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The International Organization of Multi-Stage Production

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Abstract

Although there has been much interest in the geographic fragmentation of production by stages, no generic model seems to exist that shows how the degree and pattern of fragmentation relates to country and technology characteristics and trade costs for different stages. We begin with a two-country, two-stage model where stages differ in factor intensities. We show how the equilibrium location and number of component production and assembly stages depends on relative endowments, relative country sizes, and trade costs. Interesting results include the finding that the volume of affiliate production (defined as local assembly of foreign components) is greatest when the countries are of similar size and differences in relative endowments are rather modest. The change in the volume of trade in components and the final good following liberalization (defined as the ability to fragment production) is similarly largest when the countries are similar in size and differ only modestly in relative endowments. For some specifications of the technologies, liberalization can move wage-rental ratios in the same direction in the two countries.

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1. Introduction

The geographic fragmentation of production by stages has attracted both theoretical and empirical interest over the last few years. Some of the discussion has been explicitly within the context of multinational firms reorganizing their global production plans, whether this is done through owned subsidiaries or through “outsourcing” to independent contractors. But much has also been done within the context of strictly competitive models, where we could think of fragmentation as just the question of the number of products, particularly intermediate goods, that are traded in the world economy.

Despite this interest, no generic model seems to exist that shows how the degree and pattern of fragmentation relates to country and technology characteristics and trade costs for different stages. In particular, the problem does not seem to have been addressed using analytical techniques that allow the results to be compared easily to traditional Heckscher-Ohlin models and to more recent models with endogenous multinational firms.

The purpose of this paper is to present a straight-forward model of fragmentation, and to construct that model in a way that allows it to be related to the results to the two literatures just mentioned. We use a standard two-country, two-final-good, two-factor model, except that one good (X) is produced in two stages. An intermediate good, components (C) are produced from primary factors and then C is assembled along with additional primary factors into finished X. In order to clarify the role of fragmentation, we consider worlds in which C may or may not be traded internationally. An important tool of analysis will be the world Edgeworth box, which allows us to easily see how the pattern of production, location and trade depends on differences in countries’ endowments and sizes.

Although much of the discussion of this fragmentation has been in the context of multinational firms as noted above, we will adopt a simple competitive framework in this paper. We think that this has the advantage of allowing us to relate the results to the usual Heckscher-Ohlin world without seriously compromising the model's relevance to multinational location decision and to outsourcing by these firms. Use of the competitive framework also avoids the problem of cross-hauling (whether homogeneous or differentiated) final goods in imperfect-competition models and this makes it less ambiguous to compare trade volumes with and without fragmentation. Throughout the paper, we will refer to local assembly of imported components as "affiliate production", remembering that the model does not distinguish between anonymous markets with many buyers and sellers from models with individual firms who own foreign subsidiaries or who outsource to specific foreign assemblers. The term "X-sector trade" will be shorthand for trade in both components and in assembled X.

While the model seems very simple, it is nevertheless the case that additional assumptions matter to some of the results. These include the ranking of factor intensities across the three production activities (C, A, and good Y), and elasticities of substitution in these activities. Our strategy in the here is to concentrate on one central case, and then discuss robustness of the results at the end of the paper. This central case assumes that Y has the intermediate factor intensity, where the factors are called skilled labor (or alternatively capital) and unskilled labor. C is skilled-labor intensive relative to Y and A is unskilled-labor intensive. Y is assumed to be Cobb-Douglas, while C and A have fixed coefficients. The latter assumption keeps the relationship between components and assembly clear within and across countries, but does create the possibility of factor-intensity reversals between Y and C/A. Indeed, factor-intensity reversal does occur in our

central case and some results regarding factor prices do depend on this as we will point out.

Results include the following. Affiliate production requires differences in relative factor endowments between countries, but the relationship is non-monotonic. Affiliate activity reaches a maximum when the relative endowment difference between countries is moderate. Affiliate production also conforms to a “gravity” type of relationship with differences in country size. Affiliate activity is highest when the countries are of similar size.

