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A Multi-Country Approach to Multi-Stage Production

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Abstract

Our objective is to provide some integration among literatures on market-oriented foreign production, export-platform foreign production, the international fragmentation of production, and the volume of world trade. A second objective is to overcome some difficulties with existing theoretical treatments of fragmentation, particularly the inability to solve for world general equilibrium, the avoidance of trade costs, and a reliance on two-country models. We adopt a multi-country approach in which countries may differ in relative endowments and in trade costs. We show how the ability to fragment production or the lowering of trade costs when fragmentation is possible affects the pattern of world specialization, welfare, factor prices, and the volume of trade. With moderate trade costs, we can get patterns that resemble horizontal FDI,. The volume of world trade and an Herfindahl index of world production specialization with fragmentation are indeed less than without fragmentation allowed for many countries. Lowing trade costs endogenously shifts specialization and trade into a situation which more closely resembles our concept of vertical FDI with much higher trade volumes when fragmentation is permitted.

The finer international division of production, often referred to as fragmentation, has attracted considerable attention in recent years. The growth of international production networks is documented by writers such as Dickens (1999). A number of authors have pointed to the fact that trade in parts and components is the fastest growing element of world trade (Yeats 1998, Ng and Yeats 1999). There is also evidence that an increasing part of multinational activity is now 'vertical' or export-platform production, with goods and services being exported from operations in lower wage countries to service firms' worldwide activities (Hanson, Mataloni and Slaughter, 2001).

The development of fragmentation raises three main questions that need to be addressed analytically. The first is, in this new pattern of international specialization, what countries do what? The basic insights here are clear – for example, labour intensive activities go to labour abundant countries. However, many low wage economies fail to attract fragments of the production process. In other cases, countries attract stages of the production process, but only to serve local markets, not for export. Thus, a labour abundant country may import a capital intensive final good, or it may import its component parts and assemble them for sales in the local market, or it may assemble them for sales worldwide. We need a theory that can encompass all these possibilities and yield predictions as to when each occurs.

The second question is; how are real incomes affected by fragmentation? Fragmentation provides a real efficiency gain to the world as a whole, because of the finer international specialisation of production but who gets the benefits? Some countries are more directly affected by fragmentation than are others, and there are also changes in world prices and terms of trade. We will see that, in general, some countries gain and others loose. Within countries, changes in factor demands cause changes in returns to different factors of production, so some individuals gain and others experience reductions in real income.

The third question is; what happens to the volume of trade? Fragmentation has a direct effect on the volume of trade, increasing it for some countries, and reducing it for others. The full model developed in this paper enables us show that a world in which fragmentation occurs can react quite differently to falling trade costs than does the text book model, throwing light on a recent debate on the reasons for the rapid recent growth in trade (see for example Yi 2003).

To address these questions we need an analytical framework that endogenises the changing patterns of specialisation and that is fully general equilibrium, endogenising goods

and factor prices. The model also needs to contain countries that differ in (at least) two-dimensions. One is their factor abundance, and the effects of fragmentation in such models has been the subject of recent literature by Jones and Kierszkowski (2001), Deardorff (2001) and others (see Arndt and Kierszkowski 2001 for a useful overview). The other is the trade costs and trade barriers (created by nature or by policy) that countries face. These have attracted attention in work including that of Sachs, (for example Gallup, Sachs and, Mellinger 1998), who show how apparently small trade barriers can act as a major obstacle to export activities. As we know from the literature on multinational firms (eg Markusen 2002) high levels of trade costs can be a positive force for horizontal (local market oriented) investments, but a negative force for vertical (export platform) investments.

Our goal in this paper is to develop the analytical framework that incorporates countries differing in these two dimensions and to use it to address the questions posed above. Such a framework must contain at least three countries if we are to be able to investigate the effects of endowment differences (given trade costs) and trade cost differences (given endowments). It turns out to be conceptually much cleaner – as well as empirically more relevant – to step up to a full multi-country world. The model will in fact be based on a continuum of countries lying in a 2-dimensional space. One dimension is the capital - labour abundance ratio, and the other is the trade costs that countries face in shipping goods to a 'central' market.[1] The model has several advantages over the frequently used 2-country general equilibrium model.[2] Richer patterns of specialisation are possible and, as a basis for empirical work, it offers predictions on a full cross-section of countries, rather than a series of bilateral comparisons between pairs of countries.

The next section of the paper outlines the main ingredients of the model that we develop and the methodology that we employ. Section 2 deals with a benchmark case, in which we abstract from trade costs and briefly outline the effects of fragmentation under free trade. Results here are in accord with those obtained in earlier work, although by having a full world general equilibrium approach in which goods prices are endogenous we are able to go beyond earlier work and outline the real income effects of fragmentation across the range

[1] Of course, trade costs in general depend on both source and destination, but we abstract from these variations by the fiction of a central market.

[2] As frequently developed through the two-country and two factor 'Edgeworth box', see for example Dixit and Norman (1980), Helpman and Krugman (1985).

of countries. Our core model is developed in section 3. We show exactly how the participation of countries in international specialization depends on both their factor endowments and their trade costs. Implications for real income and trade volumes are assessed. Section 4 explores some comparative static experiments, and section 5 discusses the effects of global reductions in trade costs, offering predictions about the changing patterns of specialisation and about the real income effects that globalisation might bring. We show that the effects of these reductions on the volume of trade varies, depending on whether fragmentation of production is occurring just to serve local markets, or for export to the world market. This sheds light on a recent debate about the determinants of the recent rapid growth in both trade and international investment in the world economy.

1. 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. There are two consumption goods, X and Y, and all consumers have identical homothetic preferences over these goods. Each country has fixed endowments of two factors, L and K. Production has constant returns to scale and is perfectly competitive. Unit cost functions for the two goods are $b^X(w, r)$ and $b^Y(w, r)$, the same in all countries, where w and r are factor prices.

World prices of the two goods are p^X and p^Y. However, trade is subject to iceberg trade costs. Thus, if a country with trade costs t^X, $t^Y \geq 1$ on goods X and Y (where $t^K = 1$ is free trade, K = X, Y) imports good X or Y its internal price will be $t^X p^X$, $t^Y p^Y$. Conversely, if it exports the good the price will be p^X/t^X, p^Y/t^Y, as domestic producers only receive a fraction of the world price. Notice that we assume that these trade costs are incurred both on exports and imports, and that a particular country has the same values t^K 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 countries 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 real 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 will ignore revenue that any such tariff

barriers might earn.

We add to this basic model 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

$$b^X(w,r) = B\left(b^A(w,r), b^C(w,r)\right) \qquad (1)$$

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 ischeaper to import components than 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.

The equilibrium location of production satisfies a set of inequality relationships. Each tradeable good (X, Y, C),[3] 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

$$p^K t^K \geq b^K(w,r) \geq p^K/t^K, \qquad K = C, X, Y. \qquad (2)$$

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 (1) and (2) need to be used together. For example, consider a country that uses imported components and exports its output. Its factor prices must satisfy

$$p^X/t^X = B(b^A(w,r), p^C t^C). \qquad (3)$$

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

[3]Assembly "services" cannot be exported (shipped to the component location to produce X in that location).

factor prices are determined by market clearing in the usual way. Details are spelt out more fully in section 3 and in the appendix.

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 the appendix. 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 specialised in different activities. The second part of our strategy is to characterise analytically a number of the boundaries between these regimes, showing how they depend on key parameters of the model.

2. The free trade benchmark.

We start with a benchmark case in which all countries have free trade ($t^K = 1$, for all countries and for K = X, Y, C). In this and all following numerical work we make the following assumptions, designed to give a symmetric initial equilibrium.

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

II) X and Y production are Cobb-Douglas with symmetric factor shares, eg X has labour and capital shares of 0.43 and 0.57 respectively, and Y has corresponding shares 0.57 and 0.43.

III) Countries are uniformly distributed along a range of labour endowments from from L = 0.1 to L = 0.9, and have capital endowments K = 1 - L. Thus the central country has the world endowment ratio L = K = 0.5.

IV) $t^K = 0$ for all commodities, K = X, Y, C.

Our analytical characterizations of the boundaries between regimes do not rely on these assumptions.

Figures 1a and 1b give the structure of production, level of welfare, and volume of trade (value of exports plus imports divided by GDP) for the case in which there is no fragmentation. The horizontal axis is countries in increasing order of labour abundance, i.e. along the line L $\in$ [0.1, 0.9]. The central country produces the same volume of both goods and has zero trade. Moving away from this country the structure of production changes

according to Rybczynski effects until the edge of the cone of diversification is reached. Countries with endowment ratios outside this cone are specialised and have high trade volumes (half their production exported and half their consumption imported). They have lower welfare than countries in the cone of diversification, reflecting the fact that – since they are specialized -- the marginal rate of transformation between X and Y is not equal to the world price ratio.

What happens if the X-sector fragments? We assume that the fragments C and A are Cobb–Douglas, and restrictions on their factor shares come from equation (1). Throughout the paper 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 labour 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 labour intensive activities. Results for case 2 are qualitatively similar so we will not analyze it in detail. To be specific, we set labour shares, λ^K, and the share of assembly in X production, β, as follows:

Case 1: $\lambda^C = 0.20$ $\lambda^X = 0.43$ $\lambda^Y = 0.57$ $\lambda^A = 0.66$ $\beta = 0.5$

The structure of production is illustrated in figure 2 (for case 1) and summarized (for both cases 1 and 2) in table 1. There are now two cones of diversification and – concentrating on case 1 – these contain countries in which the Y sector operates, together with either component production (region 2) or assembly (region 4).[4] The most capital abundant countries only produce components (region 1), while the most labour abundant just undertake assembly (region 4).

[4] In order to deal with potential indeterminancy (multiple equilibria) within the FPE set, we impose a 0.025% trade cost on all imports to a country.

Table 1: Equilibrium Production Structures

Region 1: most capital abundant countries, Region 5: most labor abundant countries

Region	Case1: Y has central factor intensity	Case2: A has central factor intensity
1	C	C
2	C, Y	C, A
3	Y	A
4	Y, A	A, Y
5	A	Y

N.B. the boundaries between regions are not in the same position in the two cases.

Factor prices in the no-fragmentation and new fragmentation cases are illustrated in figure 3. In the initial situation the wage-rental ratio takes the same value for all countries in the initial cone of diversification, decreasing with labour-abundance for those outside. With fragmentation there are two cones (regions 2 and 4) and the wage-rental ratio is the same for all countries in each of these cones, but different between them. The main point to note is that the deviations of the wage-rental ratios of the extreme countries (relative to the central country) are reduced by fragmentation. This comes directly from the fact that the range of factor intensities in the technology is increased by fragmentation, consistent with the discussion in Jones and Kierzkowski (2001). There is an expanded factor-price-equalization set for the central countries *but* it occurs at *different* factor prices: world equilibrium involves a fall in the relative price of X following fragmentation, so the relative price of labor (Y is labor intensive) rises in the expanded FPE set.

The welfare effects of fragmentation are shown in figure 4 that gives the change in the real income of each country (expressed as a proportion of initial real income).[5] 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). In line with intuition these gains accrue largely to countries with extreme endowments which – as we noted above – initially had relatively low welfare as marginal rates of transformation were not aligned to price ratios. Fragmentation means that technologies are now available which, in some sense, provide a better match for their endowments. The other force is that the terms of trade have changed. The price of good X

[5] National income deflated by the cost of living index (the unit expenditure function).

has now fallen relative to the price of Y, as fragmentation of X allows it to be produced more efficiently. Countries with labour endowment of less than 0.5 were initially exporters of X, and those with labour endowment greater than 0.5 were importers. The welfare implications are clear from figure 4, 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.

We make one final remark on our benchmark case. This is that fragmentation increases the volume of trade for most countries, but not necessarily all. The reason is clear. Consider a country in region 4, with labour endowment approximately equal to 0.67 (figure 5). In the initial situation its VOT measure was unity, as it was importing all its consumption of X (figures 1a, 1b). 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. It is interesting to note that the correlation between welfare and trade volume changes is far below unity in Case 1 and negative in Case 2 (not shown). This may be of some interest and relevance to research on trade openness, measured by the volume of trade, and growth. We return to the issue of the volume of trade in greater detail in section 5.

3. Endowments, trade costs, and the international pattern of production

We now move to our core model, in which countries differ in both relative endowments and trade costs. This model captures the interaction between factor endowments and trade barriers in shaping countries' trade and specialization. We start off by presenting results from numerical simulation, and show how countries with different characteristics engage in different activities and have different trade patterns. Based on this we interpret results in terms of the theories of trade and foreign investment, and demonstrate how our approach nests many of the cases and models that are in the existing literature. Then we characterise analytically the boundaries between regimes, showing how these depend on key parameters of the model. Finally, in this section, we turn to real income and factor price effects.

3.1: Production and trade

We start by illustrating outcomes from numerical simulation, and do so on figures that have countries' labour endowments on the horizontal (retaining the assumption that K = 1 - L), and their trade costs on the vertical. Thus, each point in the diagram corresponds to a particular country. Countries in the same row have the same trade costs and countries in the same column have the same factor endowments.

The pattern of specialization without fragmentation is given in figure 6. The bottom edge of this corresponds exactly to figure 1a, and outcomes above this line are exactly as would be expected. The set of countries that are non-specialized widens with increased trade costs as does the band in which there is no trade[6]. On either side of the latter are cones of diversification; in the left hand cone relatively labour scarce countries export X, the capital intensive good, and have a higher wage-rental ratio than do relatively labour abundant countries in the right hand cone, except at free trade (bottom row). Areas of specialization occur at more extreme endowments, but the range of such endowments diminishes as trade costs get higher. Specialization thus increases with more extreme factor endowments and/or lower trade costs.

