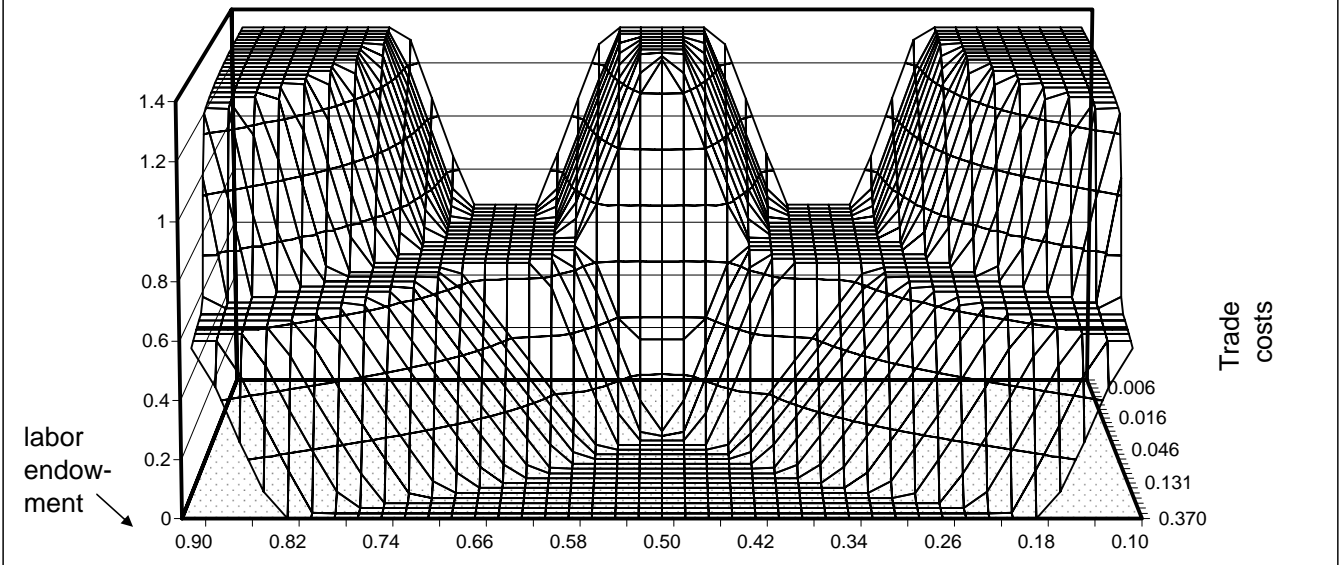


Figure 4: Change in  $w/r$  as a proportion of autarky

Figure 5: Gains from trade as a proportion of autarky welfare

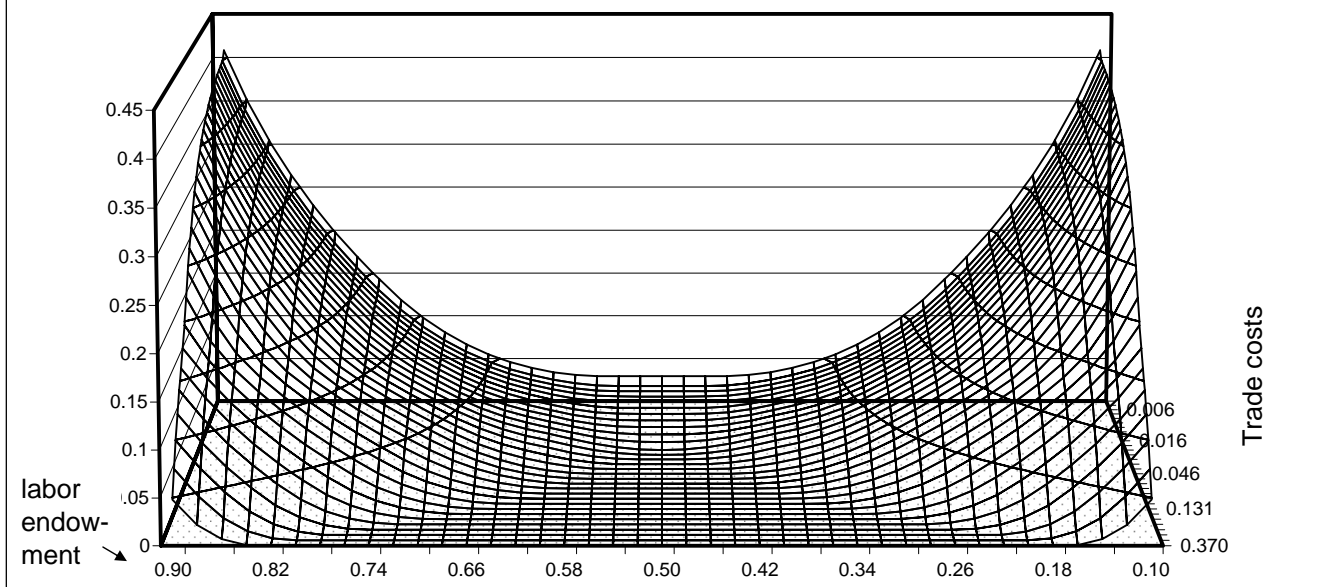