The effect of allowing fragmentation on the volume of trade in X-sector components and final goods conforms closely to the level of affiliate production generated by fragmentation. The change in the volume of trade is largest when the difference in country size is small and the difference in relative endowments are modest. But fragmentation can lead to a fall in X-sector trade when one country is both large and skilled-labor abundant. Prior to liberalization, this country produces all or almost all X and exports it to the smaller country. After liberalization, this country exports just components to the small country where they are assembled and (mostly) sold locally.

The proportional change in the volume of X-sector trade following liberalization is somewhat different. The largest proportional change in the volume of trade occurs when one country is small and skilled-labor abundant. Prior to liberalization, both countries produce X and there is a small volume of trade. Following liberalization, the small skilled-labor-abundant country produces all or nearly all components and the large skilled-labor-scarce country does all or nearly all assembly, generating a large trade of components for finished X.

The effect of allowing fragmentation on factor prices can be complex; for example, the w/r ratio can rise or fall in both countries. For better or for worse, this seems to be tied up with a factor-intensity-reversal property of the model, combined with prices changes that make X cheaper when

fragmentation is allowed.

In order to relate the results to recent empirical work on multinational firms and in particular to the question of whether most multinational activity is horizontal or vertical (the latter being the case here), we use the simulation results as an artificial data set and estimate regression equations similar to those found in the literature. Results here are analogous to results in the literature which appear to give weak support to vertical theories in spite of the fact that affiliate activity is exclusively vertical in the present model.

A final section considers the role of trade costs for components versus finished goods. When countries have a moderate difference relative endowments, we show that reductions in the costs of trading components and trading the final X good are “complements”, both with respect to generating affiliate production but also with respect to the volume of trade in components and the final good. When endowment difference are large, falling costs of component trade may raise affiliate production but lower the volume of X-sector trade.

2. Cost minimising locations

Our two countries will be denote country 1 and country 2. The two factors are unskilled (L) and skilled (S) labor. Factors are in inelastic supply, mobile within countries but immobile between countries, the usual Heckscher-Ohlin assumptions. The two final goods are Y and X. Y is produced in a single stage from S and L. X is produced in two stages. An intermediate good, components (C), is produced from primary factors, and final X is produced by components and an assembly activity (A) which uses S and L (i.e., we could term A “value added” in X production). The technology for Y is Cobb-Douglas, and the technologies for C and A are fixed coefficient. The technology for each of the three activities is identical across countries. The technologies can then be written as:

$$Y = \beta L_y^\alpha S_y^{1-\alpha} \quad \beta = \frac{(1-\alpha)^{1-\alpha}}{\alpha^\alpha} \quad (1)$$

$$C = \min \left[\frac{L_c}{a_{lc}}, \frac{S_c}{a_{sc}} \right] \quad a_{lc} + a_{sc} = 1$$

$$A = \min \left[\frac{L_a}{a_{la}}, \frac{S_a}{a_{sa}} \right] \quad a_{la} + a_{sa} = 1$$

$$X = \min \left[\frac{C}{2}, \frac{A}{2} \right]$$

Factor intensities matter to the results as does the possibility of factor-intensity reversal as

indicated above. In the numerical simulation model used throughout the paper, we benchmark or calibrate the model where the two countries are identical, and units are chosen such that all prices are unity. At this initial equilibrium, we assume that Y has the central factor intensity, and that components are skilled-labor intensive. Finally, overall factor use in producing finished X is assumed skilled-labor intensive relative to Y. These assumptions imply that:

$$\frac{S_c}{L_c} = \frac{a_{lc}}{a_{sc}} > \frac{S_x}{L_x} = \frac{a_{lc} + a_{sc}}{a_{sc} + a_{lc}} > \frac{1 - \alpha}{\alpha} > \frac{a_{la}}{a_{sa}} = \frac{S_a}{L_a} \quad (2)$$

To add some concreteness, the numerical values used in simulation below are:

$$\frac{S_c}{L_c} = \frac{35}{15} > \frac{S_x}{L_x} = \frac{55}{45} > \frac{1 - \alpha}{\alpha} = \frac{45}{55} > \frac{S_a}{L_a} = \frac{20}{30} \quad (3)$$

Consumers have Cobb-Douglas preferences with equal weights (0.50) on X and Y. Thus if each country has 100 units of each factor (i.e., we are at the center of the world Edgeworth box where the world has 200 units of each factor), then (1) - (3) imply unitary factor prices in equilibrium, with 45 units of S and 55 units of L produce 100 units of Y, and the opposite for X in each country (55 of S and 45 of L produce 100 units of X via C and A). All prices are equal to one in that calibration.