The effect of fragmentation is given in Figure 7, and initially appears very complex. The bottom row, free trade, gives the same pattern as shown in Figure 2. As would be expected, there is a lot of specialization among the low-trade-cost countries (C, CY, Y, YA, A). At higher trade costs we see much less specialization, such as the pattern CA, CYA, no trade, CYA, YA, for moderate trade costs. In general, countries are more specialized when trade costs are lower as in Figure 2. However, it is no longer generally true that countries are more specialized the more their endowment ratio differs from 1.

The location of production and pattern of trade for each activity separately is seen by looking at figure 7 in conjunction with figures 8C, 8A and 8Y, giving trade patterns. Component production is the least labour intensive activity, and consequently components are produced in and exported from labour scarce regions in figure 8C. At high trade costs it is only the least labour abundant countries that export components, although a wider range of countries produce them just for local consumption.

Assembly activity is the most labour intensive activity, so is produced and exported by the most labour abundant regions. Comparing components and assembly (figures 8C and

[6] See Norman and Venables (1995) for analysis of this in a two-country Edgeworth-box framework.

8A) we see that a much wider range of countries produce A for local consumption than produce C. This asymmetry arises because of the double trade costs that are borne by exports of assembled products using imported inputs. Thus, a country in the upper right area of figure 8A imports components and undertakes assembly just for the local market. Exporting the final product incurs a double trade cost penalty as components are imported and then re-exported embodied in the assembled product.

Good Y now has intermediate factor intensity, and is consequently produced in and exported by regions with intermediate factor endowments. Y is imported by countries that are very labour abundant, and also by those that are very labour scarce. The fact that there is a trade-direction reversal as we move up a column on the right is perhaps not intuitive. What happens is that, at very low trade costs, the countries on the right are specialized in A (Figure 7) and thus import Y. But as trade costs increase, importing and then re-exporting C becomes costly, and the countries import C only for assembly for local sale. They pay for C by exporting Y.

3.2 Vertical and horizontal specialization:

Figure 9 presents results in a form that helps tie the paper to the literature on multinational firms. Four regions 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. The country exporting the components is then the parent, denoted (p) in the figure, and the country assembling from imported components is

the host, denoted (h) in the figure.

'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).[7]

Several important points emerge from figure 9. 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. We will investigate the boundaries between these regimes, and undertake some comparative statics in following sections.

Second, the impact of these regimes on trade volumes is qualitatively quite different. Figure 10 shows changes in trade volumes following fragmentation. The regions of falling trade volume are largely (although not entirely) contained with the 'mo' regions of figure 9.[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 9 is a complement to trade.

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 existing literature, and show how both country relative

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[7] Of course, this bilateral pairing are not determined in this model in which goods are traded on a world market.

[8] The reason they are not subsets of the 'mo' regions is that figure 9 describes the equilibrium with fragmentation, while figure 10 is a comparison between this and the non-marginally different equilibrium without fragmentation.

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 Analysis:

While numerical simulation provides the full picture, analytical expressions can be derived to give exact characterisations of the regimes of figures 7 - 9. There are too many cases to study in full, so we merely describe one of the regime boundaries in detail, and then tabulate the equations describing other boundaries. Consider the boundary between regions ep(h) and mo(h) of figure 9, ie the boundary along which it just becomes profitable for labour abundant countries to become export oriented, switching from assembly of X goods just for local consumption to assembly of X for export. The fact that this export activity breaks even means that factor prices must satisfy the following relationship;

$$p^X/t^X = B(b^A(w, r), t^C p^C). \quad \textbf{(4)}$$

The effect of trade costs can be seen by totally differentiating to give,

$$-[\hat{t}^X + (1-\beta)\hat{t}^C]/\beta = [\lambda^A \hat{w} + (1-\lambda^A)\hat{r}] \quad \textbf{(5)}$$

where ^ denotes a proportionate change. The expression gives the extent to which factor prices must fall if assembly for export is to continue to break even at locations with higher trade costs. The main point to note is that proportional increases in trade costs require much larger falls in factor cost (the right hand side). The fact that both final exports and component inputs are subject to trade costs mean that these terms enter additively on the left hand side of the expression. Furthermore, assembly is only fraction β of total costs, so the trade cost effect gets multiplied by factor $1/\beta$. Intuitively, higher trade costs squeeze value added in assembly both by reducing the export price and raising input costs.

On this ep(h) and hor(h) boundary it is also the case that countries are exporting Y, so

$$p^Y/t^Y = b^Y(w, r). \quad \textbf{(6)}$$

Differentiating,

$$-\hat{t}^{Y} = [\lambda^{Y}\hat{w} + (1-\lambda^{Y})\hat{r}] \qquad (7)$$

Using equations (5) and (7) enables us to pin down the effects of trade costs on the prices of each of the factors separately. Solving, we derive

$$\hat{w} = \frac{1}{\lambda^{A}-\lambda^{Y}}\left[(1-\lambda^{A})\hat{t}^{Y} - (1-\lambda^{Y})\left(\frac{\hat{t}^{X}+(1-\beta)\hat{t}^{c}}{\beta}\right)\right]$$
$$\hat{r} = \frac{1}{\lambda^{A}-\lambda^{Y}}\left[\lambda^{Y}\left(\frac{\hat{t}^{X}+(1-\beta)\hat{t}^{c}}{\beta}\right) - \lambda^{A}\hat{t}^{Y}\right] \qquad (8)$$

These are simply Stolper-Samuelson effects, modified to include the fact that there are traded intermediate goods.[9] We see that factor price effects become still larger because, by the usual Stolper-Samuelson logic, price changes are divided by the difference in factor shares in the two active sectors ($\lambda^{A} - \lambda^{Y}$, the determinant of the technology matrix). The expressions simplify if we assume trade costs are same across all activities (as is done in the simulations), so

$$\hat{w} = \frac{\hat{t}}{\lambda^{A}-\lambda^{Y}}\left[(1-\lambda^{A}) - (1-\lambda^{Y})\left(\frac{2-\beta}{\beta}\right)\right] < 0, \qquad \hat{r} = \frac{1}{\lambda^{A}-\lambda^{Y}}\left[\lambda^{Y}\left(\frac{2-\beta}{\beta}\right) - \lambda^{A}\right]$$
$$\hat{w} - \hat{r} = -\frac{2(1-\beta)\hat{t}}{\beta(\lambda^{A}-\lambda^{Y})} < 0, \qquad (9)$$

These equations say that, in regions that export both Y and A, higher trade costs are associated with lower wages, while the effect on the rate of return is ambiguous (with the assumption that $\lambda^{A} > \lambda^{Y}$).

Other boundaries can be derived analogously, and tables 2a and 2b tabulate results for the boundaries of figure 7, maintaining the assumption that trade costs are the same in all sectors. One further analytical points needs developing. If, in one of the regions, only one

[9] See Venables and Limao (2002) for exploration of these effects in a somewhat different spatial framework.

activity is operating, then it is straightforward to go beyond the factor price changes to the associated changes in factor endowments. Thus, consider the boundary between regions YA and A on figure 7. On this boundary countries export X assembly using imported C, and import Y (see figures 8Y, 8A), so

$$p^X/t = B(b^A(w,r), p^C t), \qquad tp^Y = b^Y(w,r). \tag{10}$$

Totally differentiating and solving the pair of equations gives

$$\hat{w} - \hat{r} = -2\hat{t}/\beta(\lambda^A - \lambda^Y). \tag{11}$$

Notice also that on this boundary A production is the only activity operating in the country, so the factor demands in this sector must equal the economies' endowments. Expressing this in ratio form gives $b_w^A(w,r)/b_r^A(w,r) = L/K$, where a subscript on a function denotes a partial derivative. Totally differentiating this gives, $\hat{L} - \hat{K} = \sigma^A(\hat{r} - \hat{w})$, where σ^A is the elasticity of substitution.[10] Using this in (11) we derive

$$\hat{L} - \hat{K} = 2\hat{t}\sigma^A/\beta(\lambda^A - \lambda^Y) > 0 \tag{12}$$

which is the slope of the YA/A boundary on figure 7. The slope has positive gradient as a falling wage rental ratio makes production of each activity more labour intensive.

These effects are summarised in table 2a, for boundaries between regions in one of which only one activity is operating. Within each block the first row is the price cost relationship for the activities; thus, the first rows of A/YA block are the cost equalities for Y and A production described above, together with the statement that is it not profitable to produce components. The second row of each block gives factor price changes along the boundary, like equation (11). The third row gives factor market clearing in each country and the consequent trade costs / factor abundance locus for each boundary (like equation (12)). We see that gradients all depend on relative factor intensities and on elasticities of

[10] This equation is simply the definition of the elasticity of substitution in production.

substitution, and have the same slopes as illustrated on figure 7.

Table 2a: Production regime boundaries

	Y	C	A
A/YA	$tp^Y = b^Y(w,r)$	$tp^C < b^C(w,r)$	$p^X/t = B(b^A(w,r), p^C t)$
	$\hat{w} - \hat{r} = -2\hat{t}/\beta(\lambda^A - \lambda^Y) < 0$		
	$b_w^A/b_r^A = L/K$	$\hat{L} - \hat{K} = 2\hat{t}\sigma^A/\beta(\lambda^A - \lambda^Y) > 0$	
Y/YA	$p^Y/t = b^Y(w,r)$	$tp^C < b^C(w,r)$	$tp^X = B(b^A(w,r), p^C t)$
	$\hat{w} - \hat{r} = 2\hat{t}/(\lambda^A - \lambda^Y) > 0$		
	$b_w^Y/b_r^Y = L/K$	$\hat{L} - \hat{K} = -2\hat{t}\sigma^Y/(\lambda^A - \lambda^Y) < 0$	
CY/Y	$p^Y/t = b^Y(w,r)$	$tp^C = b^C(w,r)$	$p^X t < B(b^A(w,r), p^C t)$
	$\hat{w} - \hat{r} = -2\hat{t}/(\lambda^Y - \lambda^C) < 0$		
	$b_w^Y/b_r^Y = L/K$	$\hat{L} - \hat{K} = 2\hat{t}\sigma^Y/(\lambda^Y - \lambda^C) > 0$	
C/CY	$tp^Y = b^Y(w,r)$	$p^C/t = b^C(w,r)$	$p^X t < B(b^A(w,r), p^C/t)$
	$\hat{w} - \hat{r} = 2\hat{t}/(\lambda^Y - \lambda^C) > 0$		
	$b_w^C/b_r^C = L/K$	$\hat{L} - \hat{K} = -2\hat{t}\sigma^C/\beta(\lambda^Y - \lambda^C) < 0$	
C/CA	$tp^Y < b^Y(w,r)$	$p^C/t = b^C(w,r)$	$p^X t = B(b^A(w,r), p^C/t)$
	$\hat{w} - \hat{r} = 2\hat{t}/\beta(\lambda^A - \lambda^C) > 0$		
	$b_w^C/b_r^C = L/K$	$\hat{L} - \hat{K} = -2\hat{t}\sigma^C/\beta(\lambda^A - \lambda^C) < 0$	

Table 2b give boundaries between regions that have two or more activities operating. The relationship between trade costs and factor prices can be derived, as above. However, it is no longer possible to make such a straightforward mapping from trade costs to factor endowments, as the production structure of countries may change along the boundary. Conceptually, this step could be made using information from the demand side of each economy, but we do not pursue it here.

Table 2b: Production regime boundaries

	Y	C	A
CAY/YA	$p^Y/t = b^Y(w,r)$	$tp^C = b^C(w,r)$	$p^X/t < B(b^A(w,r), p^C t) < p^X t$
	$\hat{w} - \hat{r} = -2\hat{t}/(\lambda^Y - \lambda^C) < 0$		
CA/CAY	$tp^Y = b^Y(w,r)$	$p^C/t = b^C(w,r)$	$p^X/t < B(b^A(w,r), p^C/t) < p^X t$
	$\hat{w} - \hat{r} = 2\hat{t}/(\lambda^Y - \lambda^C) > 0$		
CY/CA	$tp^Y = b^Y(w,r)$	$p^C/t = b^C(w,r)$	$p^X t = B(b^A(w,r), p^C/t)$
	horizontal		
CY/CAY, left	$tp^Y = b^Y(w,r)$	$p^C/t = b^C(w,r)$	$p^X t = B(b^A(w,r), p^C/t)$
	horizontal		
CY/CAY, right	$p^Y/t = b^Y(w,r)$	$p^C/t = b^C(w,r)$	$p^X t = B(b^A(w,r), tp^C)$
	horizontal		

3.4 Welfare and factor prices

What is the effect of fragmentation on welfare and factor prices? Figure 11 shows the effect on welfare, and is consistent with the information in Figure 4. The countries that lose from fragmentation are those that were initially ideally suiting to specializing in and exporting integrated X, (low transport costs and appropriate factor abundance) and are less well suited to production of either C or A individually. When fragmentation is allowed, it leads to a fall in the relative price of X and so these countries suffer a terms-of-trade loss.

In further work we intend to draw out two further sets of implications. One is establish the effects on the real income of each factor separately. The other is to establish welfare effects if trade costs are revenue creating import tariffs and export taxes, rather than real trade costs. We conjecture that there may be welfare losses in regions where fragmentation causes market-oriented assembly production to substitute for imports of X, so reducing the volume of trade; this production is essentially ‘tariff-jumping’ and – if trade costs are distortionary wedges – welfare reducing.

