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

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Abstract

We provide a synthetic analysis of the different ways in which countries participate in the world economy. 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. Each country's production specialization, trade and welfare is determined by the *interaction* between its relative endowment and its trade costs. Findings include the result that the relationship between trade volumes and gains from trade is not monotonic. We consider the effects of allowing one good to ' fragment' into component and assembly production. Some countries engage in these production stages primarily to serve the domestic market, while others become 'export platforms'. The volume of trade and welfare levels are higher with fragmentation for most countries, although for a large block of countries these variables fall following 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. First, a low-trade-cost country with the average world endowment may specialize and trade a great deal. Such a country gains from trade, but those gains are small compared to countries with endowments far from the world average. Second and closely related, there is not a strong correlation between trade volumes and gains from trade. This raises questions about attempts such as that of Frankel and Romer (1999) to empirically quantify gains from trade on the basis of trade volumes.

Turning to fragmentation and outsourcing, we show that some countries engage in assembly just for the domestic market, while others operate as export platforms for assembled goods. We thereby provide an integrated treatment of patterns of production that have previously been studied in quite different models.[1] Fragmentation also effects trade volumes and welfare. While many countries respond to fragmentation with increased trade volumes, for some countries trade volumes fall[2]. Turning to welfare, we show that while most countries gain from

[1] Domestic market oriented assembly and export platform assembly correspond to the notions of horizontal and vertical investment developed in the literature on multinationals (Markusen 2002).

[2] Our results on the relationship between trade volumes, trade costs and fragmentation are consistent with those of Yi (2003).

fragmentation, 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).

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). Multi-country issues are addressed explicitly in much of the work on monopolistic competition and on gravity models, for example Anderson and van Wincoop (2003).[3]

Analyses of multi-stage production and of fragmentation are given in Jones (2000) and articles in the edited volume of Arndt and Kierzkowski (2001). Markusen (1989), Venables (1999), Hanson (1998), and Venables and Limao (2002) consider the issue, and the latter two papers introduce a multi-country framework and country or region-specific trade costs. Grossman and Rossi-Hansberg (2006) have several innovations, including a structure in which each intermediate good or service is used in all industries, so tradeability of one of these "tasks" directly affects all industries rather than just one. We build upon much of this research, solving

[3] In Anderson and van Wincoop each region produces a single composite good differentiated from other regions, and they solve for bilateral trade flows in a multi-country world. We go in a more traditional Heckscher-Ohlin direction with a richer structure for product and factor markets. Countries specialize in sub-sets of common (homogeneous goods) on the basis of their factor endowment and trade cost. We do not solve for bilateral flows, but only for each country's volume and composition of trade.

for world general equilibrium in the multi-country setting and developing the systematic relationship between the country-specific characteristics of endowments and trade costs and the resultant patterns of specialization and trade.

Although we use a competitive model, some results have analogies to the literature on multinational firms, in particular the distinction between horizontal (market serving) and vertical (export platform) activities. The horizontal model was developed in Markusen (1984), the vertical model in Helpman (1984) and Helpman and Krugman (1985), and an integrated approach is given in Markusen (2002). All of these analyses have the two-country limitation noted above. We show that, with many countries and trade costs, market serving and export platform fragmentation can coexist in a perfectly competitive economic environment.

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), 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, differing from each other in their factor endowments and in their trade costs. 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, since both the pattern of trade and the number of goods produced, traded, or non-traded, will vary across countries.[4] The three-good framework also sets the stage for our analysis of fragmentation, which we model 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.[5]

The three goods are denoted X_1, X_2 and X_3, with world prices p_i, i = 1, 2, 3. Trade is subject to iceberg trade costs which vary across countries, but which 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

[4] 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.

[5] Computationally, this indeterminancy is resolved by imposing a small trade cost of 0.025%.

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

$$p_i t \geq b_i(w, r) \geq p_i / t, \qquad i = 1, 2, 3 \tag{1}$$

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.

We start with a symmetric three-good case, and make the following assumptions:

I) Preferences are Cobb-Douglas with expenditure equally divided among 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, ranging 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 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 income) are shown in Figure 3 which, for better viewing, has the *high-trade-cost* countries 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 relationship 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, all of the economically possible combinations of production and trade in a 3-good, 2-factor model. 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;

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

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, σ_j , to give

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

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 varying either endowments or trade costs 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 adjusted by trade costs) to unit costs. For example, consider region 2 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:

$$p_1/t \;=\; b_1(w,r), \qquad p_2 t \;=\; b_2(w,r). \tag{4}$$

Factor prices in this region do not depend on endowments, but do depend on trade costs.[6] Moving around the region, changes in trade costs give Stolper - Samuelson effects according to

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

where the labor share in costs is λ_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 import X_2. Since $\lambda_3 > \lambda_2$, high trade cost countries in this region have lower real wages and higher returns to capital then do low trade cost countries. Rybczynski effects are dual.

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[6] The fundamental property is 'factor price insensitivity' see Leamer and Levinsohn (1995).

For some countries it is two export goods that set prices, for example region 4 of Figure A1, in which countries produce and export goods 1 and 2 and import good 3, so

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

In this region countries with higher trade costs have lower prices of *both* factors, with relative factor prices unchanged. Since higher trade costs also raise the price of the imported good, real incomes of all factors 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. But the conclusion is quite different, because in this region the two goods that are produced and traded are both export goods, 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, and 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, 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 be autarkic. 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: $p_2 > p_1 = p_3$. Our symmetric model has this property, and it is this that means that even 'average' countries gain from trade.

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.

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

$$b_X(w, r) = B\big(b_A(w, r),\, b_C(w, r)\big) \tag{7}$$

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*),[7] lie in the interval

$$p_z t \geq b_z(w, r) \geq p_z / t, \qquad z = C, X, Y. \tag{8}$$

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. 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

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

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

[7]Assembly "services" cannot be exported, except embodied in final good X.

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 λ and the share of components in *X* production, β, as follows:

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

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 several reasons. One is the fundamental difference between components and assembly; assembly can take place only if supplied by components, and may be subject to double trade costs. Another is that fragmentation only occurs for one good (good X), and brings with it an efficiency gain and fall in p_X/p_Y. The final reason is simply to do with 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.

3.2 Trade: vertical and horizontal fragmentation

Fragmentation of C and A occurs in two distinct contexts. One is 'market oriented' (MO), where components are imported and assembled just for the local market. The other is 'export platform' (EP) activity, where components are imported and assembly occurs for export. Figure 8 illustrates patterns of trade in *C* and *A* (trade in assembled or "final" *X*) and shows that these two different types of fragmentation occur for different countries. There are four regions of interest:

MO(imp C): countries for which assembly = local market sales; some or all components are imported.