Let w and r be the prices for unskilled and skilled labor respectively. When components are assembled in the same country in which they are produced, the cost functions corresponding to (1) are given as follow:

$$c_x(w, r) = w^\alpha r^{1-\alpha} \quad (4)$$

$$c_c(w, r) = a_{lc}w + a_{sc}r \quad (5)$$

$$c_a(w, r) = a_{la}w + a_{sa}r \quad (6)$$

$$c_x = c_c/2 + c_a/2 \quad (7)$$

In this section of the paper, we will assume that X and Y are costlessly traded. Assume that there is a small cost to fragmenting production, by which we mean that X production uses components produced in the other country. Assume that there is a small ad valorem coordination cost to fragmenting production ϵ (0.01 is used in the simulation model to follow). This acts as a “tie-breaker”, and prevents there from being infinitely many equilibria (model degeneracy) when countries are similar. The cost of producing X in country i is then given by:

$$c_{xi} = (1 + \iota)c_{cj}/2 + c_{ai}/2 \quad \iota = \epsilon \text{ if } i \neq j, \quad 0 \text{ otherwise} \quad (8)$$

Assume for the moment that components are not traded, and consider the integrated world equilibrium in which X and Y are traded and factor prices are equalized across countries. Hopefully, this concept is well understood by (almost) all readers. It restricts the differences in relative endowments across countries to no be “too large”. That is, countries must be “moderately” similar in relative factor endowments.

Now suppose that we endowments sufficiently dissimilar such that we move outside of the factor-price-equalization set, defined for integrated production only (local assembly is from local components only). Then, under the maintained assumption that each country assembles X from local components, relative factor prices are not the same across countries. At this *proposed* outcome, we can now ask whether or not fragmentation is profitable.

The answer is a qualified yes as the fragmentation cost goes to zero. The qualification is

that one country may do both all the component production and assembly. What must be true is that both countries will not both produce components and do assembly. The reasoning is a simple spanning argument. Let p_c and p_x denote the prices for components and for final X respectively, and these are equalized across countries. Let p_a denote the “price” of assembly value added, which must also be equalized across countries if p_c and p_x are equalized. Subscript i denotes countries 1 and 2.

In competitive equilibrium, price must be less than or equal to marginal cost. For each country there will be two inequalities in two unknowns in the proposed equilibrium, where complementary variables are component production and assembly value added respectively.

$$p_c \leq a_{ic}w_i + a_{sc}r_i \quad (C_i) \quad i = 1, 2 \quad (5)$$

$$p_a \leq a_{ia}w_i + a_{sa}r_i \quad (A_i) \quad i = 1, 2 \quad (6)$$

All four of these inequalities cannot hold as equalities when factor prices are not equalized across countries. It is possible that three of the four can hold, but not all four (assuming of course different factor intensities in the two activities). Thus outside of the original factor-price-equalization set (defined for integrated production only), at least one country conduct only assembly or component production or, the last possibility, specialized in Y only. Fragmentation may, of course, increase the size of the original factor-price-equalization set, but all points out side of the original (integrated production) set must involve some specialization within the X sector.

3. General-Equilibrium Simulations 1: Relative Endowments and Country Sizes

It is difficult to push the analysis very much further analytically. Once outside the initial factor-price-equalization set (again defined for integrated X production in each country) it is easy to say what is not an equilibrium production regime, but it is much more difficult to say what the equilibrium regime actually is. One difficulty, which will be apparent shortly, is that country sizes matter as well as differences in factor endowments.