4. Comparative statics I: trade policy and factor accumulation in a single country

We can undertake several distinct sorts of comparative static exercises in this model. One is to vary a parameter that effects many or all countries and consequently changes world prices; in the next section we look at reductions in trade costs, drawing a picture of how globalisation affects countries. Another is to simply to move a single country around the space of factor endowments and trade costs. Since there are a continuum of countries, moving a single one has no effect on world prices, and the experiment is simply small-open-economy comparative statics. However, our approach enables us to compared comparative static responses in different regimes, and to explore the effects of crossing a regime boundary.

Figures in the preceding section give an overview of the effects of a single country reducing its trade costs or accumulating factors of production. Clearly, by successfully reducing trade costs a labour abundant country can go from having market-oriented assembly to assembly for export. By accumulating capital it can change its comparative advantage.

In further work the implications of these changes for real incomes and factor prices will be explored. How do reductions in trade costs affect factor prices and real income in labour scarce and labour abundant countries? Of course, small open economies always gain from unilateral reductions in trade costs or tariffs, but how do these changes affect internal income distribution, and are gains quantitatively more valuable in some regions than in others? Similarly, for factor accumulation. The returns to accumulating capital will vary according to the pattern of specialisation a country is following. In some of the regions of figure 7 countries are in cones of diversifications so factor prices are invariant to small changes in endowments. However, larger changes may alter trade and production patterns, moving countries out of a cone of diversification and causing changes in returns to factors. Pursuing these issues will illuminate interactions between trade policy and factor accumulation, central to so many of the debates about trade and development.

5. Comparative statics II: 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 regimes is illustrated by comparing figure 12 and figure 9. As expected, reducing trade costs has the effect of stretching all 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 labour abundant countries. At the same time a range of labour abundant countries switch from appearing 'import substituting' (assembling X goods just for local consumption) to becoming export oriented (exporting assembled X goods).

This change is associated with dramatic increases in the degree of specialisation and the volume of world trade relative to income. Figure 13 has on the horizontal axis a measure of world trade costs (falling from left to right) and average (over countries) Herfindahl index of production specialization 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 6-12.

The uppermost of the positively sloped lines is the Herfindahl index of specialisation when fragmentation is possible (HERFY); the lower line is the same index computed when fragmentation is not possible. Evidently, fragmentation is associated with more specialization, the relative difference between the two measures increasing at lower trade costs. A similar pattern is recorded for the volume of trade measures with (VOTY) and without (VOTN) fragmentation, see Figure 14. Our modeling of fragmentation therefore offers a simple explanation for the dramatic increases in trade volumes studied by Yi (2003) and others.

The mechanism driving the evolution of specialization and of trade volumes can be can be seen by focusing on a set of countries which initially transit through the experience of horizontal then export-platform activity. Figures 15 and 16 are analogous to figures 13 and 14, but just report the average Herfindahl indices and trade volumes for countries that, in the central case of figure 9, were largely engaged in horizontal activity (to be precise, 16 out of 31 countries, those with central-case trade costs of 0.091 and labour endowments in the range 0.21-0.39 and 0.61-0.79). 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 6-12).

The point about these figures is the cross over of the curves. Thus, for these countries,

fragmentation reduces specialization when trade costs are relatively high, and increases it when trade costs are low. Similarly for the volume of trade, the interval in which fragmentation is associated with market-oriented investments is one in which fragmentation reduces trade volumes. The intuition for the fact that the Herfindahl index 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.

Finally, we note that the effects of globalisation on the real incomes of countries and factors of production within countries will be developed in future versions of this paper.

5. Summary and Conclusions

We adopt a multi-country approach to analyzing the effects of allowing one production sector (X) to fragment into two geographically separated production activities (C and A). Here is an outline of our main findings.

(1) 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. A Herfindahl index of specialization confirms our intuition that fragmentation should lead to more specialization in the world economy.

(2) 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.

(3) Fragmentation enables low trade cost countries to specialise in export activities that match their factor endowments, while higher trade cost countries use fragmentation as a means of ‘import substituting’. Thus, labour abundant countries that have low trade 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 relate closely to the results in the literature on multinational firms that make the distinction between horizontal (market-oriented) and vertical (export-platform) investments. Our approach also captures the difference between import substituting and export oriented development strategies.

(4) Reducing trade costs worldwide moves some countries from one pattern of specialisation to another. In particular, final assembly activities move from a set of labour scarce countries to labour abundant ones, with impacts on the real income and factor prices of these countries. For low enough trade costs, the volume of trade increases very substantially, in line with recent experience and empirical findings.

(5) Not withstanding 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) or import X.

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Appendix: Countries differing in relative endowments and trade costs: 31x41 = 1271 countries: 29236 inequalities in 29236 complementary non-negative variables:

i, j are countries,

k are production activities: k ∈ {Y, C, A, X}

p_{kij} - producer price of k in country ij

pc_{kij} - consumer price of k in country ij

p_k - world price of k

EK_{ij} - exports of k from country ij

IK_{ij} - imports of k into country ij

U_{ij} - utility of ij, p_{uij} - price of utility

Inequality	Complementary Variable	Number of inequalities and unknowns
<u>zero profit inequalities</u>	<u>activity levels</u>	
$c_y(w_{ij},r_{ij}) \geq p_{yij}$	Y_{ij}	651
$c_c(w_{ij},r_{ij}) \geq p_{cij}$	C_{ij}	651
$c_x(w_{ij}, r_{ij}, p_{cij}) \geq p_{xij}$	X_{ij}	651
$c_a(w_{ij}, r_{ij}, pc_{cij}) \geq p_{xij}$	A_{ij}	651
$c_{uij}(pc_{yij}, pc_{xij})) \geq p_{uij}$	U_{ij}	651
$p_{xij} \geq pc_{xij}$	XX_{ij}	651
$p_{yij} \geq pc_{yij}$	YY_{ij}	651
$p_{yij}(1 + tc_i) \geq p_y$	EY_{ij}	651
$p_{cij}(1 + tc_i) \geq p_c$	EC_{ij}	651
$p_{xij}(1 + tc_i) \geq p_x$	EX_{ij}	651
$p_y(1 + tc_i) \geq pc_{yij}$	IY_{ij}	651
$p_c(1 + tc_i) \geq pc_{cij}$	IC_{ij}	651
$p_x(1 + tc_i) \geq pc_{xij}$	IX_{ij}	651

market clearing inequalities	prices	
$XX_{ij} + IX_{ij} \geq \frac{\partial c_{uij}}{\partial pc_{xij}} U_{ij}$	pc_{xij}	651
$YY_{ij} + IY_{ij} \geq \frac{\partial c_{uij}}{\partial pc_{yij}} U_{ij}$	pc_{yij}	651
$IC_{ij} \geq \frac{\partial c_{aij}}{\partial pc_{cij}} A_{ij}$	pc_{cij}	651
$\sum_i \sum_j EY_{ij} \geq \sum_i \sum_j IY_{ij}$	p_y	1
$\sum_i \sum_j EC_{ij} \geq \sum_i \sum_j IC_{ij}$	p_c	1
$\sum_i \sum_j EX_{ij} \geq \sum_i \sum_j IX_{ij}$	p_x	1
$U_{ij} \geq M_{ij}/p_{uij}$	p_{uij}	651
$X_{ij} \geq XX_{ij} + EX_{ij} - IX_{ij}$	p_{xij}	651
$Y_{ij} \geq YY_{ij} + EY_{ij} - IY_{ij}$	p_{yij}	651
$C_{ij} \geq \frac{\partial c_{xij}}{\partial p_{cij}} X_{ij} + EC_{ij}$	p_{cij}	651
$L_{ij} \geq \frac{\partial c_{yij}}{\partial w_{ij}} Y_{ij} + \frac{\partial c_{xij}}{\partial w_{ij}} X_{ij} + \frac{\partial c_{aij}}{\partial w_{ij}} A_{ij} + \frac{\partial c_{cij}}{\partial w_{ij}} C_{ij}$	w_{ij}	651
$K_{ij} \geq \frac{\partial c_{yij}}{\partial r_{ij}} Y_{ij} + \frac{\partial c_{xij}}{\partial r_{ij}} X_{ij} + \frac{\partial c_{aij}}{\partial r_{ij}} A_{ij} + \frac{\partial c_{cij}}{\partial r_{ij}} C_{ij}$	r_{ij}	651
Income balance inequalities	incomes	
$M_{ij} = w_{ij} L_{ij} + r_{ij} K_{ij}$	M_{ij}	651

```
*Multi-country model with countries differing in relative endowments and
trade *costs (figures xx - xx) using Rutherford's MPS/GE subsytem of GAMS:
29,236 *inequalities and unknowns.

SET     I       countries               /1*21/,
            J       countries               /1*31/,
            F       factors of production   /L, S/;


PARAMETERS
 TC(I)
 ENDOW(I,J,F)
 FX(F)
 FY(F)
 FC(F)
 CX;

FX("L") = 33;
FX("S") = 17;
FY("L") = 57;
FY("S") = 43;
FC("L") = 10;
FC("S") = 40;
CX = 50;


$ONTEXT
$MODEL:MULTI

$SECTORS:
        X(I,J)          ! production index: assembly using domestic C
        A(I,J)          ! production index: assembly using imported C
        C(I,J)          ! production index for C
        Y(I,J)          ! production index for Y
        W(I,J)          ! welfare index ("production" of utility from Y,
X)
        EC(I,J)         ! exports of C
        IC(I,J)         ! imports of C
        EX(I,J)         ! exports of X
        IX(I,J)         ! imports of X
        EY(I,J)         ! exports of Y
        IY(I,J)         ! imports of Y
        XX(I,J)         ! domestic supply of domestically produced X
        YY(I,J)         ! domestic supply of domestically produced Y

$COMMODITIES:
        PW(I,J)         ! utility price index
        PX(I,J)         ! domestic producer price of X
        PY(I,J)         ! domestic producer price of Y
        PC(I,J)         ! price of domestically produced C
        PCI(I,J)        ! price of imported C
        PCX(I,J)        ! domestic consumer price of X
        PCY(I,J)        ! domestic consumer price of Y
        PF(I,J,F)       ! price of factor F in country i,j
        PFC             ! world price of C (price at "market")
        PFX             ! world price of X (price at "market")
        PFY             ! world price of Y (price at "market")
```

```
$CONSUMERS:
        CONS(I,J)          ! Representative consumer in country i,j

$PROD:X(I,J) s:1
        O:PX(I,J)          Q:100
        I:PF(I,J,F)        Q:FX(F)
        I:PC(I,J)          Q:CX

$PROD:A(I,J) s:1
        O:PX(I,J)          Q:100
        I:PF(I,J,F)        Q:FX(F)
        I:PCI(I,J)         Q:CX

$PROD:C(I,J) s:1
        O:PC(I,J)          Q:50
        I:PF(I,J,F)        Q:FC(F)

$PROD:EC(I,J)
        O:PFC              Q:100
        I:PC(I,J)          Q:(100*TC(I))

$PROD:IC(I,J)
        O:PCI(I,J)         Q:100
        I:PFC              Q:(100*TC(I))

$PROD:Y(I,J) s:1
        O:PY(I,J)          Q:100
        I:PF(I,J,F)        Q:FY(F)

$PROD:W(I,J) s:1
        O:PW(I,J)          Q:200
        I:PCX(I,J)         Q:100
        I:PCY(I,J)         Q:100

$DEMAND:CONS(I,J)
        D:PW(I,J)          Q:(SUM(F, ENDOW(I,J,F)))
        E:PF(I,J,F)        Q:ENDOW(I,J,F)

$PROD:EX(I,J)
        O:PFX              Q:100
        I:PX(I,J)          Q:(100*TC(I))

$PROD:EY(I,J)
        O:PFY              Q:100
        I:PY(I,J)          Q:(100*TC(I))

$PROD:IX(I,J)
        O:PCX(I,J)         Q:100
        I:PFX              Q:(100*TC(I))

$PROD:IY(I,J)
        O:PCY(I,J)         Q:100
        I:PFY              Q:(100*TC(I))

$PROD:XX(I,J)
        O:PCX(I,J)         Q:100
        I:PX(I,J)          Q:100
```

```
$PROD:YY(I,J)
        O:PCY(I,J)        Q:100
        I:PY(I,J)         Q:100


$OFFTEXT
$SYSINCLUDE MPSGESET MULTI


LOOP(I,
LOOP(J,

ENDOW(I,J,"S") = (180+(160/30) - (160/30)*ORD(J));
ENDOW(I,J,"L") = (20-(160/30) + (160/30)*ORD(J));

TC("21") = 1.00025;
TC(I)$(ORD(I) LT 21) = 1 + (1.25**(20 - ORD(I)))*0.005;

);
);

$INCLUDE MULTI.GEN
SOLVE MULTI USING MCP;

* compute no-fragmentation case

A.FX(I,J) = 0;
IC.FX(I,J) = 0;
EC.FX(I,J) = 0;

$INCLUDE MULTI.GEN
SOLVE MULTI USING MCP;
```