MO(exp C): countries for which assembly = local market sales; some components are exported.

EP(imp C): countries that export assembled X produced with imported components.

EP(exp C): countries that import assembled X and export components.

All countries in the market-oriented (MO) regions meet local demand for good X entirely from local assembly; they neither import nor export the good. ‘EP’ denotes export-platform production, involving either the export of goods assembled with imported components, EP(imp C), or the supply of such components with corresponding imports of assembled goods, EP(exp C).

The distinction between MO and EP activity has been central to a good deal of earlier literature, particularly that on foreign direct investment. Market oriented fragmentation corresponds to ‘horizontal’ fragmentation because the same horizontal stage of production (assembly) is taking place both in both MO(imp C) and MO(exp C) regions. In terms of existing literature it corresponds to ‘trade barrier jumping’ investments and to horizontal foreign direct investment (Markusen 1984).[8] Export platform fragmentation corresponds to ‘vertical’ fragmentation in which a good or “task” may be imported and then re-exported. The EP regions correspond to what Hummels, Rappoport and Yi (1998) , Hummels, Ishi and Yi (2001) and Yi (2003) term vertical specialization. In the foreign direct investment literature it is captured in the vertical models of Helpman (1984) and Helpman and Krugman (1985).

The most important point derived from Figure 8 is that the same basic model generates

[8] This literature focuses on firms and draws a distinction between parent and affiliate operations. This could be superimposed on the present structure to obtain predictions about bilateral trade flows.

both market-oriented and export-platform activity, occurring simultaneously but for different sets of countries. This is in contrast to approaches in existing literature that have used quite different types of models to derive these two types of activity (see for example Markusen 2002). Here we show how both types emerge very naturally from the combination of factor-proportions trade and trade costs. 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.

3.3 Trade volumes, factor prices, and welfare.

The two different types of fragmentation are associated with changes in trade volumes and welfare, and effects are summarized in Figure 9, in which 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 with 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 export-platform activity is a complement to trade.

Figure 9 also indicates that there are 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; fragmentation of X allows it to be produced more efficiently, and its relative price is reduced. 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 have initial comparative advantage in integrated X production and experience terms-of-trade decline when fragmentation of X becomes possible.

Space constraints do not allow us to present a full description of the quantitative results similar to Figures 3-5, so we will just describe several interesting results. With respect to trade volumes, countries specialized in assembly have a higher trade volume than those specialized in components. 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. Of course, non-traded goods would greatly reduce these absolute numbers, but their relative sizes would be the same if each country spent the same share of income on the non-tradeables.

With respect to welfare, 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.

Factor price changes follow the Hecksher-Ohlin pattern for countries with endowment ratios that are very different from the average: fragmentation increases the relative return to the abundant factor and decreases that to the scarce factor. However, there is a set of countries that are moderately capital abundant for which the result goes the other way. These countries were specialized in X and Y production and after fragmentation specialize in C and Y. They have therefore outsourced assembly, their most labor intensive activity (in line with their factor endowment), but nevertheless experience an increase in their wage-rental ratio. The reason is that efficiency gains in fragmented X production mean that the price of components (the most capital-intensive activity) has fallen, this inducing a Stolper-Samuelson effect. [9]

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

[9] Grossman and Rossi-Hensburg (2006) also draw attention to this possibility, likening outsourcing to a technical improvement in the labor-intensive activity.

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 discussed with reference to Figure 8. 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 'import substituting' (assembling X goods just for local consumption: MO(imp C)) to becoming export oriented (exporting assembled X goods: EP(imp C)).

This change is associated with dramatic increases in the degree of specialization and the volume of world trade relative to income. Figure 10 has on the horizontal axis a measure of world trade costs and, on the vertical, trade volume as a proportion of world GDP. 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 corresponding to Figures 1-9.[10] 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.

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[10] 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 role of fragmentation in creating trade is similar to that pointed out by Yi (2003) and others, although comparison of our result and that of Yi (2003) is not straightforward, as they are derived from different models. Indeed, trade expansion at the e*xtensive* 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 differences among countries hidden by the aggregate statistics in Figure 10. This can be can be seen by focusing on a set of countries which transit through the experience of horizontal then export-platform activity. Figure 11 is analogous to Figure 10, but just reports the trade volumes for countries that, in the central case of Figure 10, were largely engaged in market-oriented assembly (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 1-9). 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 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 strong positive association between trade volumes and gains from trade for high trade cost countries, but

less so for low trade cost countries, a finding with important implications for empirical work on the gains from trade.

(2) Specifically, low-costs countries with endowments near the world average can specialize and trade a lot. Such countries gain from trade, but their gains are very small. Thus, especially for low cost countries, the correlation between trade volume and gains from trade is far from perfect. For the 10 lowest-cost rows of countries, the correlation between trade as a share of income (Figure 3) and gains from trade as a proportion of autarky welfare (Figure 5) is 0.601.

(3) 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.

(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 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; by capturing both these cases in a single model we are able to compare the characteristics of countries that engage in these different production and trade patterns.

(5) 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 translate into a fall in the relative price of X. The countries that lose suffer a terms-of-trade deterioration on their initial export good.

(6) 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.

(7) Notwithstanding our results that a world wide fall in trade costs increase world trade volumes 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: 31x41 = 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 $k \in \{1, 2, 3\}$