Thus we now turn to general-equilibrium simulations of the model, using the factor-intensity values from (3) and the substitution elasticities in (1). The tool for expositing the results is the world Edgeworth box, where we show the equilibrium production regime for various combinations of differences in country sizes and differences in relative endowments. Good Y and (finished) X are freely traded, but we impose a 1% “fragmentation cost” for trading C as given in equation (5). This prevents model degeneracy, a situation of infinitely many equilibria, by creating a sort of “tie-break rule” in which assembly from locally produced components is slightly cheaper than assembly from imported components. Preferences are Cobb-Douglas with equal weights on the two goods, so half of all world income is always spend on each good.

Figure 1 shows the equilibrium regimes over the Edgeworth box, with country 1 measured from the southwest corner and country 2 from the northeast corner. The model is repeatedly solved by changing endowments in 5% steps, so there are $19 \times 19 = 361$ solutions shown (zero endowments of a factor are not considered since both factors are needed for positive output of any activity). The top panel of Figure 1 divides the Edgeworth box into areas of partial/complete specialization. In area D, both countries do both component production and assembly, so D is what would be the factor-price equalization set under an assumption that components could not be traded. Given the

small but positive fragmentation cost assumed here for reasons noted, D continues to be the factor-price equalization set with components traded, but point outside of but near the boundary of D are quite “close” to FPE. The bottom panel of Figure 1 gives the detail accounting of exactly what X-sector activities are conducted in each country, distinguishing between assembly from locally produced components and assembly from imported components.

Both panels of Figure 1 illustrate that country size has a role in addition to the role played by factor endowment differences.¹ The areas A1 and A2 are regions of complete specialization within the X sector, and these are regions in which the difference in market sizes is relatively small. In area B1, country 1 is small and so country 1, the skilled-labor-abundant country does component production but no assembly while the large country 2 does both. In area C1, country 1 is large and so country 1 does both while country 2 only assembles or produces only Y at a couple of points.

As suggested earlier, let us define *affiliate production* to be local assembly of imported components, as if the assembly plant were owned by a foreign firm which exports components to the assembly plant. We emphasize that this is simply a convenient definition, and that ownership has no particularly meaning in a competitive model. Figure 2 shows the volume of affiliate production at constant prices given by the equilibrium prices at the center of the Edgeworth box. The central valley of Figure 2 has zero affiliate production, which is eliminated by the small fragmentation cost discussed above. This is the factor-price-equalization set.

What is surprising about this diagram, at least to the authors, is that affiliate production is

¹The model is calibrated such that relative factor prices equal 1 in the center of the box, but the equal relative income (country size) locus in these figures is not exactly equal to the NW-SE diagonal of the box due to differences in the elasticities of substitution between goods (it is slightly steeper). However, for general discussion the equal-income locus is very close to this diagonal, so when “eyeballing” the results, treat the NW-SE diagonal as a locus along which the two countries have the same relative income.

far from monotonically increasing in relative endowment differences. Even when country sizes are relatively similar (roughly the NW-SE diagonal as noted in the preceding footnote), affiliate production rises sharply from the central valley but reaches a maximum point at a relatively modest difference in relative endowments.

This fall-off in affiliate production as relative endowment differences increase, country sizes equal (NW-SE diagonal), is explained by the inefficiency introduced by the increasing unequal endowments, which we could also think of as the loss in world income from not being able to trade factors directly. Figure 3 makes this point by graphing affiliate production as a share of all X assembly. Note the high plateaus, which are the areas A1 and A2 in the top panel of Figure 1. In these regions, affiliate production is 100% of all assembly activity; i.e., all assembly uses imported components. It is the fall-off in total X production rather than something about affiliate activity per se that explains the shape of Figure 2 along the NW-SE diagonal. In the NW and SE corners, world real income is only about 30% of real income at the center of the box.

Figures 2 and 3 are similar with respect to differences in country size, however. Affiliate production falls off as countries differ in size, which we could roughly define as movements along a line parallel to the SW-NE diagonal. The intuition seems clear if we consider that affiliate production is the highest when all world X assembly is from imported components. Since there will never be cross hauling in this competitive model, this in turn occurs when all component production is in one country and all assembly is the other. But for this to be an equilibrium, the countries must be relatively similar in size. If one country is quite small, it cannot either produce all the components or do all the assembly to meet total world demand. The larger country will therefore be diversified, doing at least some assembly from locally produced components. Note that

this is precisely what we have in regions B and C of Figure 1. Thus affiliate production will decrease in absolute amounts as countries become dissimilar in size (Figure 2) and also decrease as a share of all final X production (Figure 3).