Figure 1a: No fragmentation: Production shares of GDP

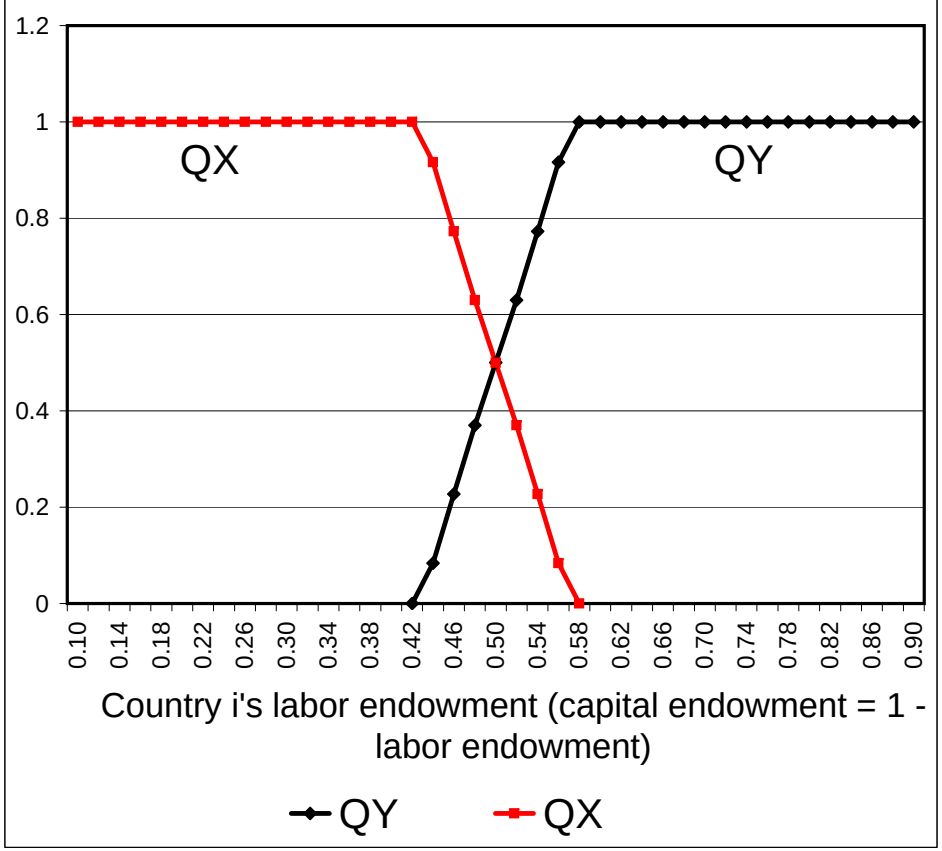
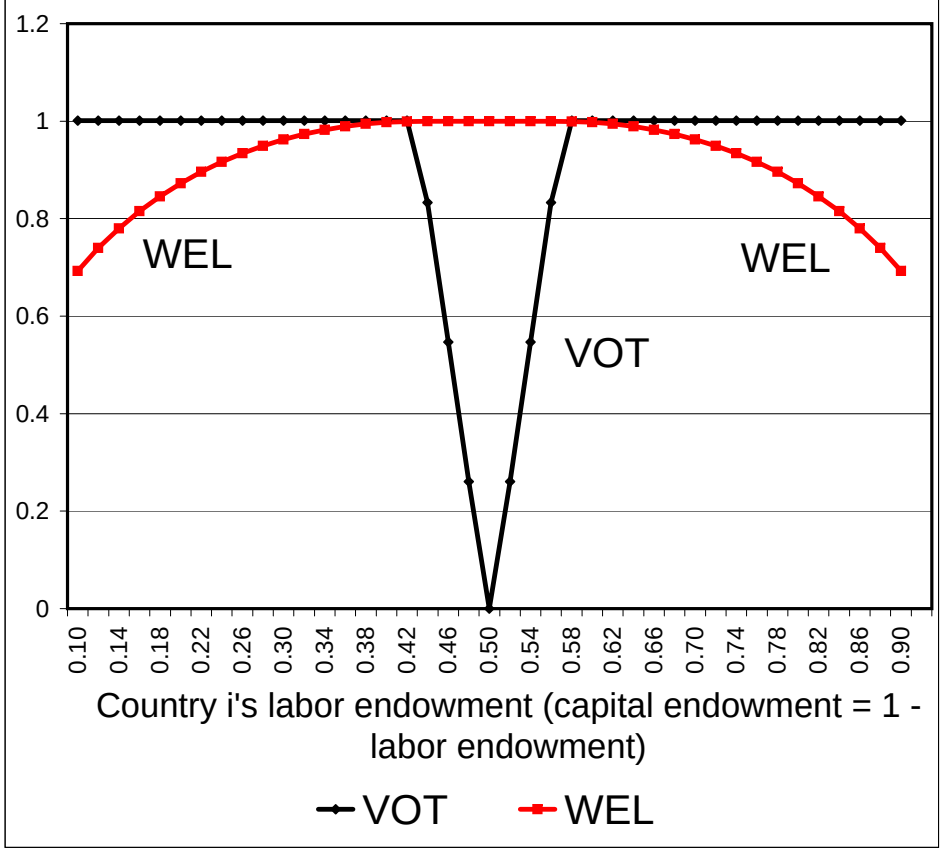


Figure 1b: No fragmentation: Volume of trade and Welfare



Herfindahl Index of Specialization: 0.705

Figure 2: Multi-country model with fragmentation: production shares of GDP

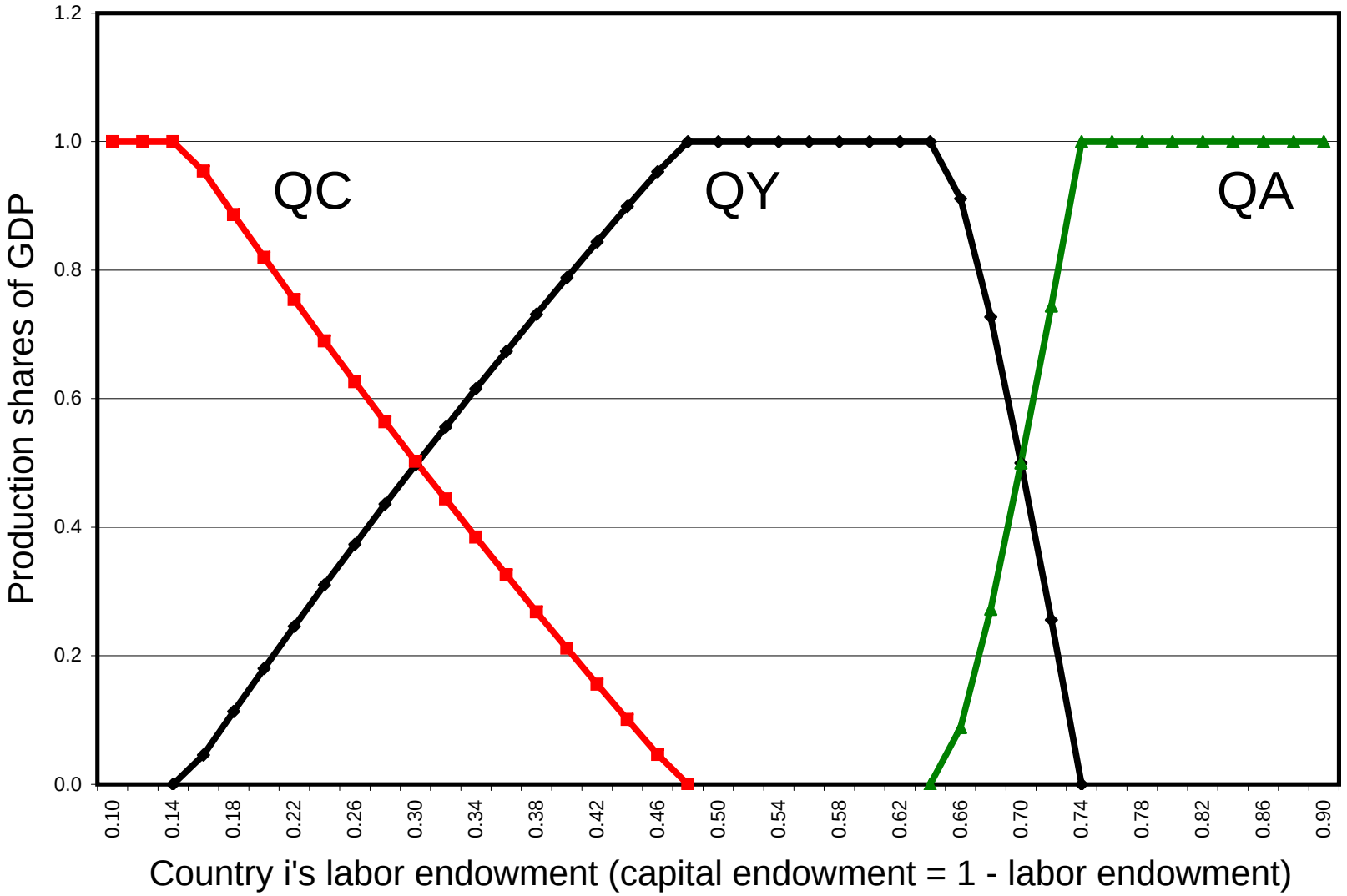


Figure 3: Multi-country model: change in the volume of trade / GDP due to fragmentation

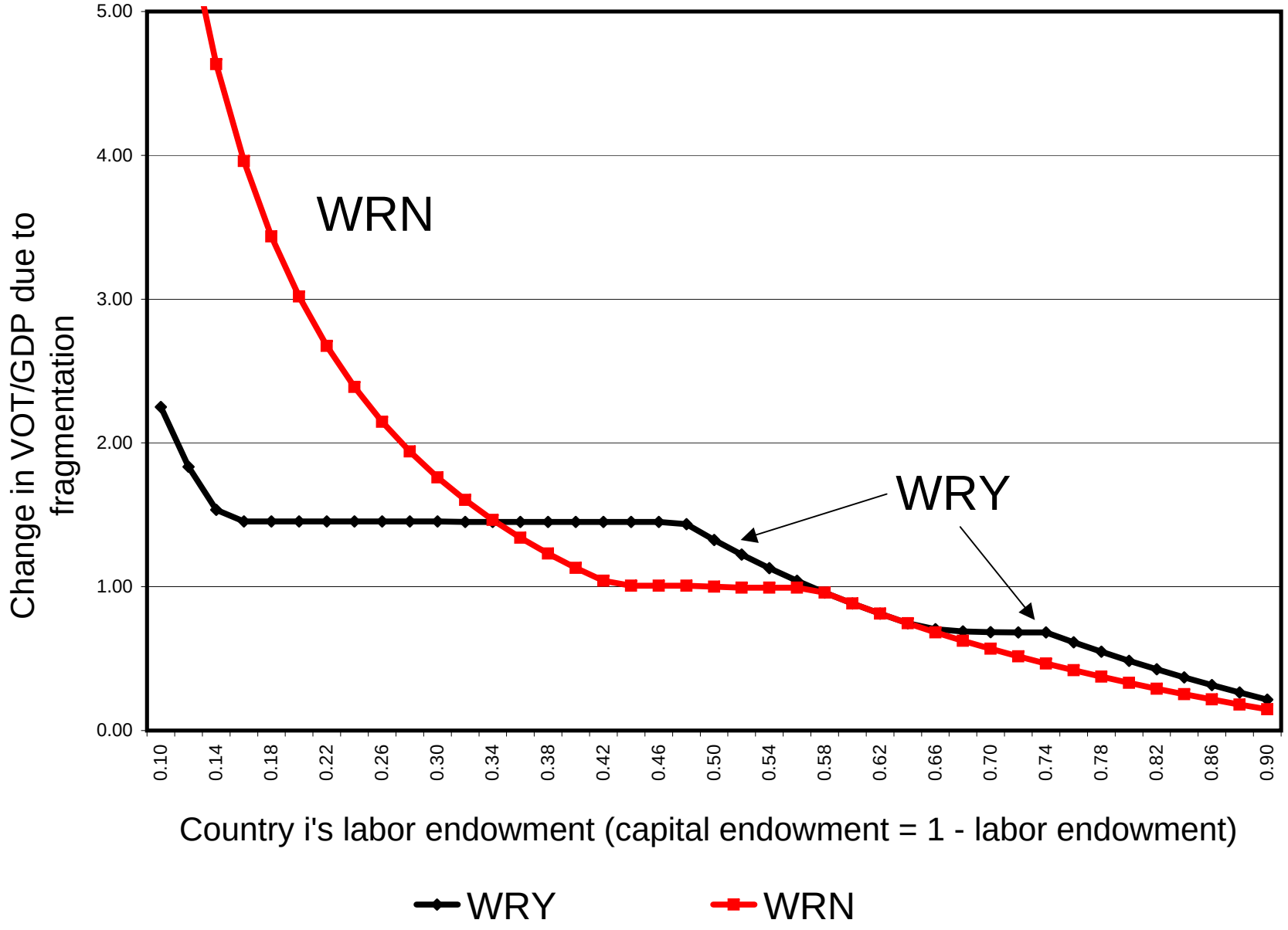
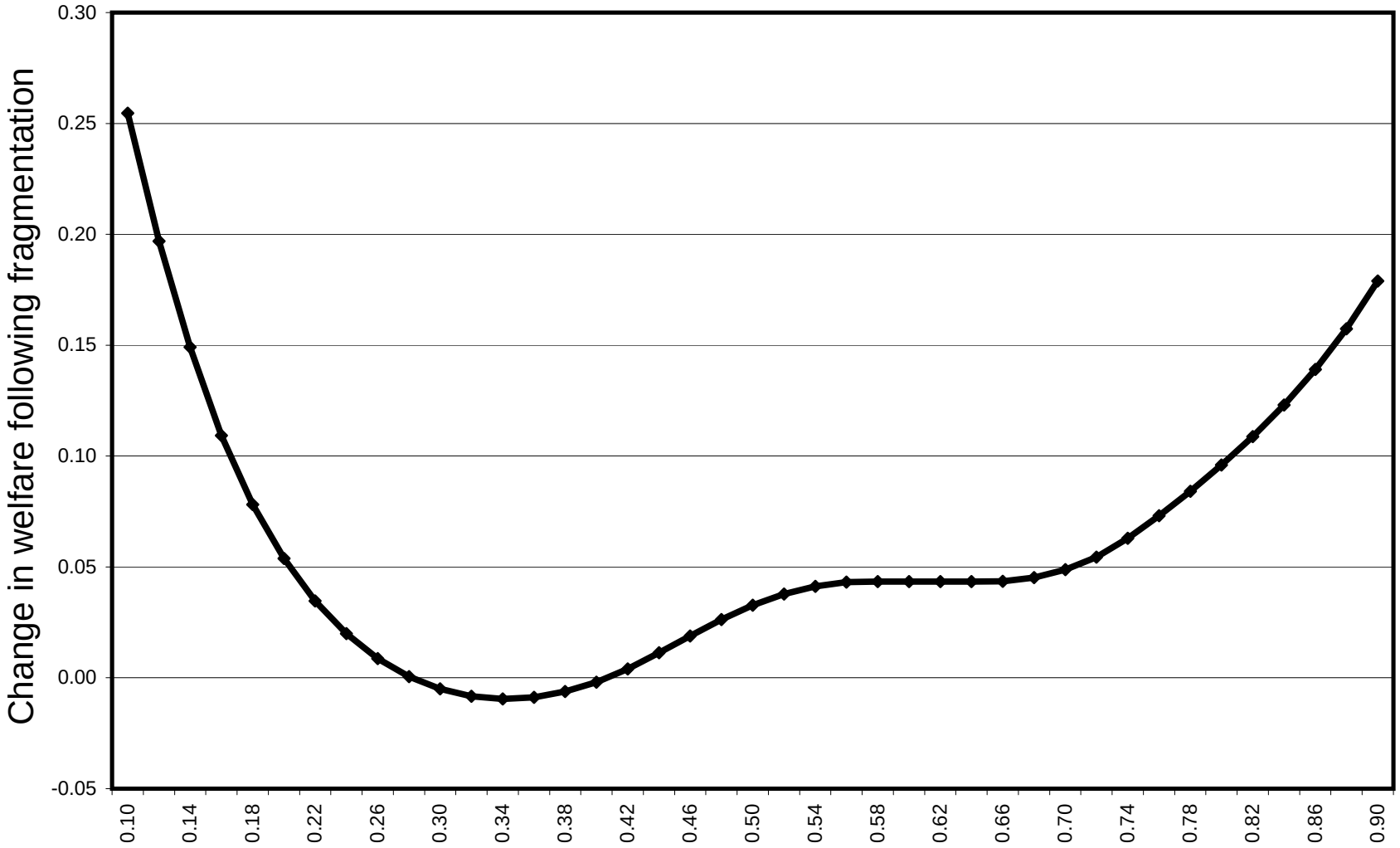