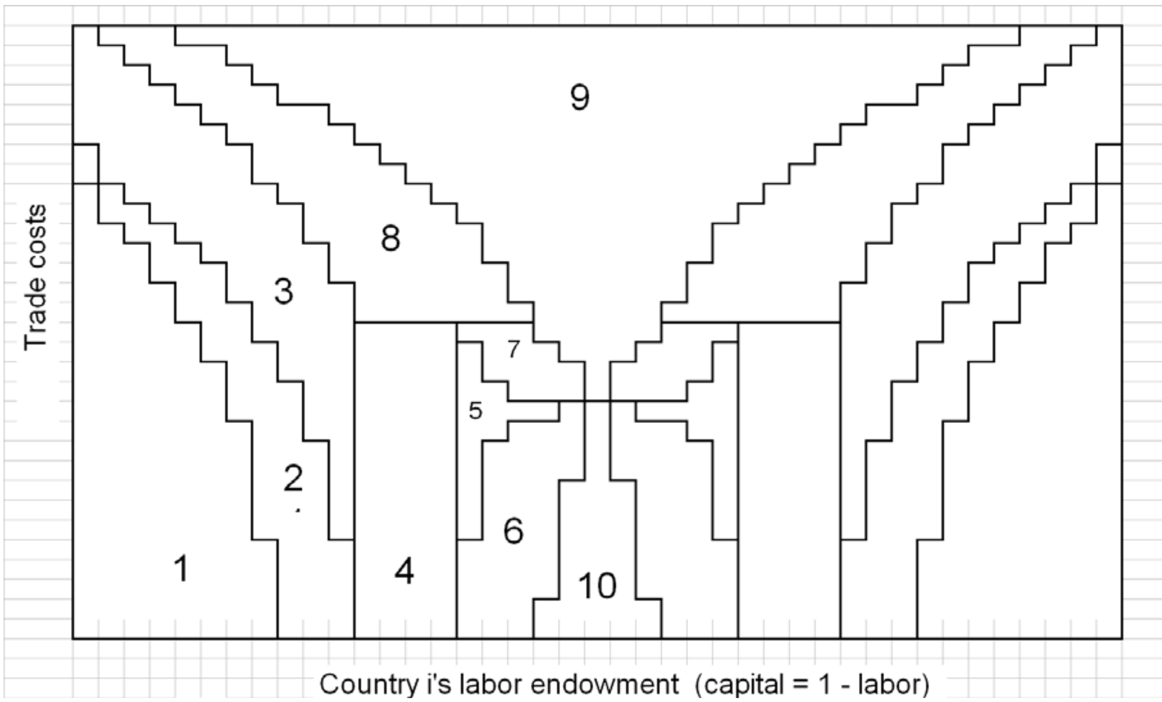
p_{kij} - producer price of X_k in country ij
pc_{kij} - consumer price of X_k in country ij
p_k - world price of k
p_{uij} - price of utility

EX_{kij} - exports of X_k from country ij
IX_{kij} - imports of X_k into country ij
XX_{kij} - supply of domestic X to home
U_{ij} - utility of consumer in country ij

Inequality	Complementary variable	Number of unknowns
zero profit inequalities	activity 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 inequalities	prices	
$XX_{kij} + IX_{kij} \geq \frac{\partial c_{uij}}{\partial pc_{kij}} U_{ij}$	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
$L_{ij} \geq \sum_k \frac{\partial c_{kij}}{\partial w_{ij}} X_{kij}$	w_{ij}	1271
$K_{ij} \geq \sum_k \frac{\partial c_{kij}}{\partial r_{ij}} X_{kij}$	r_{ij}	1271
Income balance inequalities	incomes	
$M_{ij} = w_{ij}L_{ij} + r_{ij}K_{ij}$	M_{ij}	1271

Appendix 2:
The 3-good 2-factor model has 18 distinct production and trade regimes. These are illustrated in figure A1 and the associated table. Just 10 cases are listed in the table, because of symmetry.

Figure A1



Region	Produce	Export	Import	Non-traded
1: Specialization	1	1	2, 3	
2: H-O	1, 2	1	2, 3	
3: Partial spec	1, 2	1	3	2
4: H-O	1, 2	12	3	
5: Partial spec	1, 2	2	3	1
6: H-O	1, 2	2	1, 3	
7: H-O	1, 2, 3	2	3	1
8: H-O	1, 2, 3	1	3	2
9: Autarky	1, 2, 3			1, 2, 3
10: Specialization	2	2	1, 3	

The regions illustrated cover all possible cases, and the 10 cases listed in the table cover all cases for relatively capital abundant countries. Specialization in good 1must involve export of good 1 and import of goods 2 and 3 (region 1). Regions 2-6 cover all possible production and trade patterns given that goods 1 and 2 are produced. Regions 7-9 cover all possible production and trade patterns given that (a) goods 1, 2 and 3 are produced; (b) that one good is non-traded (because there is no region of positive measure in which countries produce and trade all 3 goods in a 2 factor model); and (c) that if any goods are imported, they will include the good with the factor intensity furthest from the country's endowment (good 3).

The table below characterizes each region analytically, and equations implicitly define factor prices. Subscripts *w*, *r*, denote partial derivatives; α_i denotes the share of a good in consumers' expenditure.

1: Specialisation	produce	trade	Costs	Factor markets
X_1	✓	EX	$p_1/t = b_1(w,r)$	$Y = wL + rK$
X_2		IM	$p_2 t < b_2(w,r)$	$L = X_1 b_{1w}$
X_3		IM	$p_3 t < b_3(w,r)$	$K = X_1 b_{1r}$
2: H-O	**produce**	**trade**	**Costs**	**Factor markets**
X_1	✓	EX	$p_1/t = b_1(w,r)$	$Y = wL + rK$
X_2	✓	IM	$p_2 t = b_2(w,r)$	$L = X_1 b_{1w} + X_2 b_{2w}$
X_3		IM	$p_3 t < b_3(w,r)$	$K = X_1 b_{1r} + X_2 b_{2r}$
3: Partial-spec	**produce**	**trade**	**Costs**	**Factor markets**
X_1	✓	EX	$p_1/t = b_1(w,r)$	$Y = wL + rK$
X_2	✓	NT	$p_2/t < b_2(w,r) < p_2 t$	$L = X_1 b_{1w} + \alpha_2 Y b_{2w}/b_2$
X_3		IM	$p_3 t < b_3(w,r)$	$K = X_1 b_{1r} + \alpha_2 Y b_{2r}/b_2$
4: H-O	**produce**	**trade**	**Costs**	**Factor markets**
X_1	✓	EX	$p_1/t = b_1(w,r)$	$Y = wL + rK$
X_2	✓	EX	$p_2/t = b_2(w,r)$	$L = X_1 b_{1w} + X_2 b_{1w}$
X_3		IM	$p_3 t < b_3(w,r)$	$K = X_1 b_{1r} + X_2 b_{1r}$

5: Partial-spec	produce	trade	Costs	Factor markets
X_1	✓	NT	$p_1/t < b_1(w,r) < p_1 t$	$Y = wL + rK$
X_2	✓	EX	$p_2/t = b_2(w,r)$	$L = \alpha_1 Y b_{1w}/b_1 + X_2 b_{2w}$
X_3		IM	$p_3 t < b_3(w,r)$	$K = \alpha_1 Y b_{1r}/b_1 + X_2 b_{2r}$