A related question which has been of interest to both theorists and empiricists is the relationship between affiliate production and trade volumes. In particular, is affiliate production a substitute or complement to trade in C and X? Figure 4 considers an experiment in which trade in components is initially banned, meaning there is no affiliate production as defined in this paper, and then the implicitly prohibitive cost of trading components is reduced to 1%. Figure 4 shows the change in the volume of trade in components and assembled X following this “liberalization”. These are real values at the calibrated prices at the center of the box, where one component has half the value of one unit of X.

Figure 4 has a similar shape to Figure 2, and shows that affiliate production and trade in C and X are generally complements. There are a few areas where the effect of liberalization on the volume of trade is negative, and we will return to these shortly. The general results of Figure 4 suggest that the effect of liberalization is most positive when countries are similar in size, and differences in relative endowments are moderate.

In order to see if the fall-off at large endowment differences is due to the production inefficiencies cause by large differences, we can look at the proportional differences as we did in Figure 2. The resulting 3D diagram is rather hard to interpret, so we have given a more qualitative interpretation in Figure 5. In order to avoid some wild numbers due to small or even zero denominators, the figures shown divide the change in the trade volume with minus without trade in components allowed, over the sum of these two number. If VOTY denotes volume of trade in X

and C with component trade allowed, and $VOTN$ denotes the volume of trade in X when component trade is not allowed, the statistic calculated is $(VOTY - VOTN)/(VOTY + VOTN)$. This statistic has the convenient property of being bound between 1 and -1.

Figure 5 indicates the areas of proportionately largest increase in trade volumes correspond roughly, but not exactly, to the areas A1 and A2 of complete specialization in C and A shown in Figure 1. There are indeed a couple of points in Figure 5 where the value of the statistic is close to one. With trade in C banned, the skilled-labor abundant country could be specialized in X, and export half of its output (half of world output) to the other country (countries are of equal size). When fragmentation is allowed, the former country could be specialized in C (and produce Y as well), exporting all of world C output to the other country which exports half of world X output back in the other direction. This double trade in components and final X, since a unit of C is world half a unit of X at initial prices.

There are also points in Figure 5 where the volume of trade in C plus X falls following liberalization of C trade. Consider the shaded points at the top of the box in Figure 5. With no C trade, these are points in which country 1 specialized in X, and a significant share of X is exported to country 2. When C trade is permitted, C is exported from country 1 to country 2, where it is assembled into finished X. In other words, allowing fragmentation switches country 2 from importing finished X to importing components for local assembly. Since the component are worth less than finished X, the value of X-sector trade falls following liberalization. Thus it is important to note that allowing fragmentation does not always lead to an increased volume of trade.

Now let us turn to the effects of allowing fragmentation on factor prices. Figure 6 shows the effects of allowing fragmentation on the w/r ratio in both countries. The striking thing about these

results is that this relative price can move in the same direction in both countries. In order to explain these results, we will consider a specific point, when country 1 has 75% of the world endowment of skilled labor and 25% of the world endowment of unskilled labor. When fragmentation is not allowed both countries produce X from local components and both produce good Y . In country 1, the relative endowment ratio is sufficiently skewed that there is a factor-intensity reversal in equilibrium, such that good Y is skilled-labor intensive in production (components use a S/L ratio of $35/15$, which is lower than the endowment ratio of $75/25$).

The equilibrium regime when fragmentation is allowed is that all components are produced in country 1 and all assembly is done in country 2, and both countries produce Y . The general-equilibrium effects of this liberalization are that the prices of components, value-added in assembly, and final X all fall relative to the price of Y (used as numeraire). For country 1 with the factor-intensity reversal, it is the unskilled-labor-intensive good C that is falling in price, so w/r falls in equilibrium. In country 2, it is also the unskilled-labor-intensive good, in this case assembly, that is falling in price so w/r falls in country 2 as well.