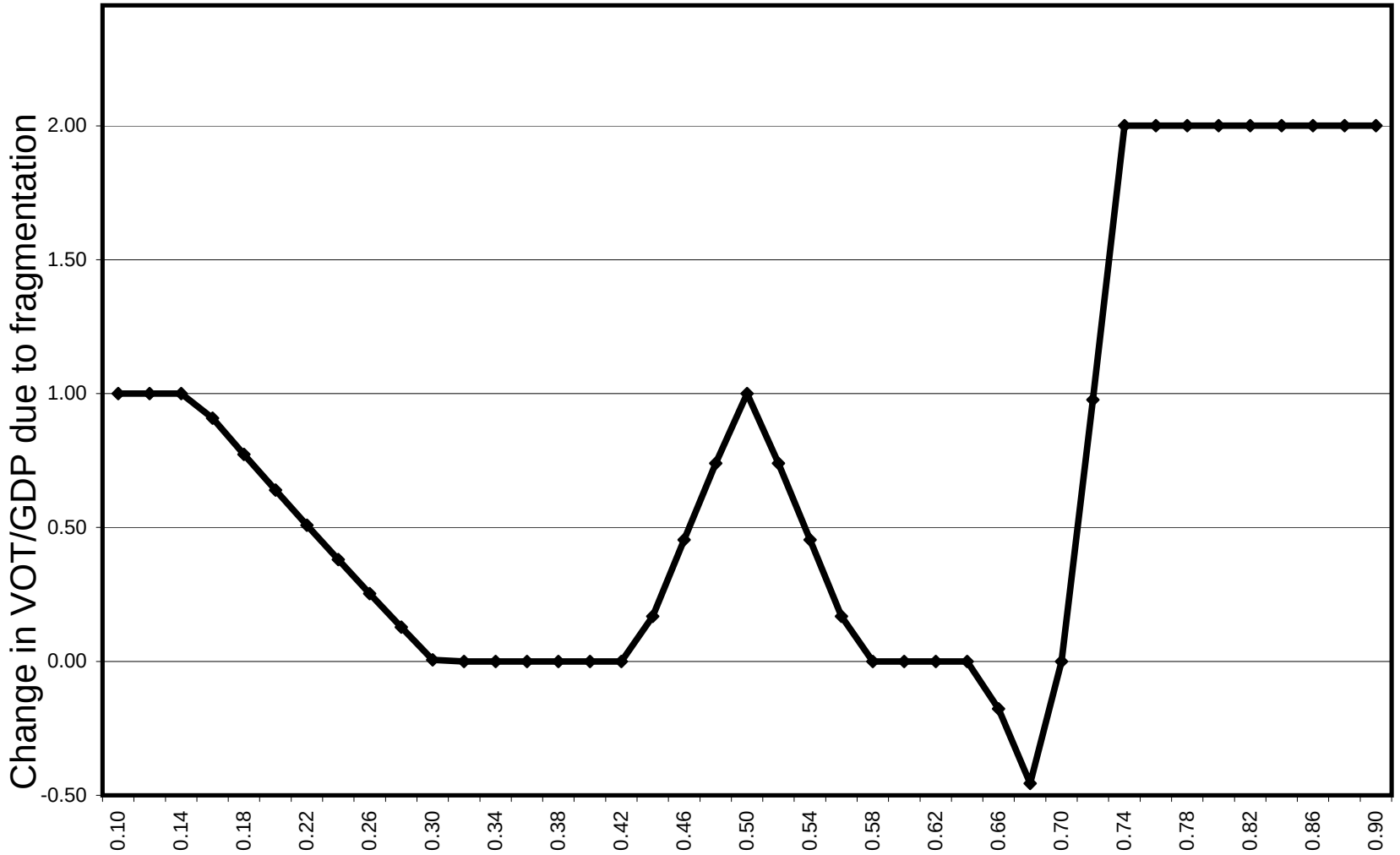
Figure 4: Multi-country model: proportional change in welfare due to fragmentation



Country i's labor endowment (capital endowment = 1 - labor endowment)

Mean change: 0.060

Figure 5: Multi-country model: change in the volume of trade / GDP due to fragmentation



Mean change: 0.699 Correlation with welfare change: 0.656

Figure 6: Production Regimes with no fragmentation

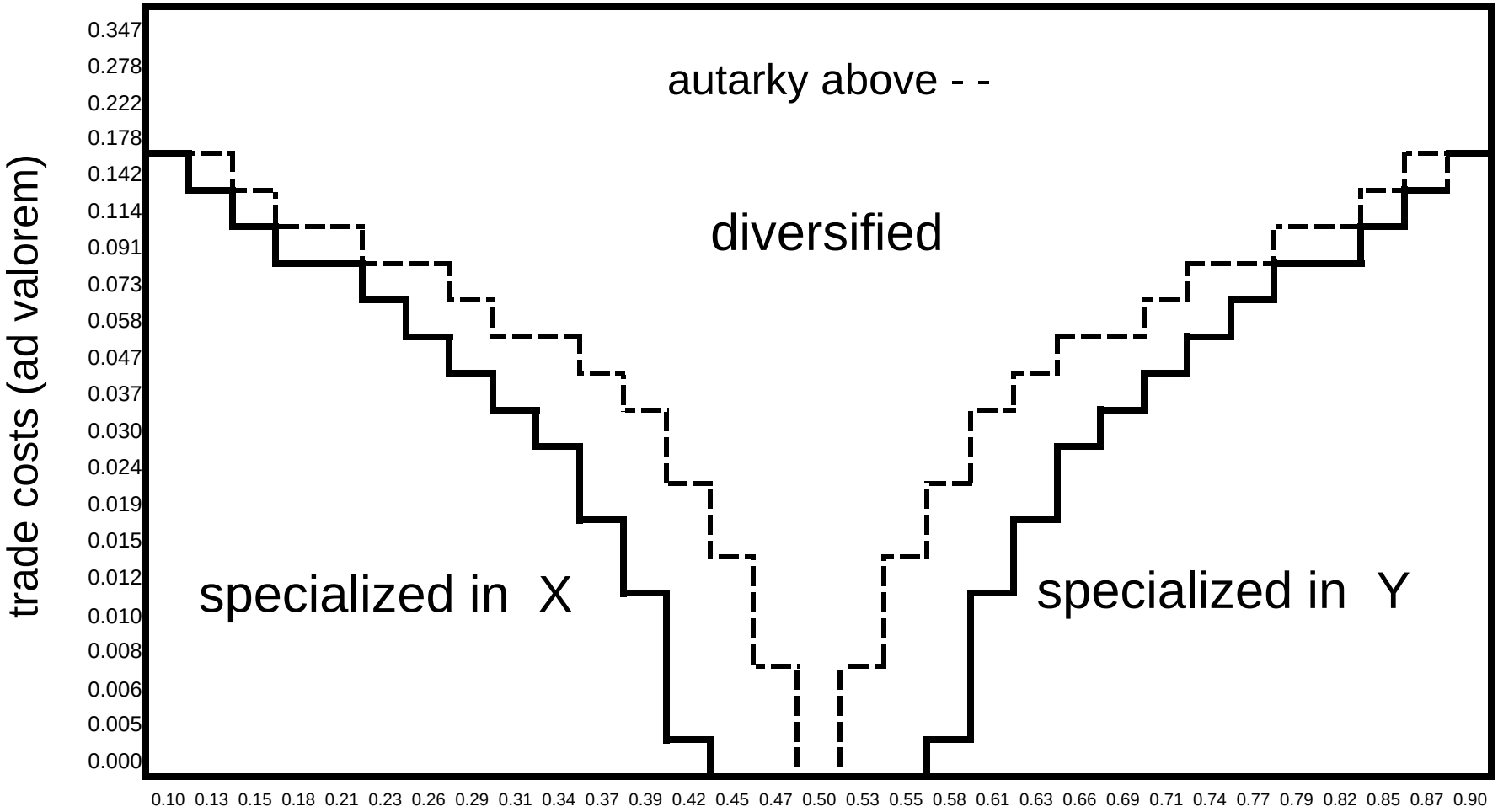
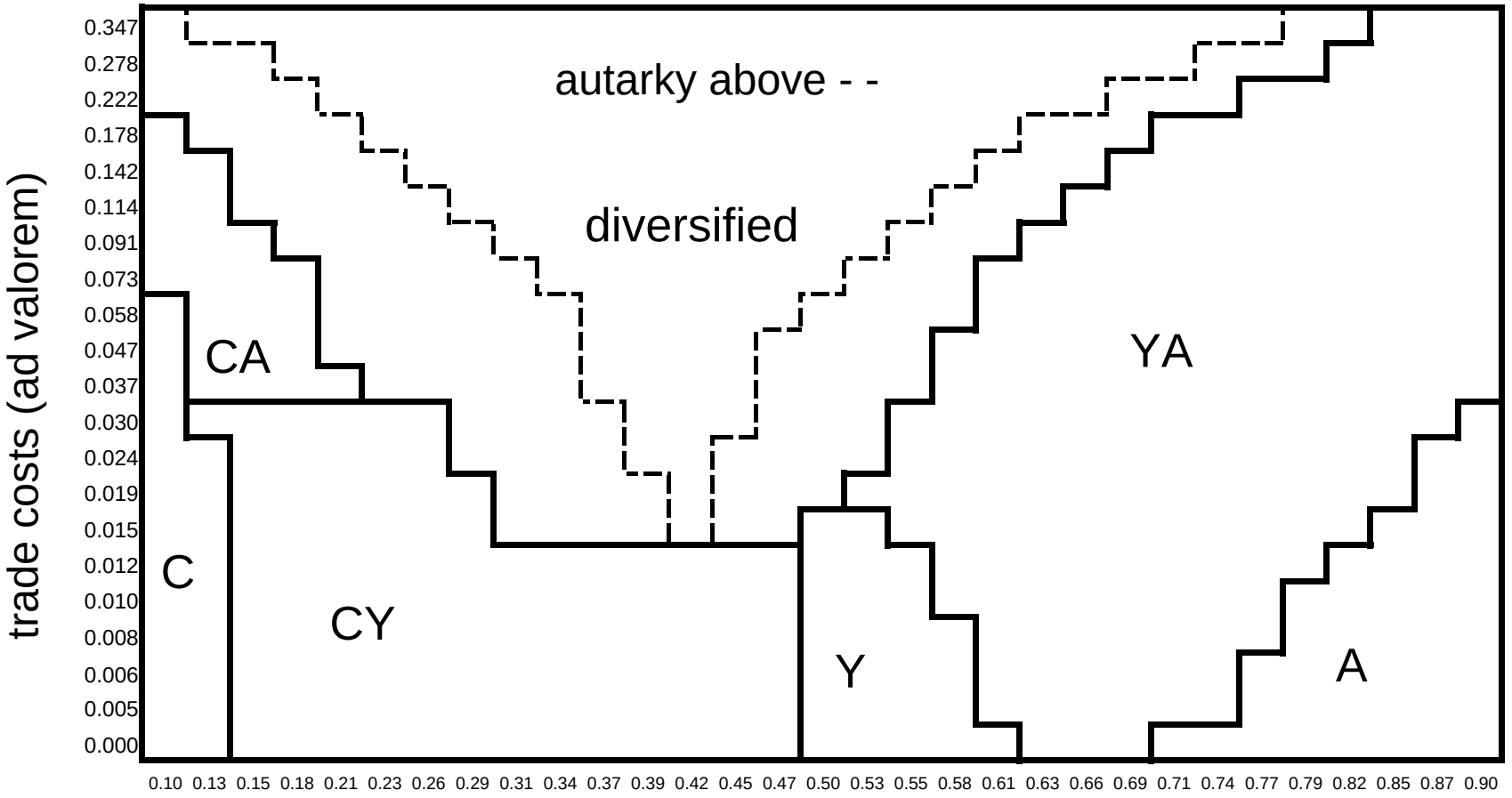