6: H-O	produce	trade	Costs	Factor markets
X_1	✓	IM	$p_1 t = b_1(w,r)$	$Y = wL + rK$
X_2	✓	EX	$p_2/t = b_2(w,r)$	$L = X_1 b_{1w} + X_2 b_{1w}$
X_3		IM	$p_3 t < b_3(w,r)$	$K = X_1 b_{1r} + X_2 b_{1r}$

7: H-O	produce	trade	Costs	Factor markets
X_1	✓	NT	$p_1/t < b_1(w,r) < p_1 t$	$Y = wL + rK$
X_2	✓	EX	$p_2/t = b_2(w,r)$	$L = \alpha_1 Y b_{1w}/b_1 + X_2 b_{2w} + X_3 b_{3w}$
X_3	✓	IM	$p_3 t = b_3(w,r)$	$K = \alpha_1 Y b_{1r}/b_1 + X_2 b_{2r} + X_3 b_{3r}$

8: Partial-spec	produce	trade	Costs	Factor markets
X_1	✓	EX	$p_1/t = b_1(w,r)$	$Y = wL + rK$
X_2	✓	NT	$p_2/t < b_2(w,r) < p_2 t$	$L = X_1 b_{1w} + \alpha_2 Y b_{2w}/b_2 + X_3 b_{3w}$
X_3	✓	IM	$b_3(w,r) = p_3 t$	$K = X_1 b_{1r} + \alpha_2 Y b_{2r}/b_2 + X_3 b_{3r}$

9: Autarky	produce	trade	Costs	Factor markets
X_1	✓	NT	$p_1/t < b_1(w,r) < p_1 t$	$Y = wL + rK$
X_2	✓	NT	$p_2/t < b_2(w,r) < p_2 t$	$L = \alpha_1 Y b_{1w}/b_1 + \alpha_2 Y b_{2w}/b_2 + \alpha_3 Y b_{3w}/b_3$
X_3	✓	NT	$p_3/t < b_3(w,r) < p_3 t$	$K = \alpha_1 Y b_{1r}/b_1 + \alpha_2 Y b_{2r}/b_2 + \alpha_3 Y b_{3r}/b_3$

10: Specialisation	produce	trade	Costs	Factor markets
X_1		IM	$p_1 t < b_1(w,r)$	$Y = wL + rK$
X_2	✓	EX	$p_2/t = b_2(w,r)$	$L = X_2 b_{2w}$
X_3		IM	$p_3 t < b_3(w,r)$	$K = X_2 b_{2r}$