While it is not entirely satisfying to have results which depend on factor-intensity reversals, we have used the assumption of fixed coefficients in the X -sector activities in order to ensure a clear comparison across countries as to the factor intensities of C , versus A , versus integrated X production. With fixed coefficients, these comparisons do not depend on equilibrium factor prices. Many runs of this model under alternative assumptions demonstrate that results in which the w/r ratio rises in both countries are not robust when all activities have the same elasticity of substitution so that there are no factor-intensity reversals. Nevertheless, our fixed-coefficient version has some conceptual advantages as just noted, and the results on factor prices are interesting even if not

robust. Most of the other results in this central case do not depend upon the fixed-coefficient assumption.

4. Empirical Implications of the Model

There has been a good deal of interest lately in the determinants of affiliate production and sales, and in the relationship between these and trade flows. Much of the discussion has been framed by the question of whether multinational activity is primarily horizontal or vertical. In horizontal production, firms basically produce the same goods and/or services in multiple locations to serve local markets. Horizontal production generally arises from firm-level and opposed to plant-level scale economies, and is encouraged by various sources of trade costs. Theoretical models predict that horizontal production arises between countries that are similar in both size and in relative endowments.

Vertical production, on the other hand, refers to fragmenting the production chain into stages, locating stages of production where the factors of production they use intensively are relatively cheap. Theoretical models make the rather obvious prediction that vertical affiliate activity should arise between countries that differ in relative endowments. The present model is clearly in the vertical tradition as noted earlier.

To date, the bulk of the empirical evidence strongly favors the horizontal model. Affiliate activity is concentrated among large, relatively similar high-income countries, and there is a high degree of cross penetration of firms from these countries into each other's markets. Much of the analysis relies on indirect evidence and estimation, because existing data do not allow us to know exactly what intermediate and final products are produced by affiliates. We know how much is sold locally by affiliates versus exported to the parent or third countries, but we do not know the exact nature of products produced and traded.

Given the fall-off in affiliate production when countries differ in size and differ significantly

in relative endowments as noted in the previous section, it might be interesting to see how the predictions from the present model compare to earlier work on the vertical versus horizontal model of direct investment. In this section, we treat our theoretical results as an artificial data set, and apply regressions to these data which are similar to those found in the literature.

Most regressions use one-way observations in affiliate production so as to increase the degrees of freedom over using two-way totals as we did in Figures 1-3. Figure 7 shows the same experiment as Figure 1, except we only use assembly in country 2 of components produced in country 1. These values (in quantities, or constant prices) form the dependent variable in the regression, and positive numbers for the dependent variable are confined to the region where country 1 is skilled-labor abundant.

Right-hand side variables are as follows:

SGPD is the sum of the two countries real incomes (measured in utility units). This variable should have a positive coefficient.

GDPDIFFSQ is the squared difference in the two countries GDP. We expect this to be negative, the fall-off in affiliate production noted in Figures 1 and 7 when countries differ in size.

SKDIFF is the difference in the share of all labor that is skilled in country 1 minus the share of all labor in country 2 that is skilled, if this difference is positive. SKDIFF is zero country 1 is skilled-labor scarce, since that is what is suggested by Figure 7. This variable is used in a number of papers by Markusen and by other authors. Horizontal models suggest that this should be negative while a vertical model suggests that it should be positive.

SKDIFFSQ is the squared difference in the skilled-labor shares (when the difference is positive) in the two countries. It allows for the influence of the endowment difference SKDIFF to

have a concave or convex effect. It is apparent from Figure 7 that this variable should have a negative sign in our regression, but that is not necessarily suggested by other approaches to vertical models, which tend to assume that affiliate activity is monotonically increasing in endowment differences.

$GDPDIFF*SKDIFF$ is an interactive term between size and endowment differences (again, when $SKDIFF > 0$, and 0 otherwise). While there is a lot of non-linearity and non-monotonicity in Figure 7, eye-balling the figure suggests that affiliate production will be higher when country 1 is skilled-labor abundant and small versus skilled-labor abundant and large. In the former case, country 1 concentrates on component production with assembly in country 2 (which is then affiliate production) while in the latter case, country 1 does most of the assembly as well as component production (which is then not defined as affiliate production). Figure 7 thus suggests a negative sign for this coefficient. Existing theory either does not address this interaction effect, or it is hypothesized to be negative in the “knowledge-capital model”.