Figure 7: Production Regimes with fragmentation



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 8c: Trade in C

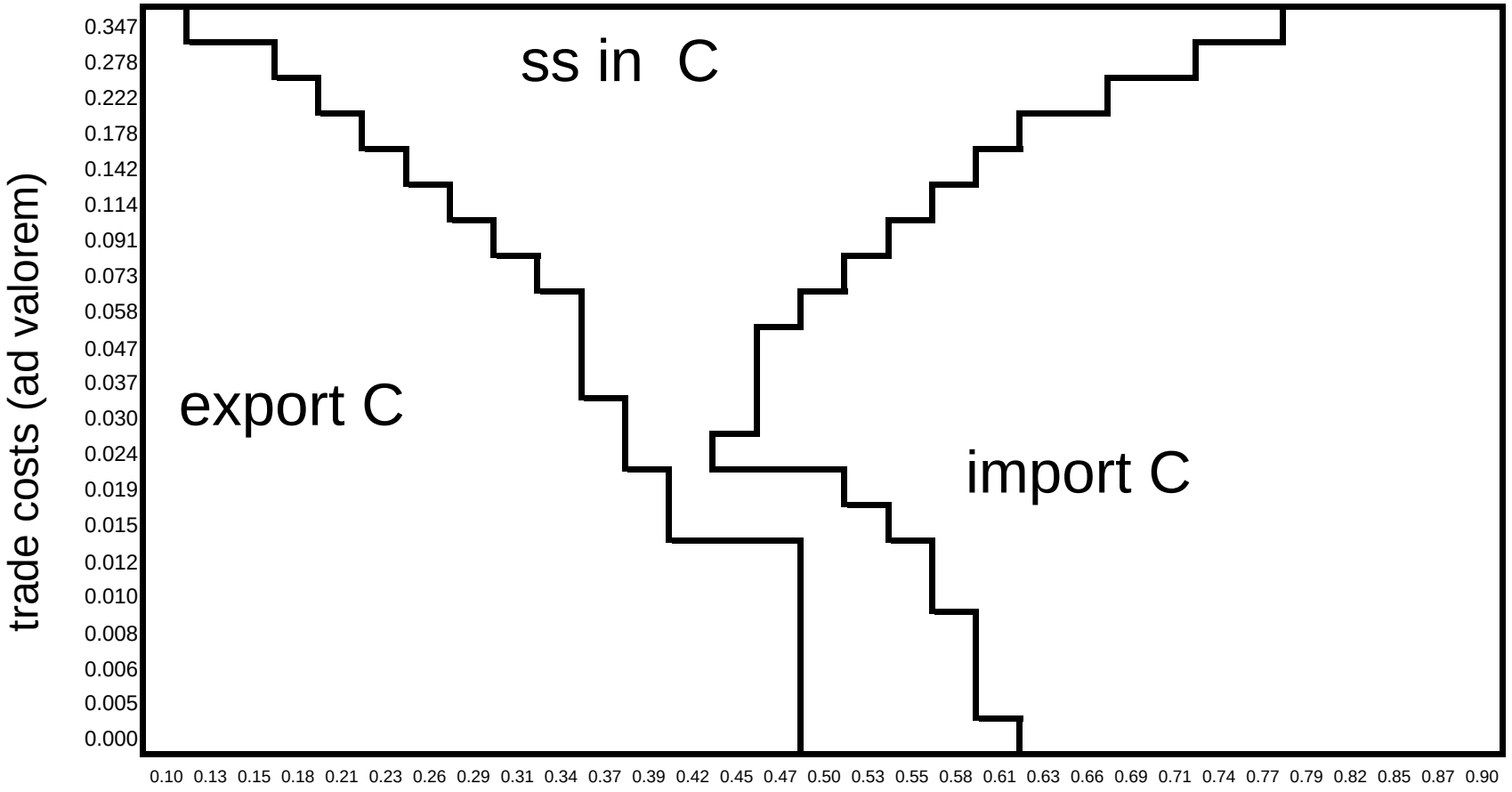


Figure 8a: Trade in A

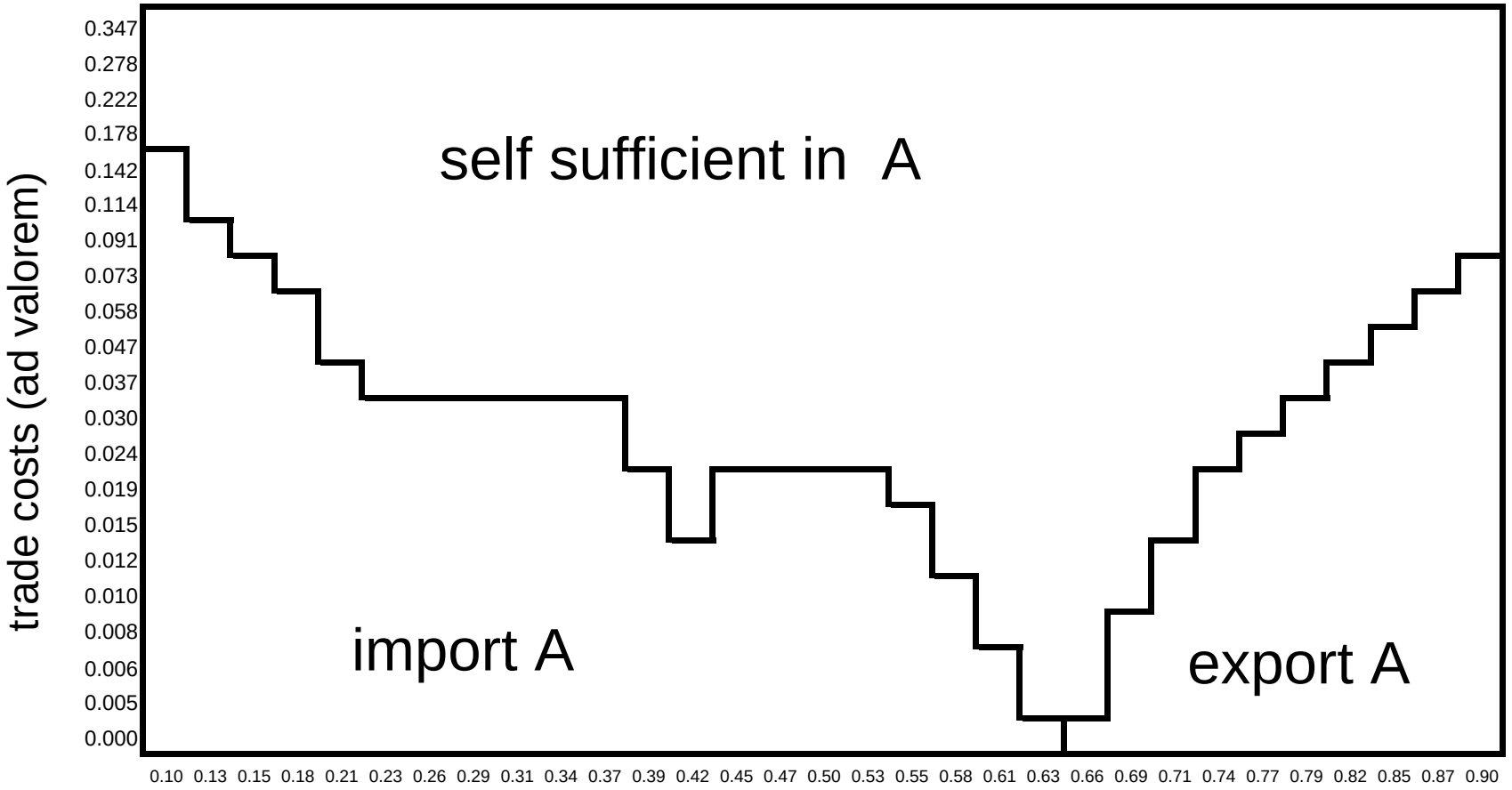
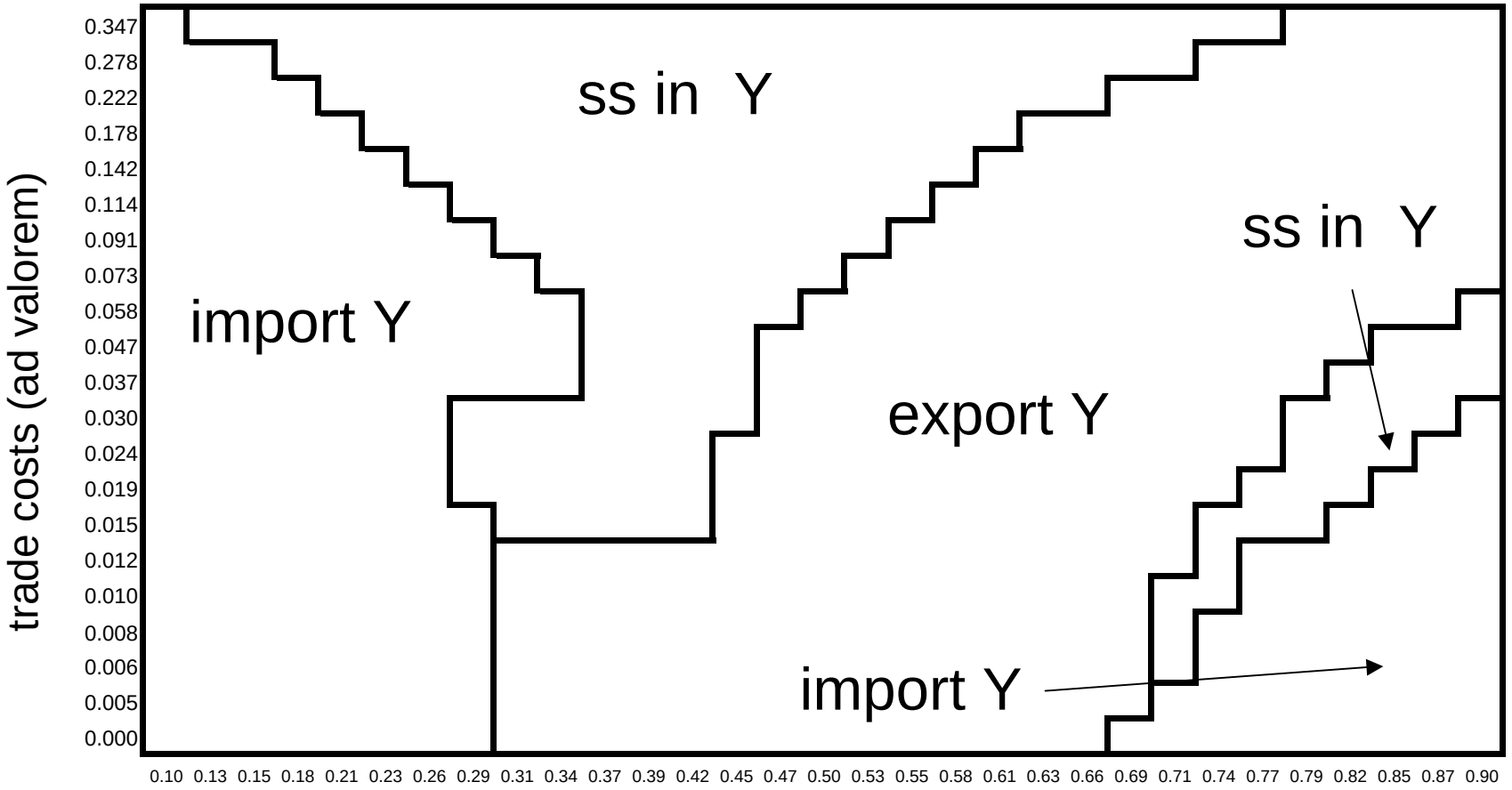
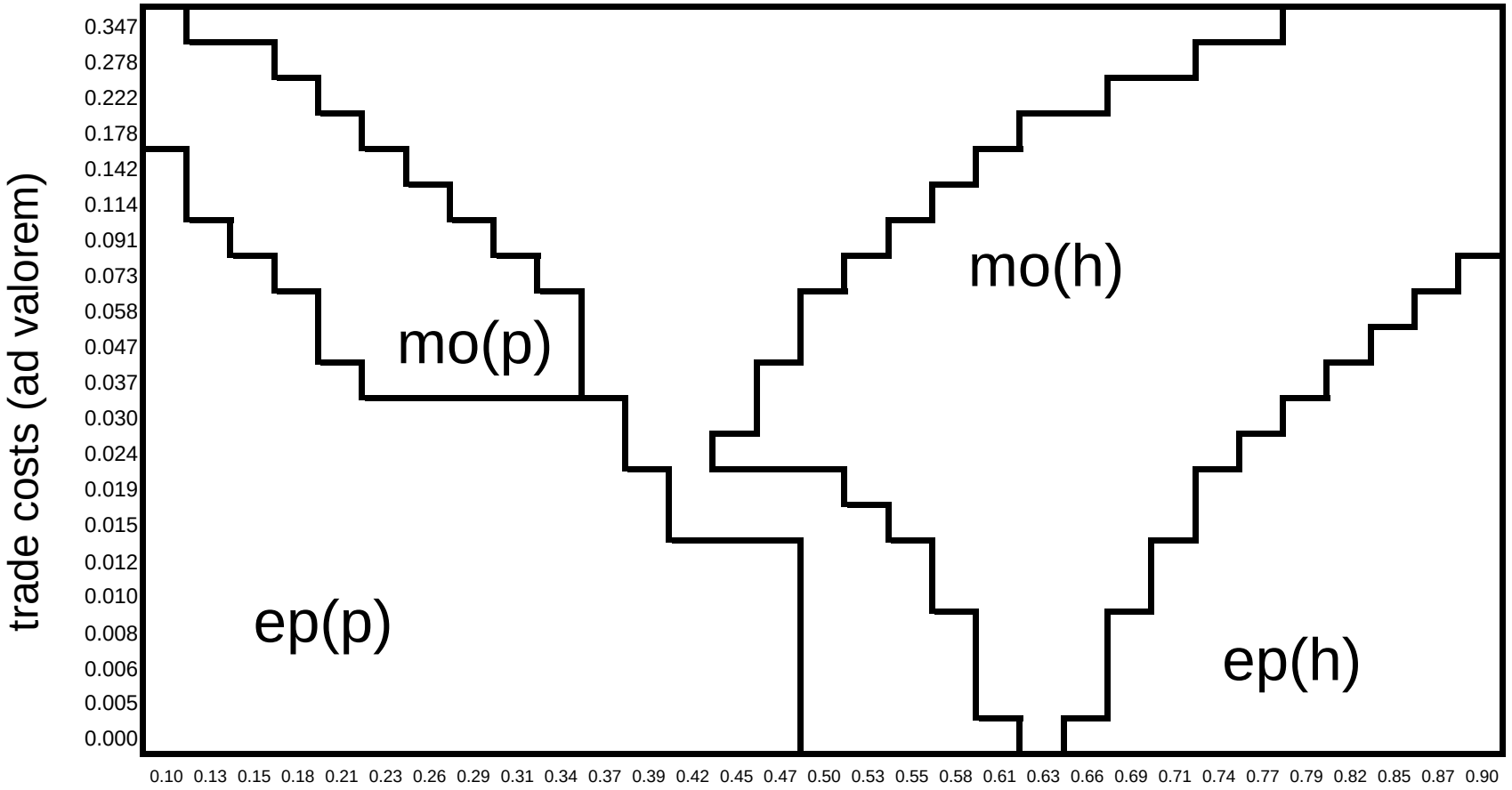