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

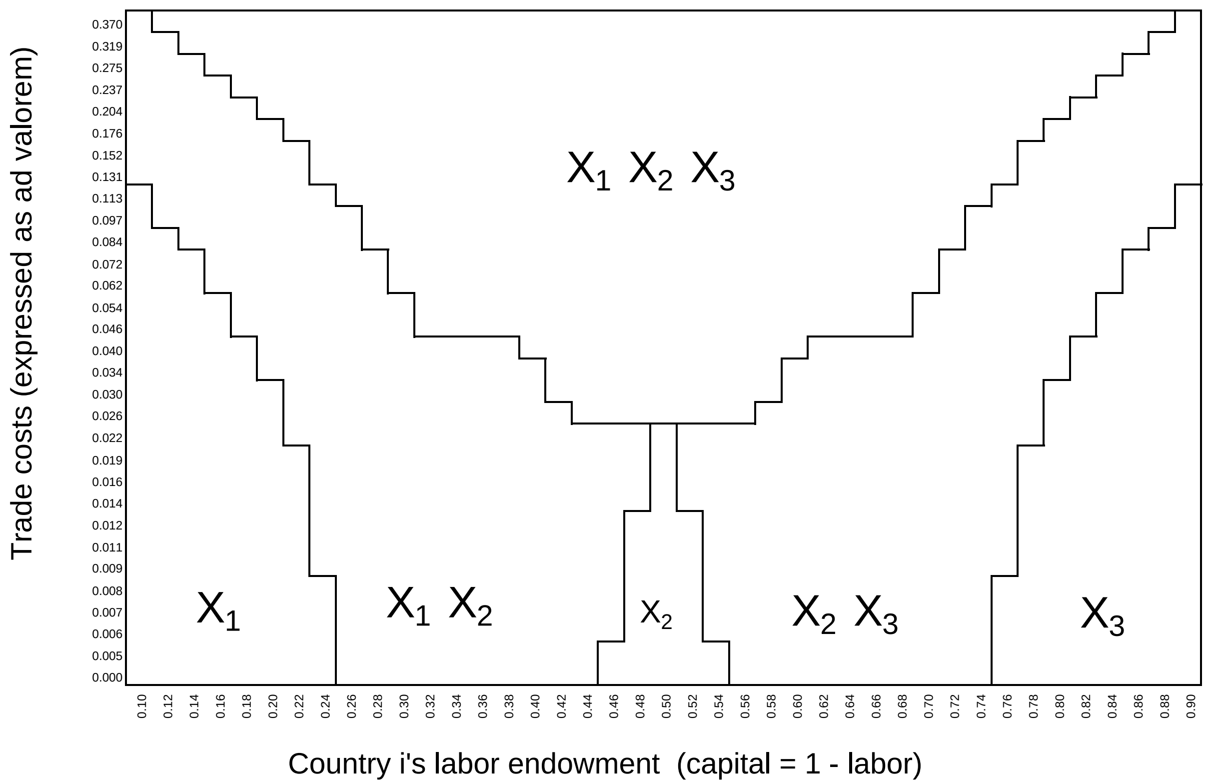


Figure 2: Regions of trade specialization in the three-good model

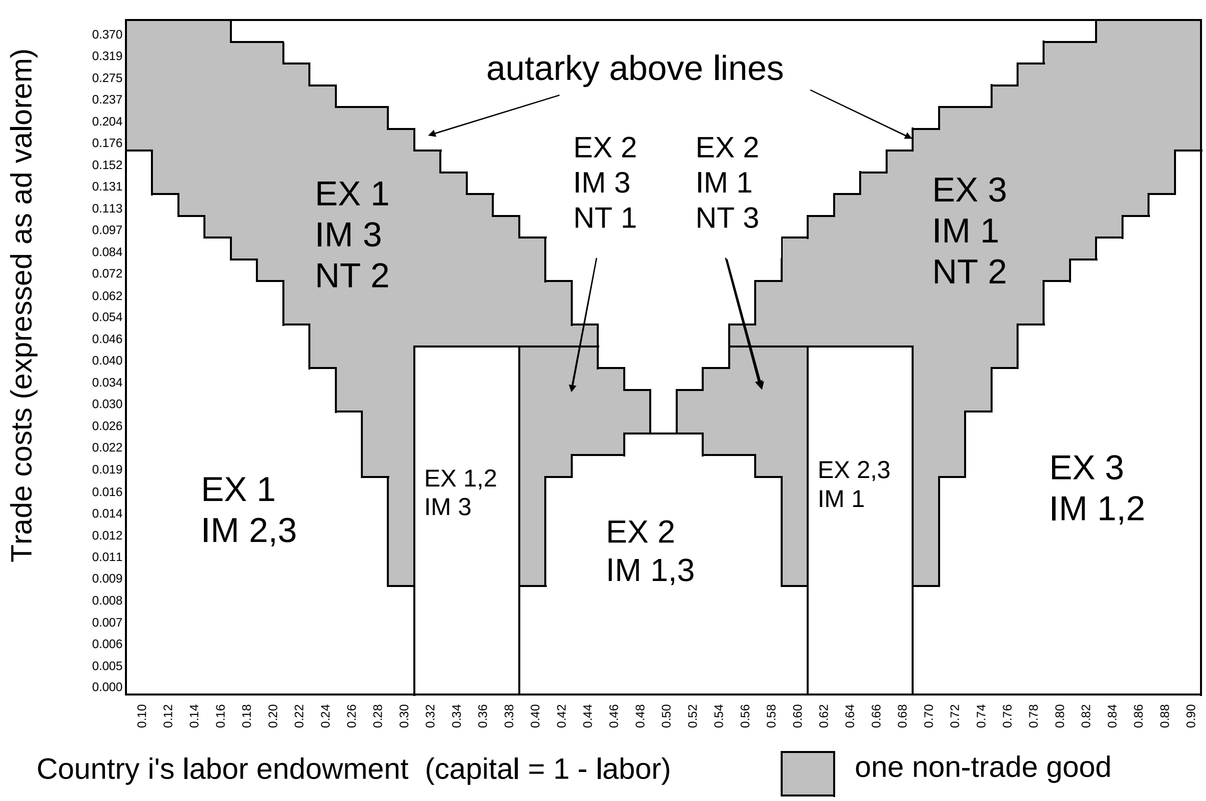
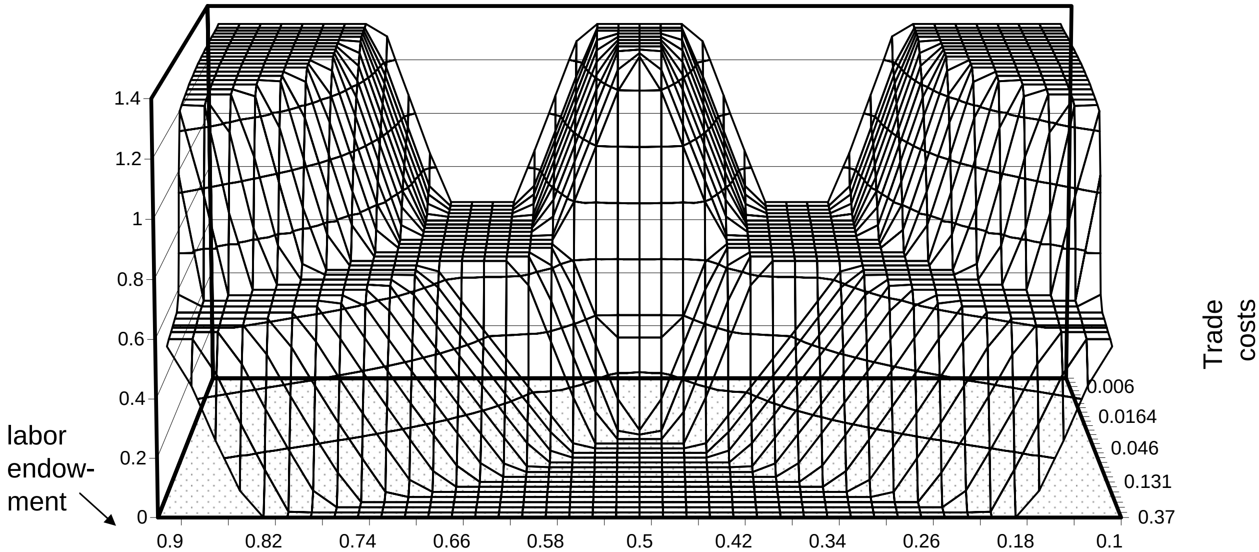