Figure 8: Trade in C and A: analogy to affiliate production

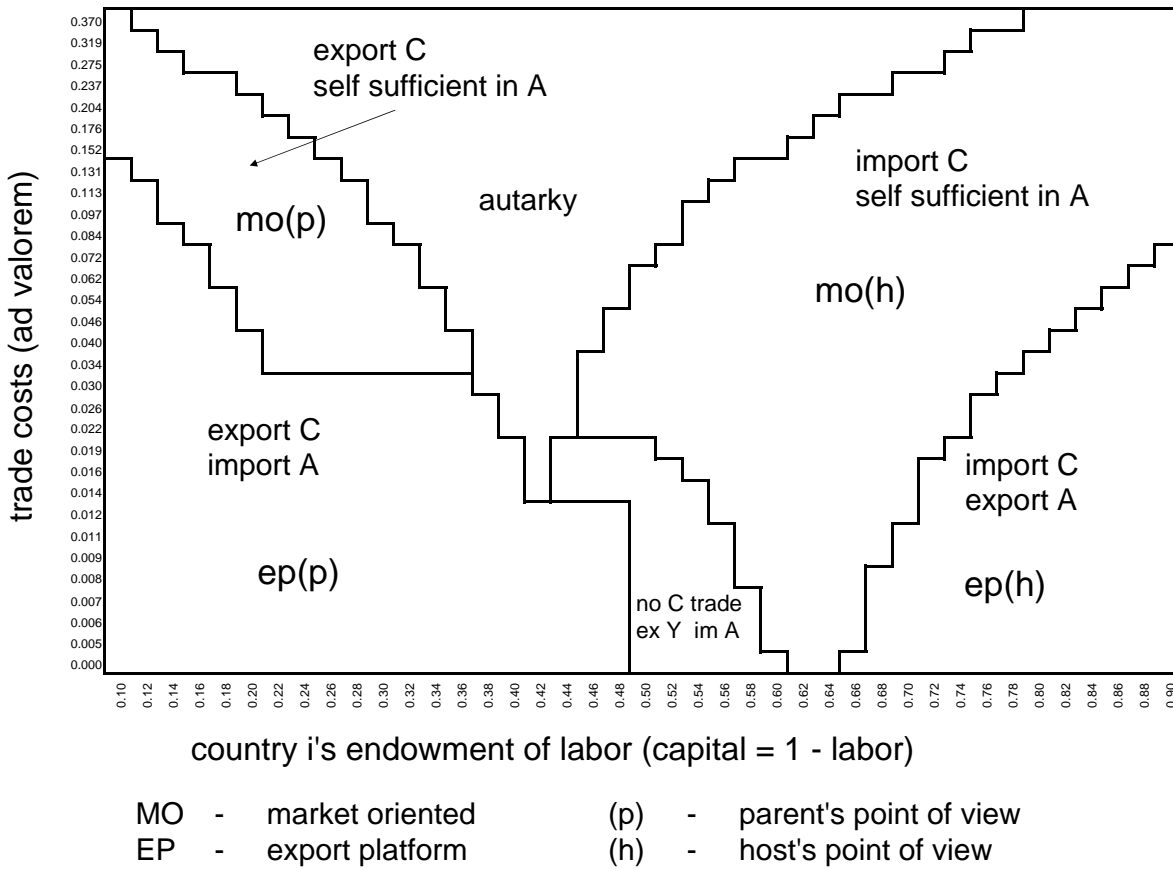


Figure 9: Change in the volume of trade following fragmentation

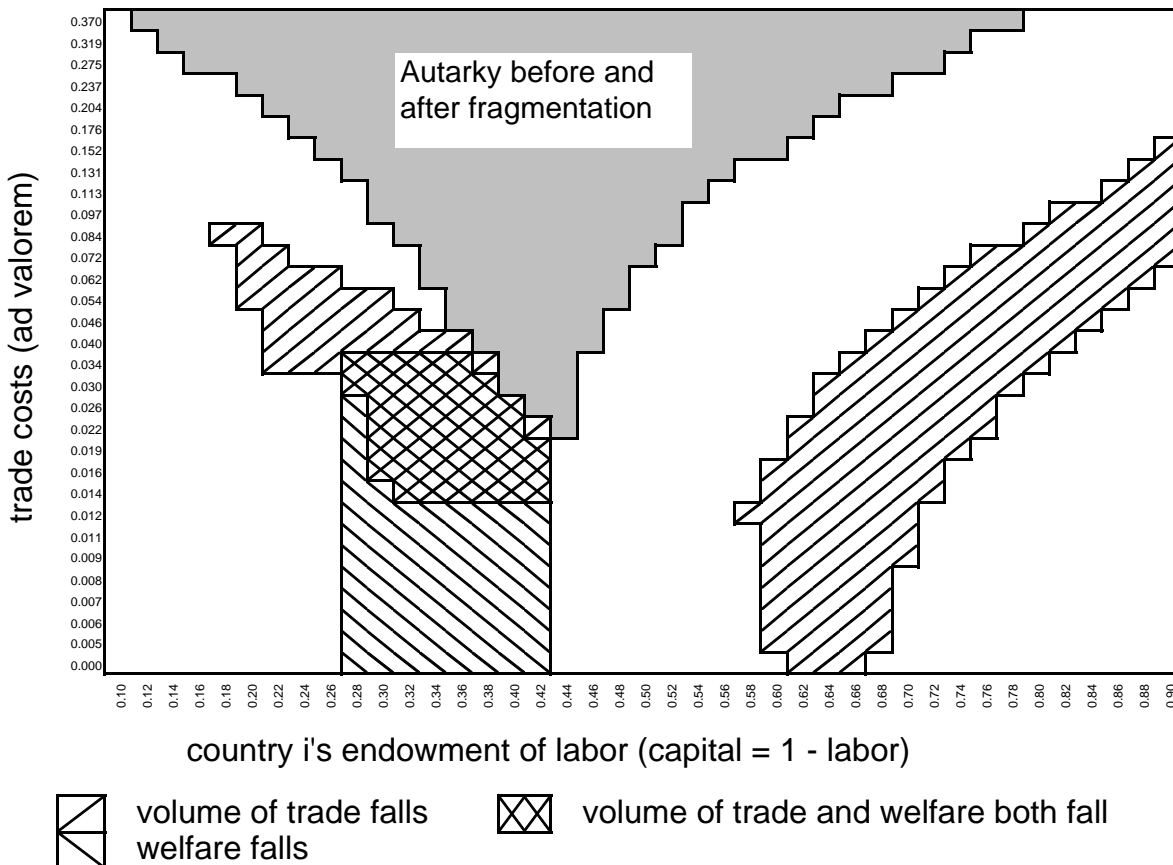