Figure 8y: Trade in Y



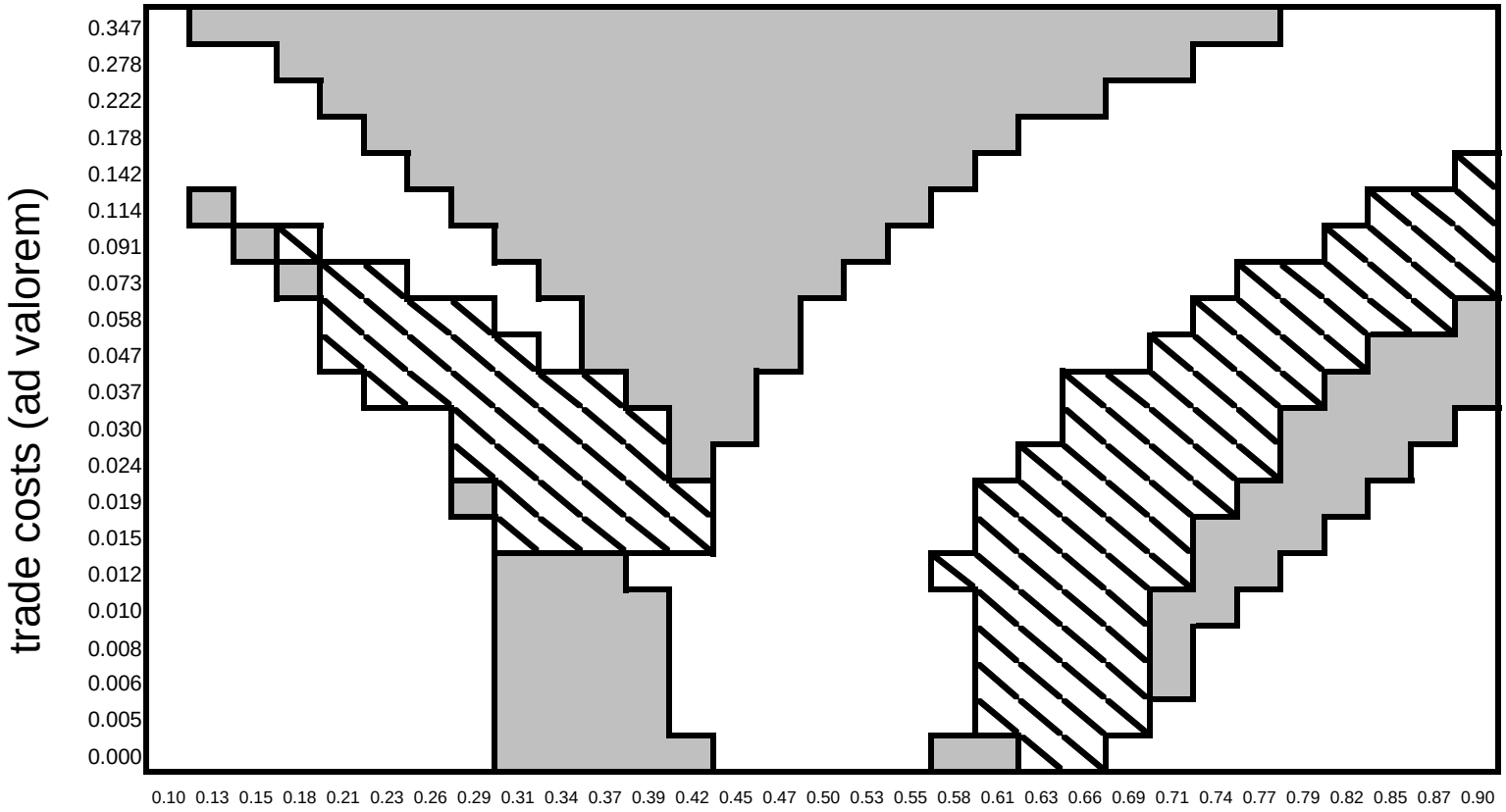
country i's endowment of labor (capital endowment = 1 - labor endowment

Figure 9: Affiliate production



ss = self sufficient mo = market oriented ep = export platform

Figure 10: Change in trade volume following fragmentation



0 country i's endowment of labor (capital endowment = 1 - labor endowment

volume of trade unchanged
volume of trade rises
volume of trade falls

average over all cells: 0.183 (change in trade as a proportion of GDP)

Figure 11: Change in welfare following fragmentation

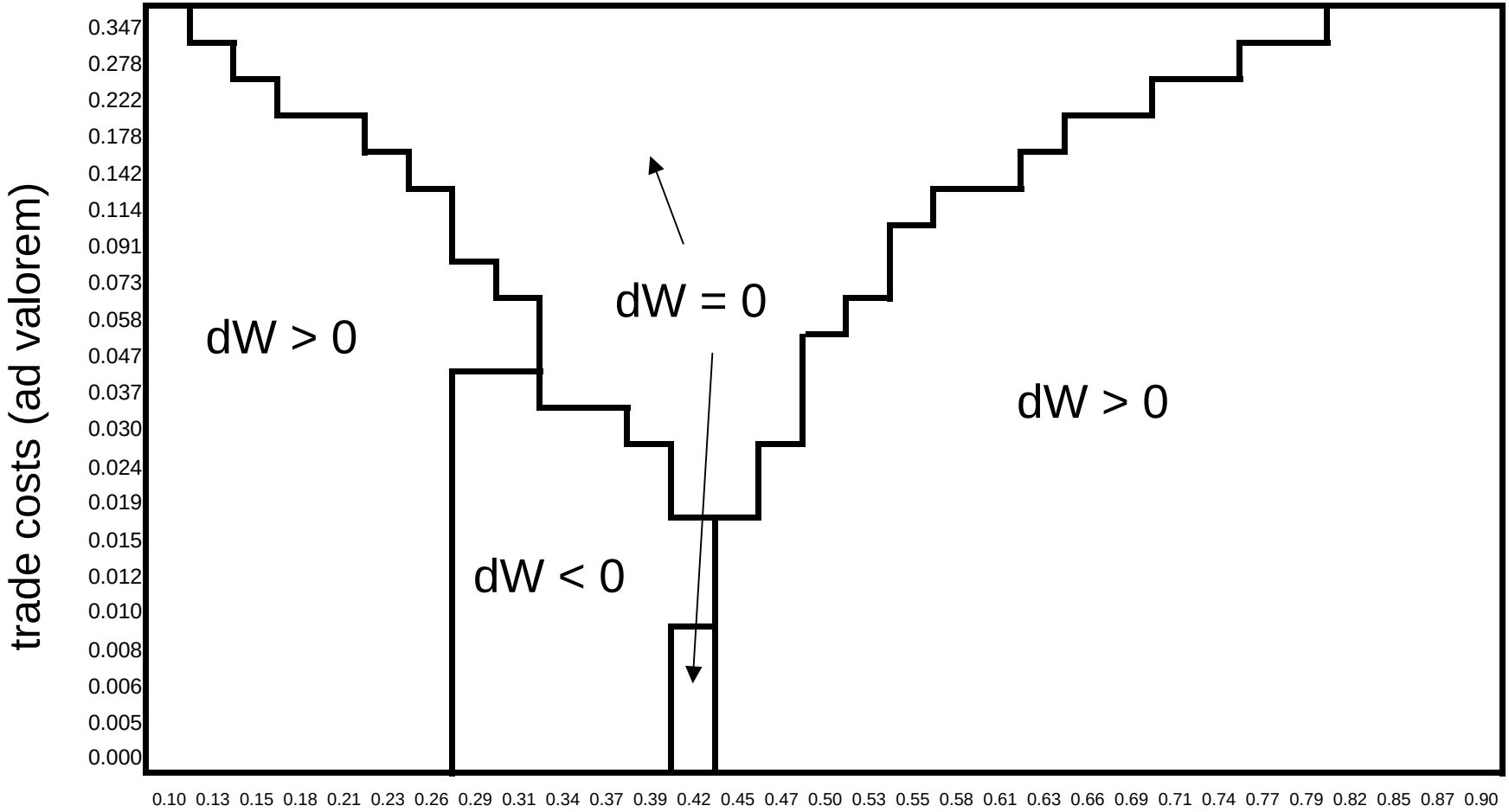
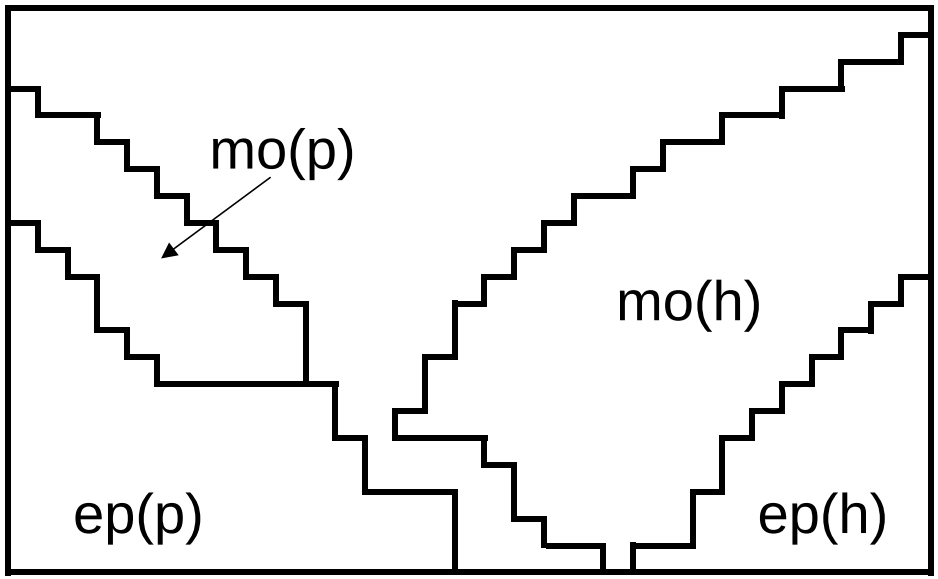