Figure 3: Volume of trade as a share of income



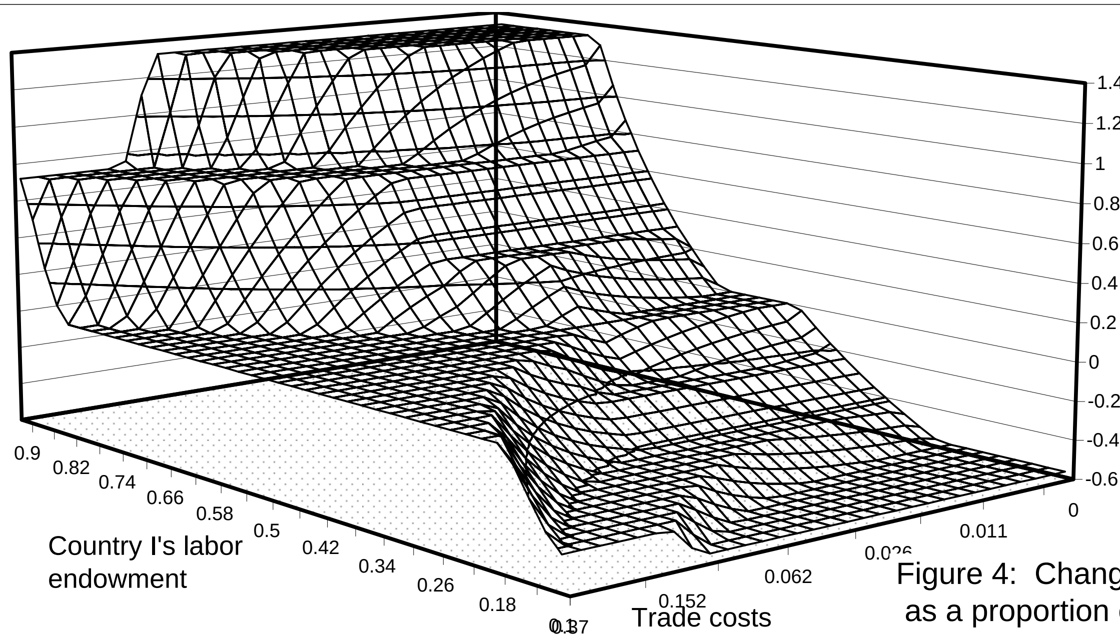


Figure 4: Change in w/r as a proportion of autarky

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

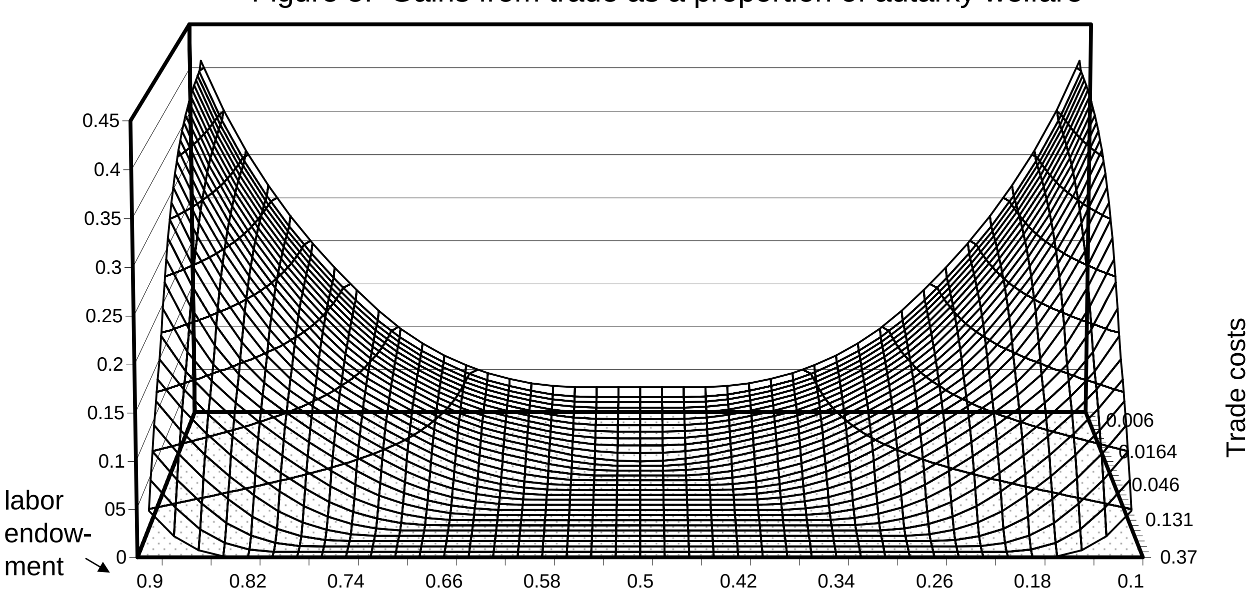
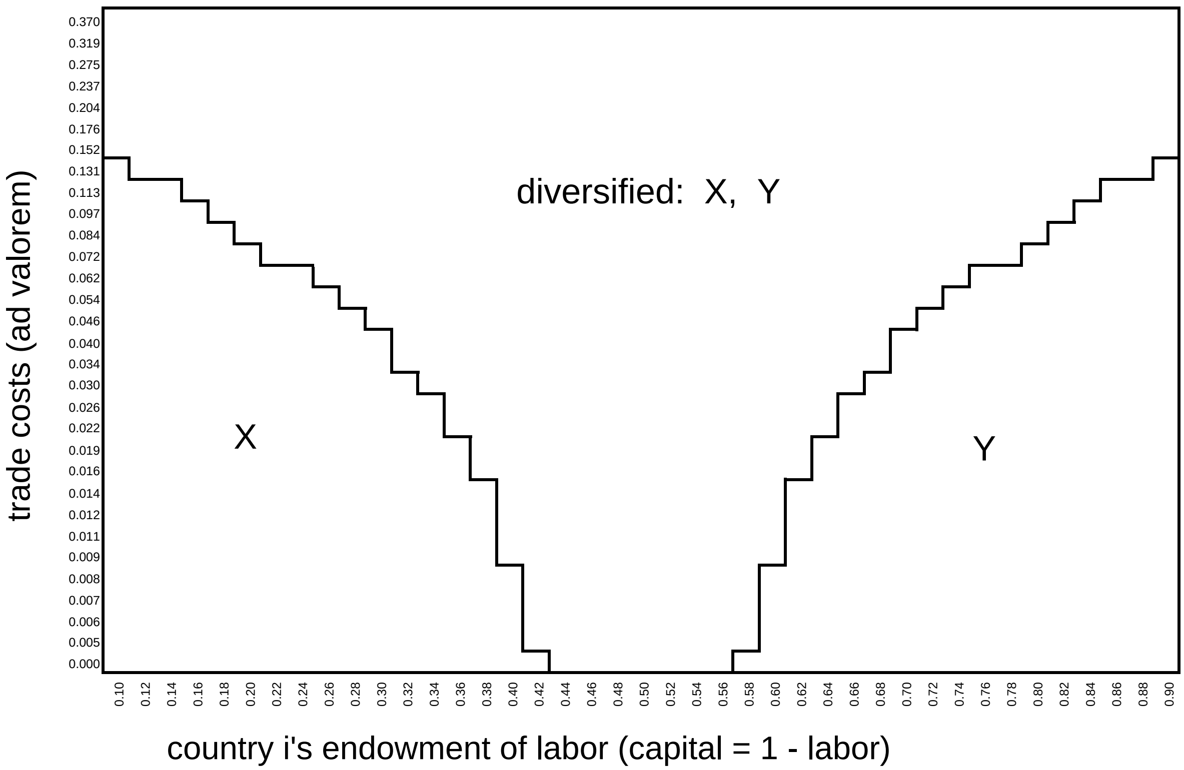
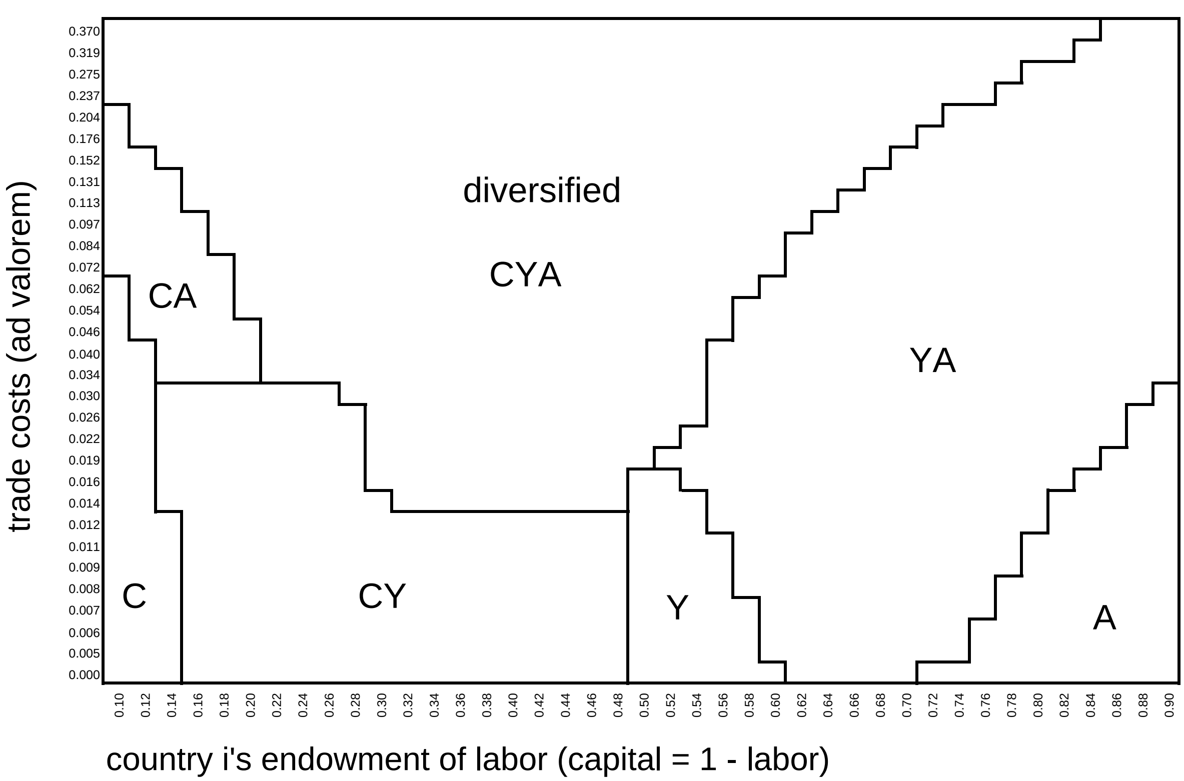