Figure 10a: Change in the volume of trade following fragmentation

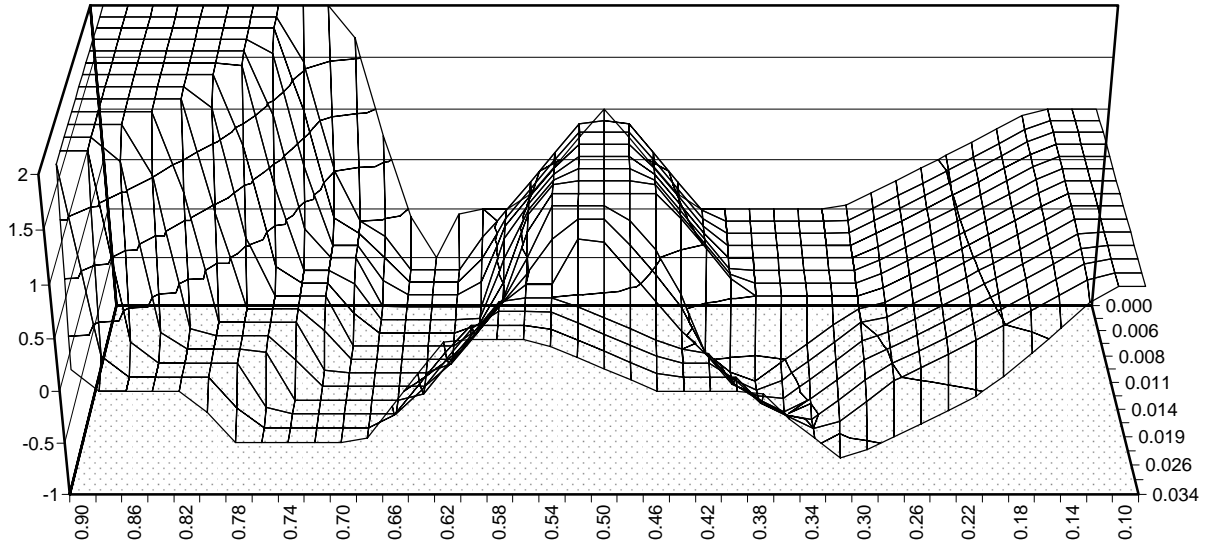


Figure 10b: Proportional change in welfare following fragmentation

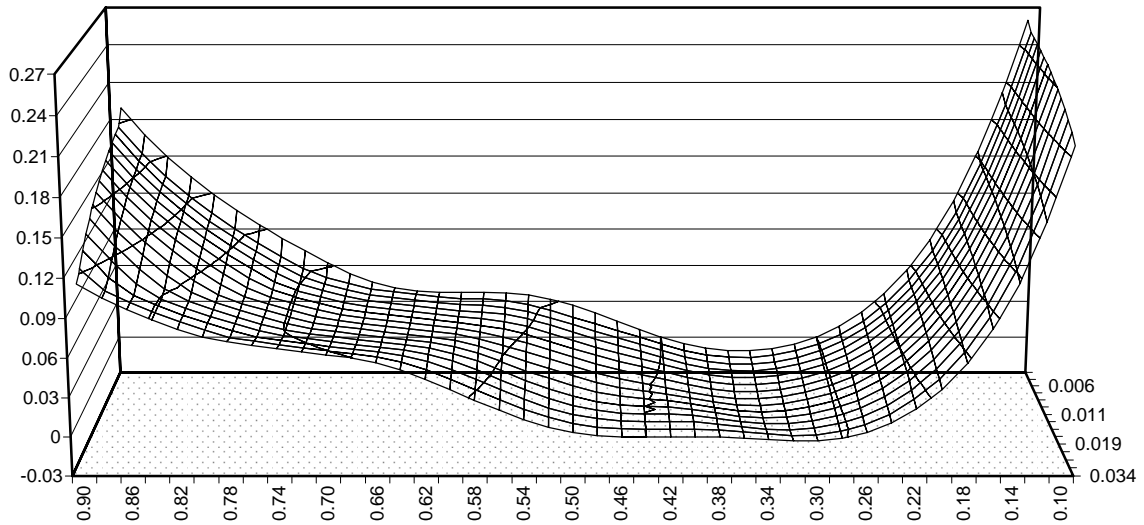