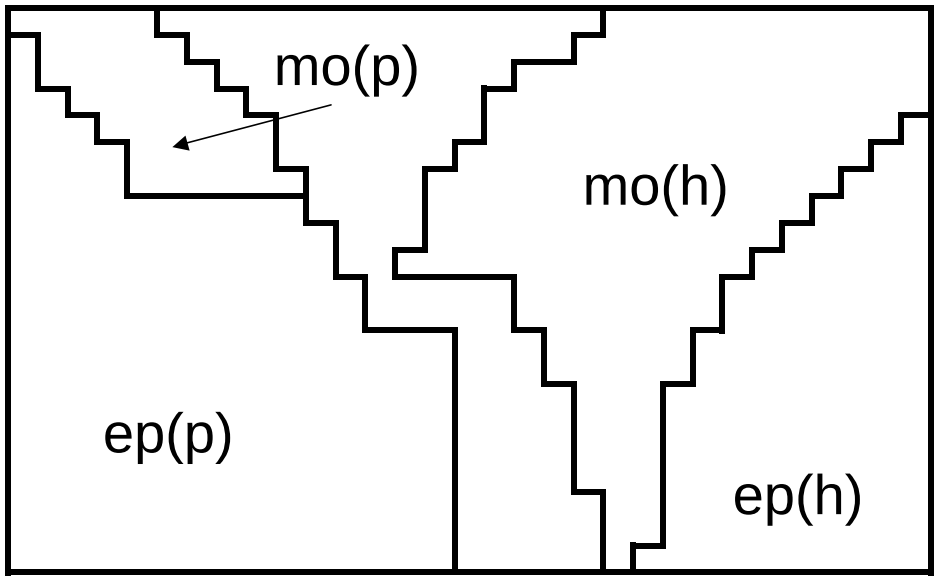
Figure 12: Affiliate production, changing trade costs

each country's trade costs double base case



country i's endowment of labor (capital endowment = 1 - labor endowment

each country's trade costs 50% of base case



country i's endowment of labor (capital endowment = 1 - labor endowment

ss = self sufficient mo = market oriented ep = export platform

Figure 13: Herfindahl Indices with and without fragmentation
(vary trade costs for all countries)

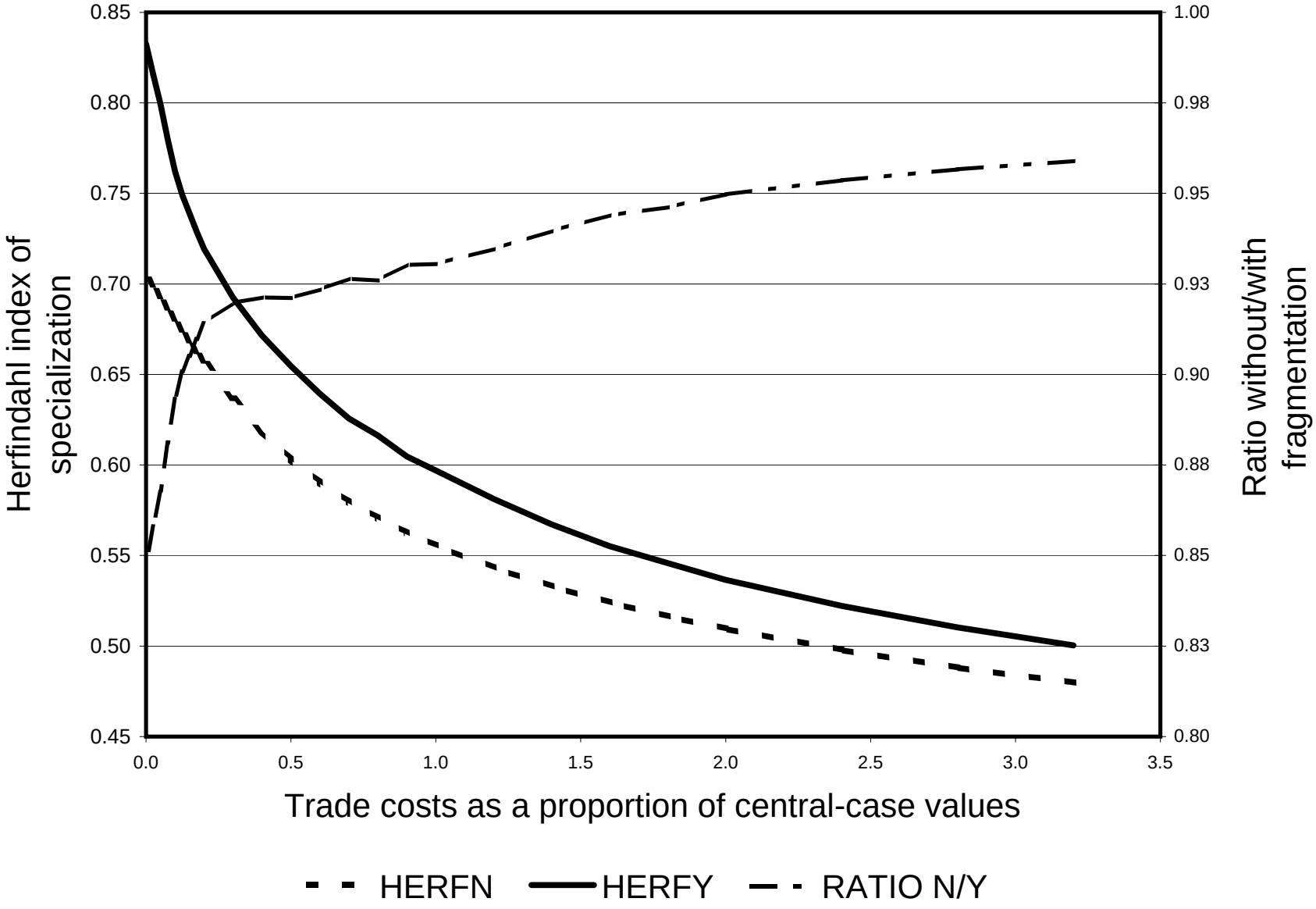


Figure 14: World VOT/GDP with and without fragmentation
(vary trade costs for all countries)

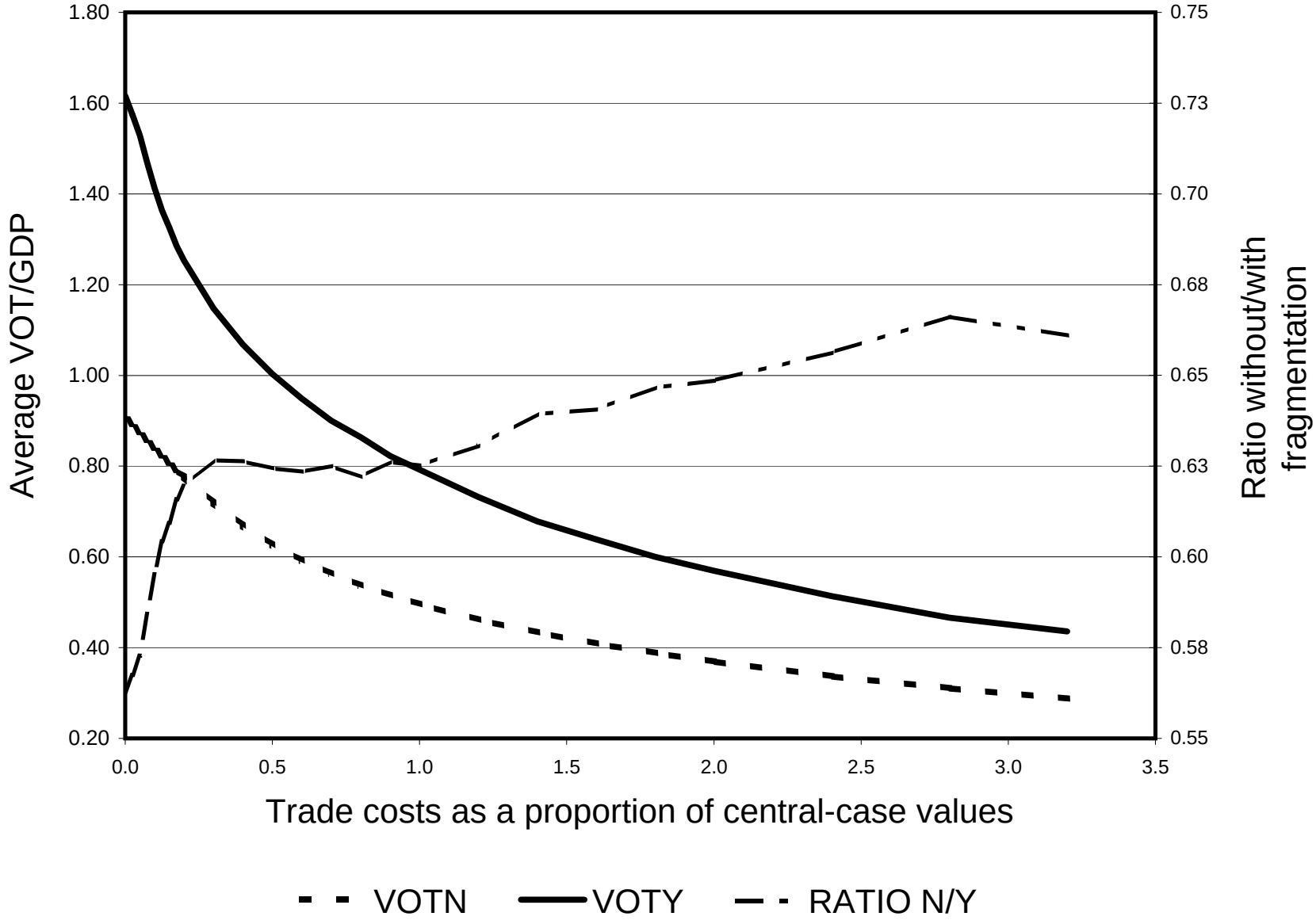


Figure 15: Herfindahl Indices for a subset of 16 countries
(vary trade costs for all countries)

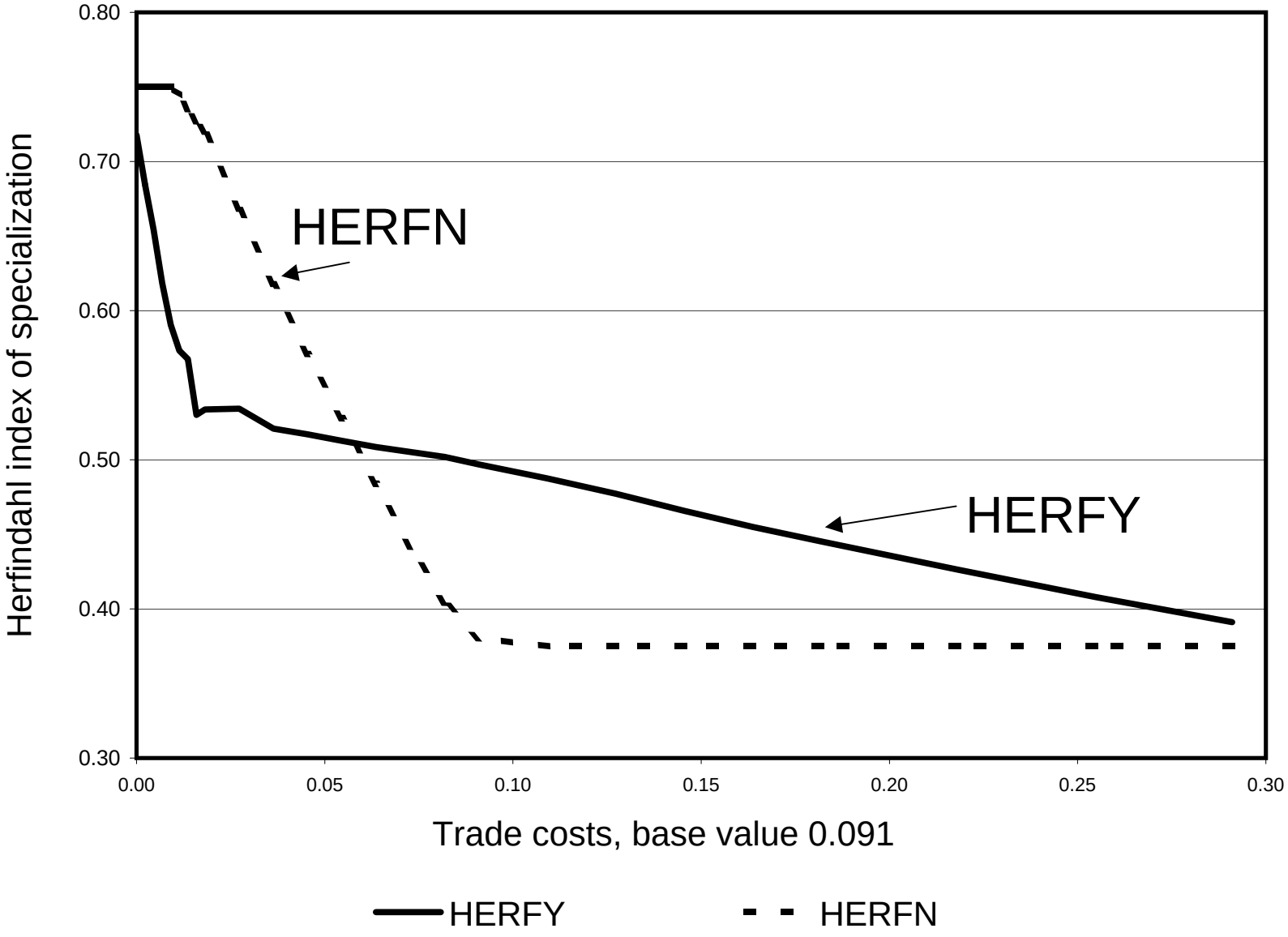


Figure 16: World VOT/GDP for a subset of 16 (vary trade costs for all countries)