Figure 6: Production Regimes with no fragmentation, two-good model



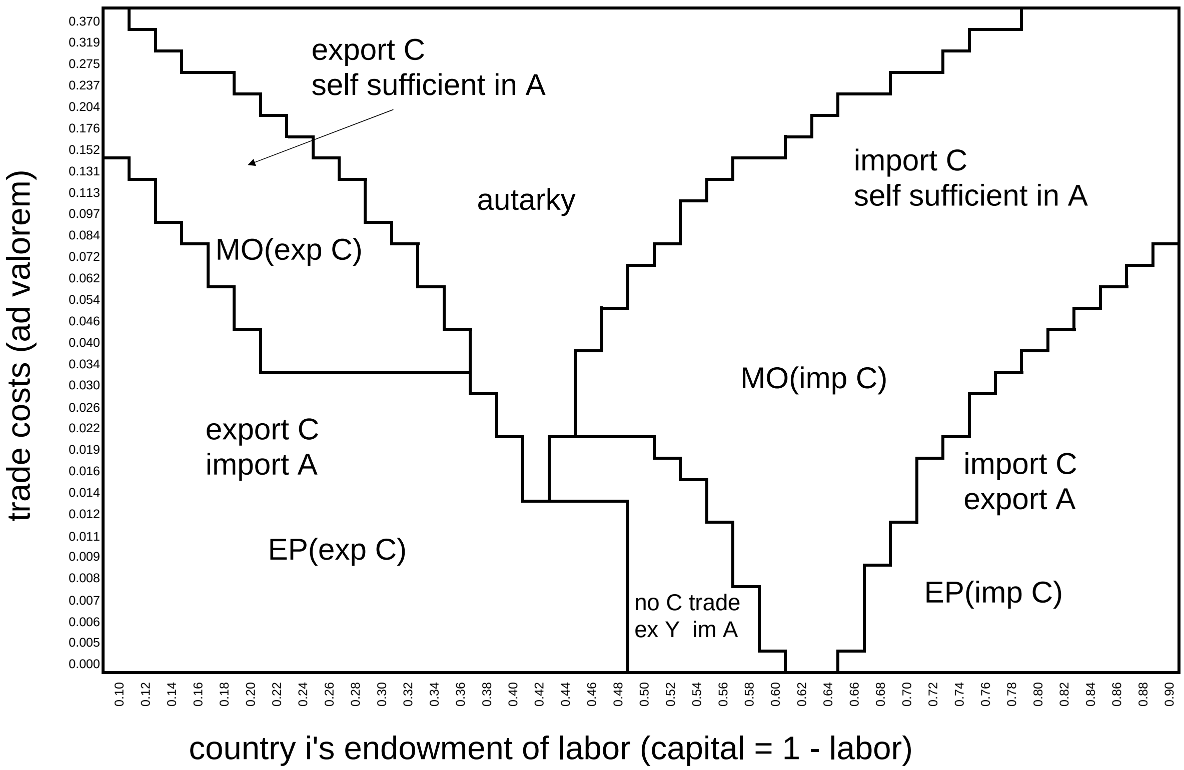
X specialized in X Y specialized in Y

Figure 7: Production Regimes with fragmentation



C	specialized in C	C A	partial specialization in C and A
Y	specialized in Y	CY	partial specialization in C and Y
A	specialized in A	YA	partial specialization in Y and A

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



MO	-	market oriented	(exp C)	-	export components
EP	-	export platform	(imp C)	-	import components