Figure 10c: w/r ratios with (WRY) and without (WRN) fragmentation

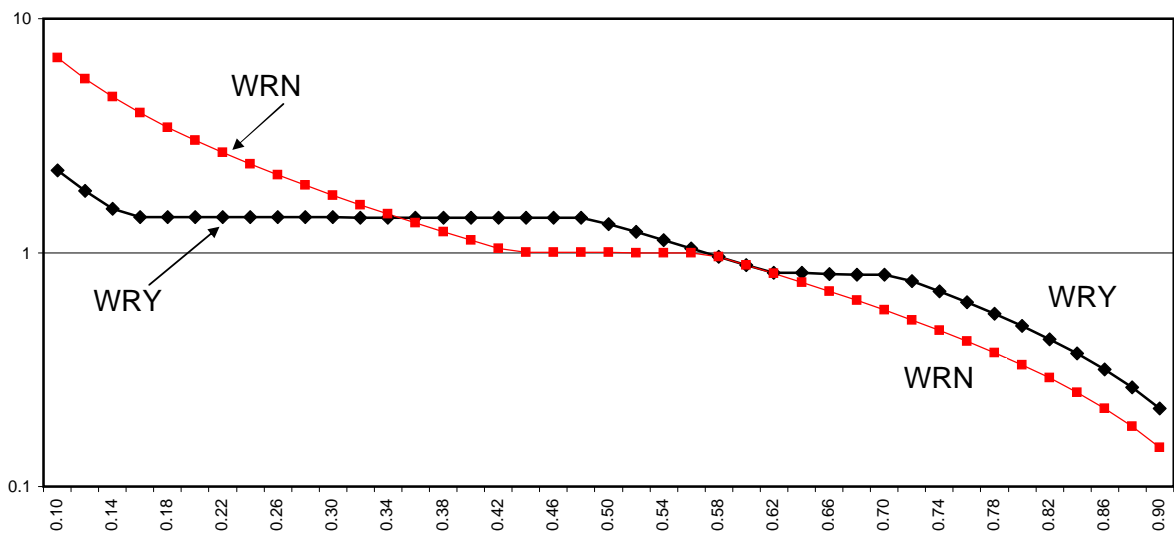


Figure 11: World VOT/GDP with and without fragmentation  
(vary trade costs for all countries)