Results for the regression on the artificial data are shown in Table 1. All of the variables have the anticipated signs, and are highly significant. We expect this of course, the results per se are not the point. The point is what light they can shed on existing empirical work, particularly that on horizontal versus vertical models. The most interesting results in relation to this debate are on the effects of skill difference. The partial derivate of country 1's affiliate production in country 2 with respect to skill difference is given by:

$$\frac{\partial AFFIL12}{\partial SKDIFF} = 5.745 - 6.999*2*SKDIFF - 0.906*GDPDIFF \quad (11)$$

Clearly, this derivative is positive when the countries are identical, which supports the vertical model. But what about when they differ? One approach is to evaluate this derivative at the mean of In the data, the mean of GDPDIFF is of course zero. The mean of SKDIFF in the artificial data is 0.178 and the standard deviation is 0.239. What this implies is that (11) is positive at the mean values of SKDIFF and GDPDIFF, but negative at one standard deviation above the mean of SKDIFF (and mean GDPDIFF).

$$\frac{\partial \text{AFFIL12}}{\partial \text{SKDIFF}} > 0 \quad \text{at mean SKDIFF} \quad < 0 \quad \text{at } + 1 \text{ standard deviation} \quad (12)$$

This implies that if the parent country is quite skilled-labor abundant relative to various host countries, we may observe that the parent's outward affiliate activity is skilled-labor seeking, apparently in contradiction to the vertical theory. This is indeed the finding in Markusen and Maskus (2001) and Carr, Markusen and Maskus (2002) for US outward investment. Furthermore, the switching point in the sign of the derivative occurs as a smaller value of SKDIFF the larger is the parent country (the larger is GDPDIFF). This will reinforce the probability that an econometric analysis will conclude that US outward investment is skilled-labor seeking, even if the current theoretical model were close to the "true" economy.

5. Trade costs for components and assembled X

We now turn to a consideration of how cost for trading components and assembled X affects affiliate production and trade. We do this by considering a specific example, one in which we assume that country 1 has an endowment of 75% of the world supply of skilled labor, and 25% of the world supply of unskilled labor. Income levels of the countries are approximately equal. Figure 8 shows the results, where we simulate the model over a matrix of values for component and assembled good trade costs. Free trade is at the lower left (southwest) corner (recall that we used a value of 1.01 for trade costs in X above to prevent indeterminacy when the countries are quite similar).

Figure 8 is divided into four regimes. In regime A, there is complete specialization within the X sector, with country1 producing all the components and country 2 doing all of the assembly. Increases in the cost of trading assembled goods moves us to region B: these trade costs “protect” assembly in country 1 and so country 1 produces all components and does some local assembly. But note that we can also move into region B starting from the SW corner by increasing trade costs for components. In region A, the countries are trading components for finished goods, so in some loose sense over some range, raising the cost of either component trade or final X trade is going to have a similar effect.

This equivalence is far from complete in general equilibrium, however, since sector Y also produces a traded good. Starting at free trade in the SW corner of Figure 8, increasing the trade cost for assembled X will eventually cut out any trade in X, but country 1 will continue to export components in exchange for Y and country 2 will do not assembly no matter how high the cost of trading X. If we increase trade costs for components beginning in the SW corner, eventually

country 2 will also begin producing components for local assembly, region D.

Region C of Figure 8 is a regime that only occurs when the costs of trading both C and X are significant. This is a region where country 1 produces components, some for local assembly and some for export. But country 2 also produces some components, and assembles from both imported and locally produced components. Autarky for the countries occurs in the NE corner of Figure 8.