Figure 9: Change in the volume of trade following fragmentation

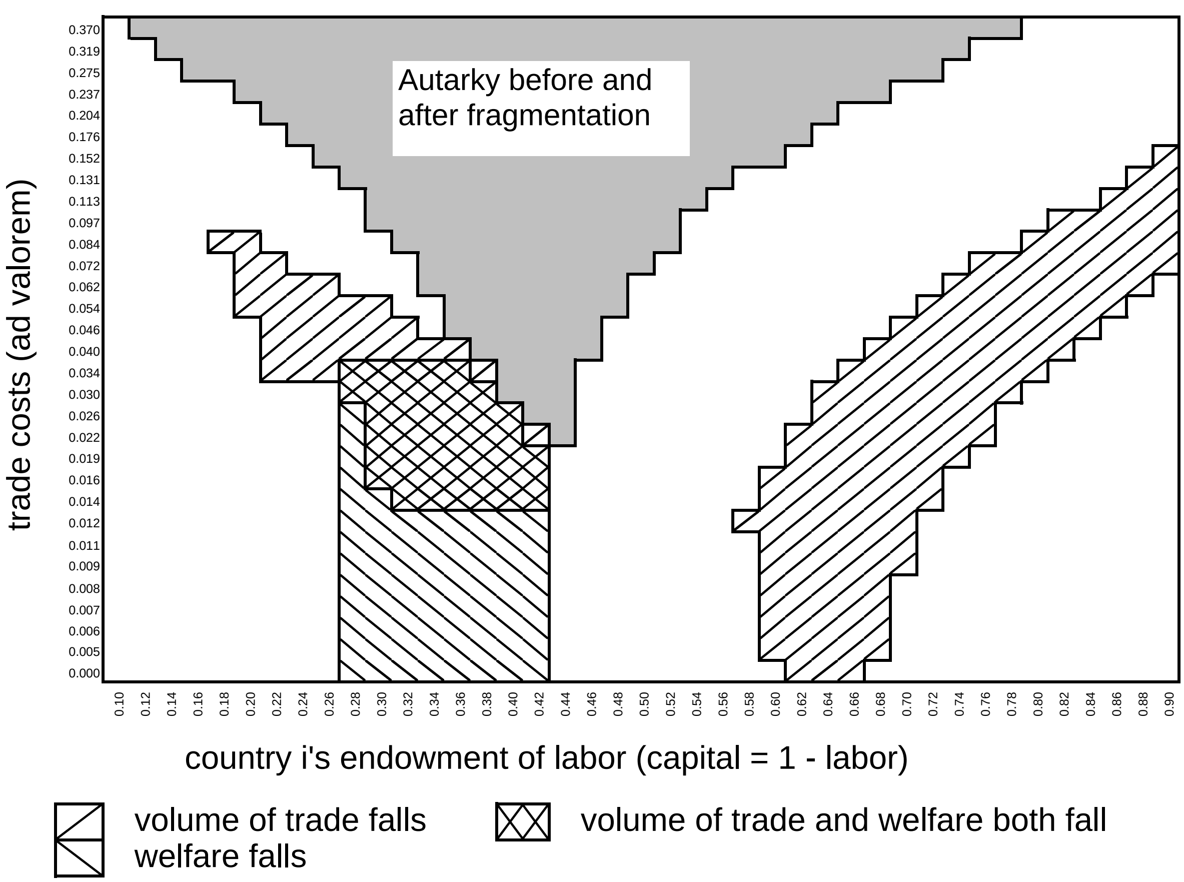


Figure 10: World VOT/GDP with and without fragmentation (vary trade costs for all countries)

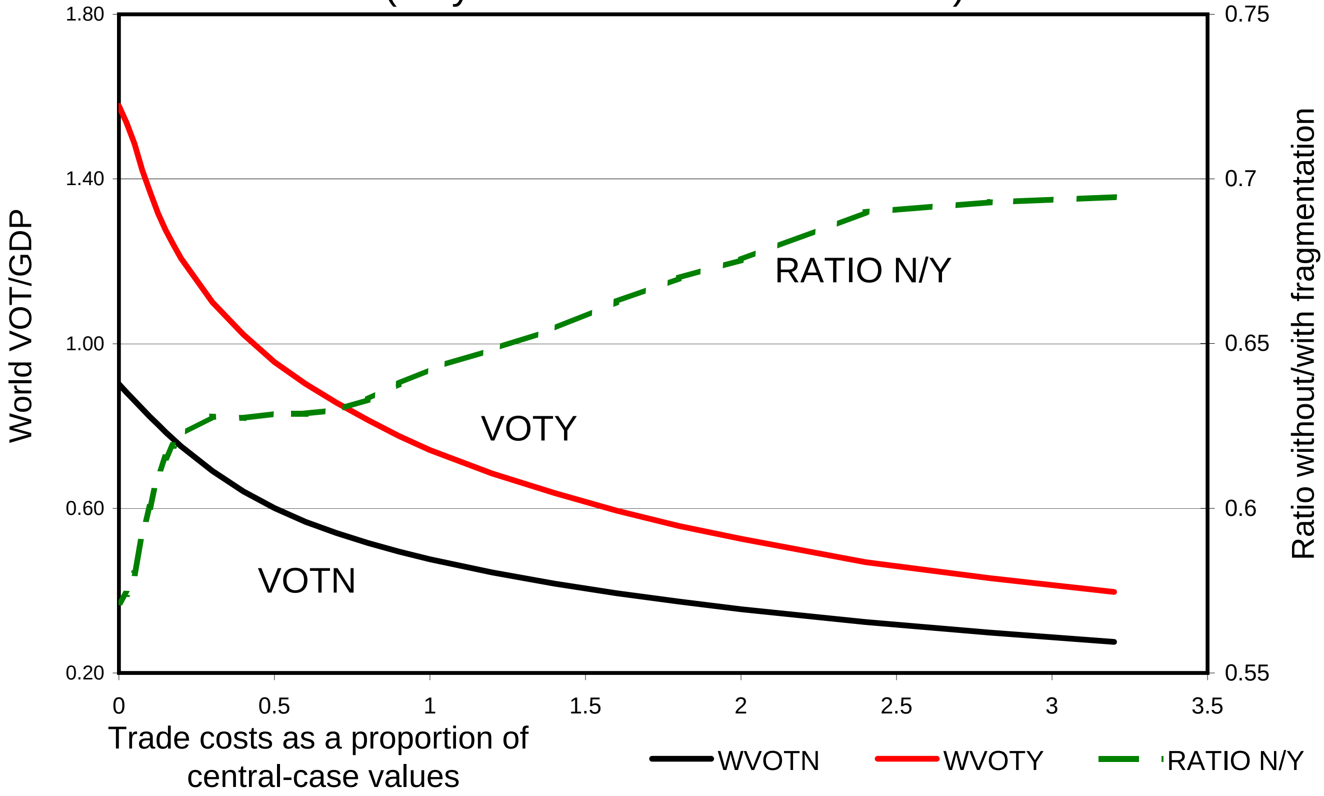


Figure 11: World VOT/GDP for a subset of 22 countries (vary trade costs for all countries)