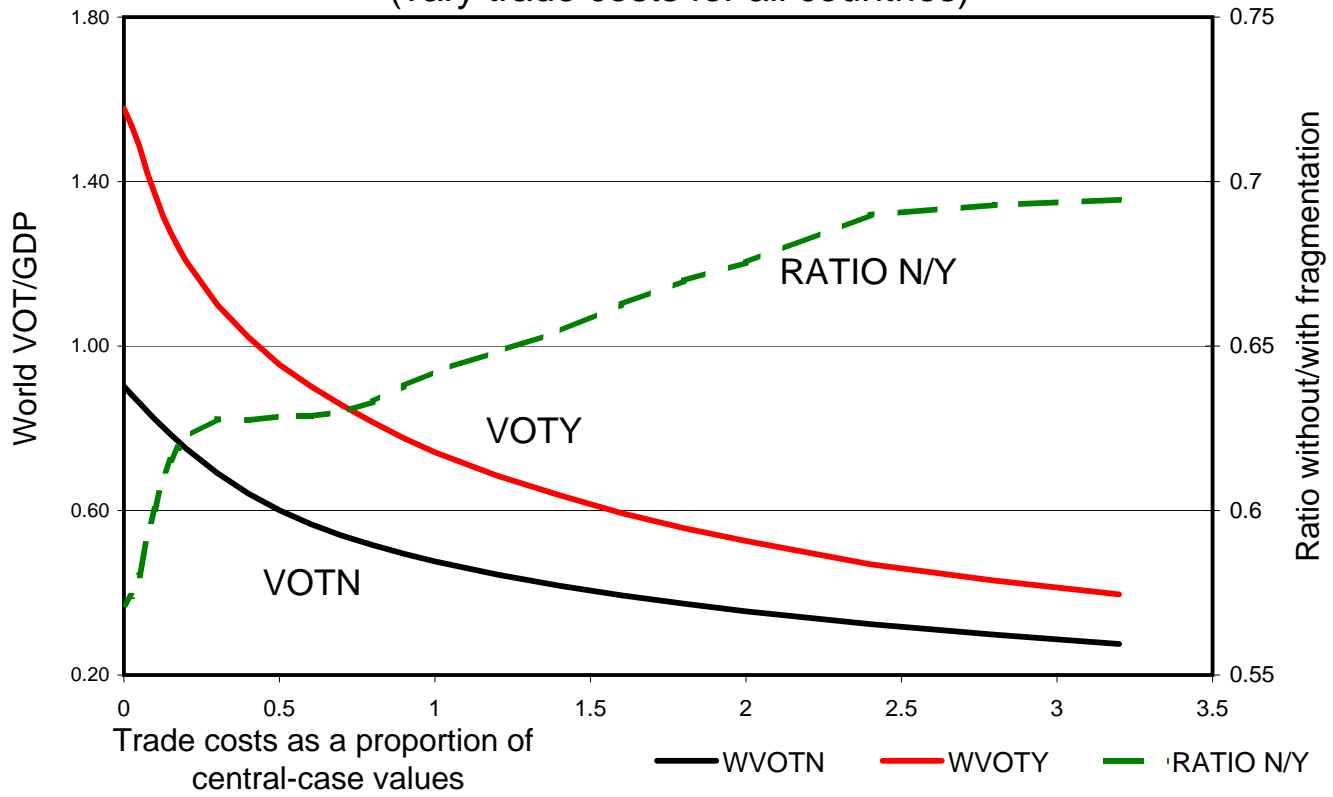


Figure 12: World VOT/GDP for a subset of 22 countries (vary trade costs for all countries)

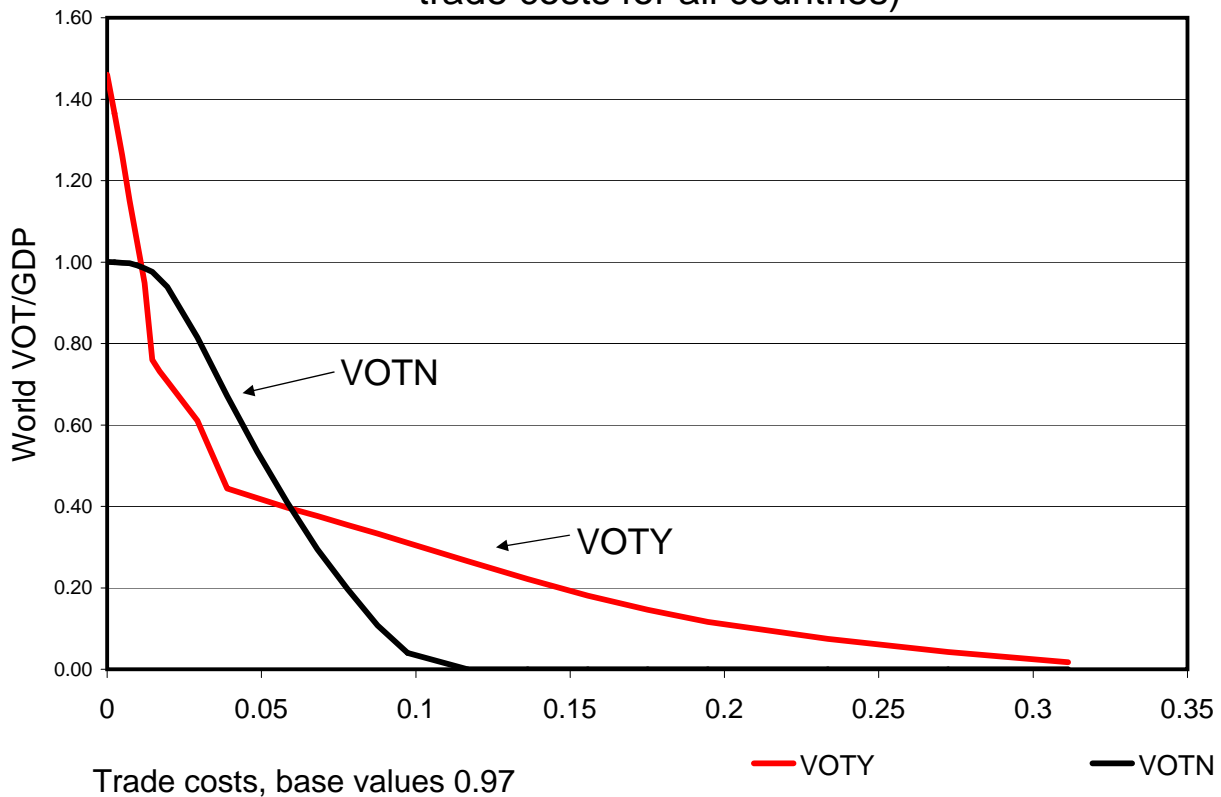
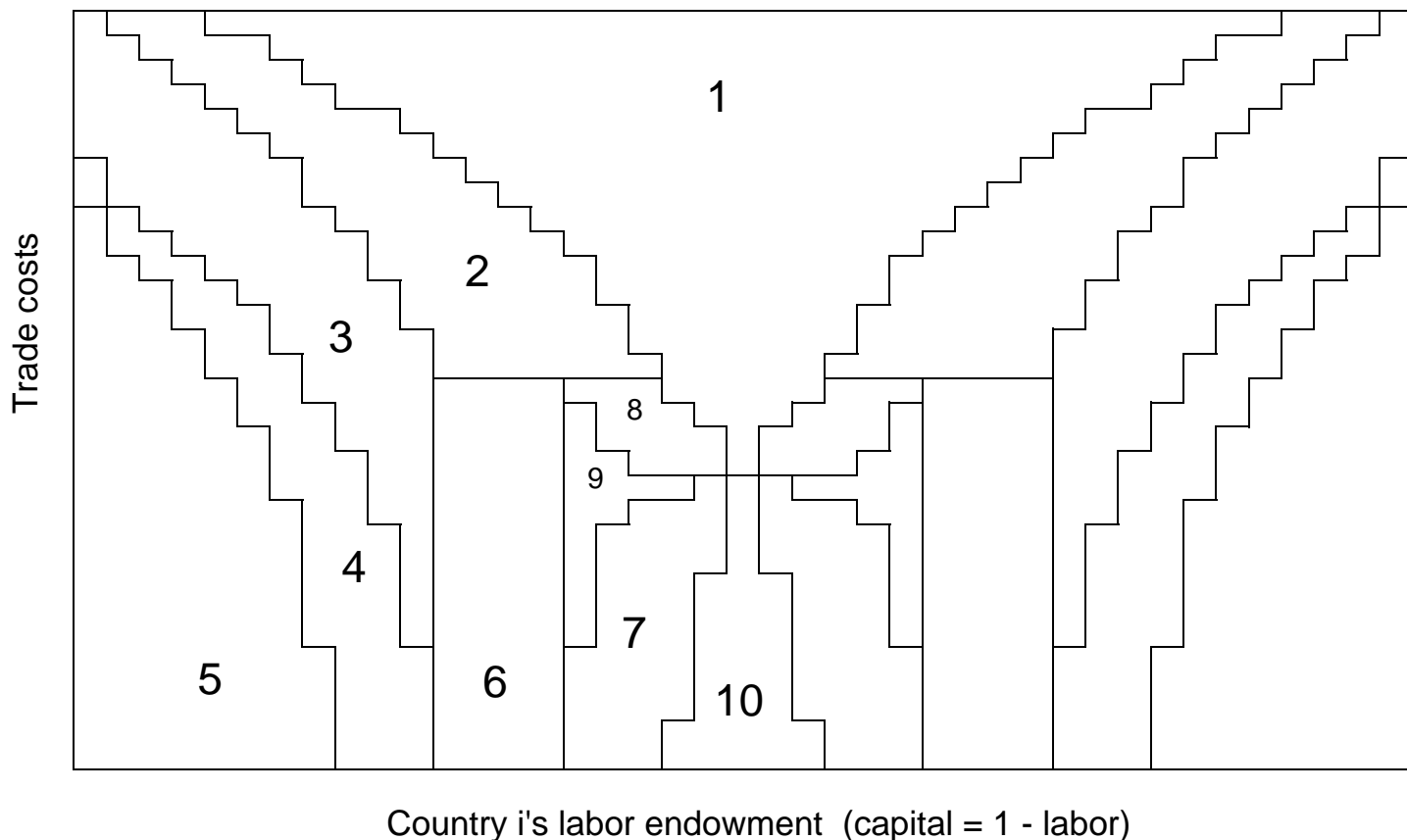


Figure A1: Regions of production and trade specialization in the three-good model



1	autarky	1, 2, and 3 produced and non-traded
2	H-O	1, 2, and 3 produced, 1 exported, 3 imported, 2 non-traded
3	partial specialization	1 and 2 produced, 1 exported, 3 imported, 2 non-traded
4	H-O	1 and 2 produced, 1 exported, 2 and 3 imported
5	specialization	1 produced and exported, 2 and 3 imported
6	H-O	1 and 2 produced, 1 and 2 exported, 3 imported
7	H-O	1 and 2 produced, 2 exported, 1 and 3 imported
8	H-O	1, 2, and 3 produced, 2 exported, 3 imported, 1 non-traded
9	partial specialization	1 and 2 produced, 2 exported and 3 imported, 1 non-traded
10	specialization	2 produced and exported, 1 and 3 imported