Figure 9 plots affiliate production as a function of trade costs. This diagram has to be reoriented for clarity, such that the near corner of Figure 9 is autarky, and corresponds to the NE corner of Figure 8. The principal point of Figure 9 is that the costs of trading finished X and components are in some sense complements, with the highest volume of affiliate production occurring when both costs are low. High costs of trading components ensure that there is no affiliate production, no matter how low the cost of trading assembled X. On the other hand, some affiliate production can arise when trade cost for assembled X are prohibitively high but trade costs for components are moderate. Components are exported from country 1 to country 2 where they are assembled for local sale only. This pattern resembles what we often think of as horizontal production, thereby pointing to some ambiguity in this term. Distinguishing affiliate activity on the basis of whether or not the output is exported back to the home country does not match perfectly with usual definitions of horizontal and vertical production.

Figure 10 plots total X-sector trade, components and finished goods, as a function of the two trade costs. Again, the two types of costs are complements, in the sense that the highest level of trade occurs when both costs are low.

As we noted earlier, empirical studies generally do not have the data to distinguish exactly what types of intermediate and final goods are produced and traded by affiliates of multinational

firms. Data in regressions do often have trade costs (aggregate for all goods) into the host country and back into the home country. In our present special case, country 1 exports components and imports finished X. Thus in this special case, the trade cost for components is essentially a trade cost from parent into host, and the trade cost for assembled X is a trade cost for shipping from the host to the parent. In our special case, both trade costs into the host and back to the parent discourage affiliate production and they interact to reinforce one another. Empirical support for this is at best mixed, with the Markusen-Maskus papers in particular clearly indicating that trade costs into the host country encourage affiliate production (trade costs into the parent country are generally insignificant). The difference in these results from the present paper is surely due to the importance of horizontal investments in the real data, which are excluded by definition from the present analysis.

6. Summary and Conclusions

This paper has explored the issue of the fragmentation of production in a general-equilibrium trade model. The model is “generic” in the sense that it nests within the traditional Heckscher-Ohlin model of trade, and also relates closely to many of the models used in the recent literature on multinational firms. Yet we find that even in the basic model we present, there are still a number of possibilities to consider, including the ordering of factor intensities and elasticities of substitution among inputs. Our strategy has been to choose a central case which generates a number of interesting results, rather than to try to present a taxonomy of many different cases. This central case assumes that the “outside” good Y has the central factor intensity between components and assembly, and that components and assembly have fixed-coefficient technologies. This last assumption allows us to have consistent factor intensities for X-sector activities across countries but can create factor-intensity reversals between the X and Y sectors within a country.

Several interesting results emerge from the central case. Affiliate production requires differences in relative factor endowments between countries, but reaches a maximum when these differences are moderate. Affiliate production conforms to a gravity-type relationship with respect to both country-size and relative-endowment differences.

In order to answer several questions, we use a counterfactual methodology, asking what are the changes produced by moving from prohibited trade in components, thereby ruling out affiliate production by its definition, to free trade. Results indicate that the change in the volume of X-sector trade, components and assembled goods, bears a close relationship to the level of affiliate production under free trade. That is, affiliate production and trade are generally complements. However, there are many pairs of economies (points in the world Edgeworth box), where

liberalizing trade in components causes the volume of X sector trade to fall, as component trade displaces trade in more valuable assembled X.

The effects of liberalization on factor prices are complex, and at many points in the world Edgeworth box relative factor prices move in the same direction in both countries following liberalization. This appears to be due to factor-intensity reversals in the model, and thus this result, while interesting, is not general.

In the second-to-last section, we present a regression analysis using artificial data from the simulation model, applied to regression equations similar to those used in recent empirical work. One interesting finding is a concave and non-monotonic relationship between relative endowments and affiliate production as alluded to above, which bears on recent empirical finding that US outward investment is skilled-labor seeking. In our artificial data, a skilled-labor abundant country such as the US may indeed have this characteristic even though the underlying investments are actually vertical.

The final section considers trade costs in components and in assembled goods. These are complements in our model. Results predict that affiliate production should rise both with falls in the parent and host country inward trade costs. This result does not receive much support from empirical analysis, but the latter of course includes a great deal of (even dominated by) horizontal investments which are excluded here by assumption.

Table 1: Regressions for artificial data from Figure 7

Dependent variable: Assembly in country 2 of components made in country 1

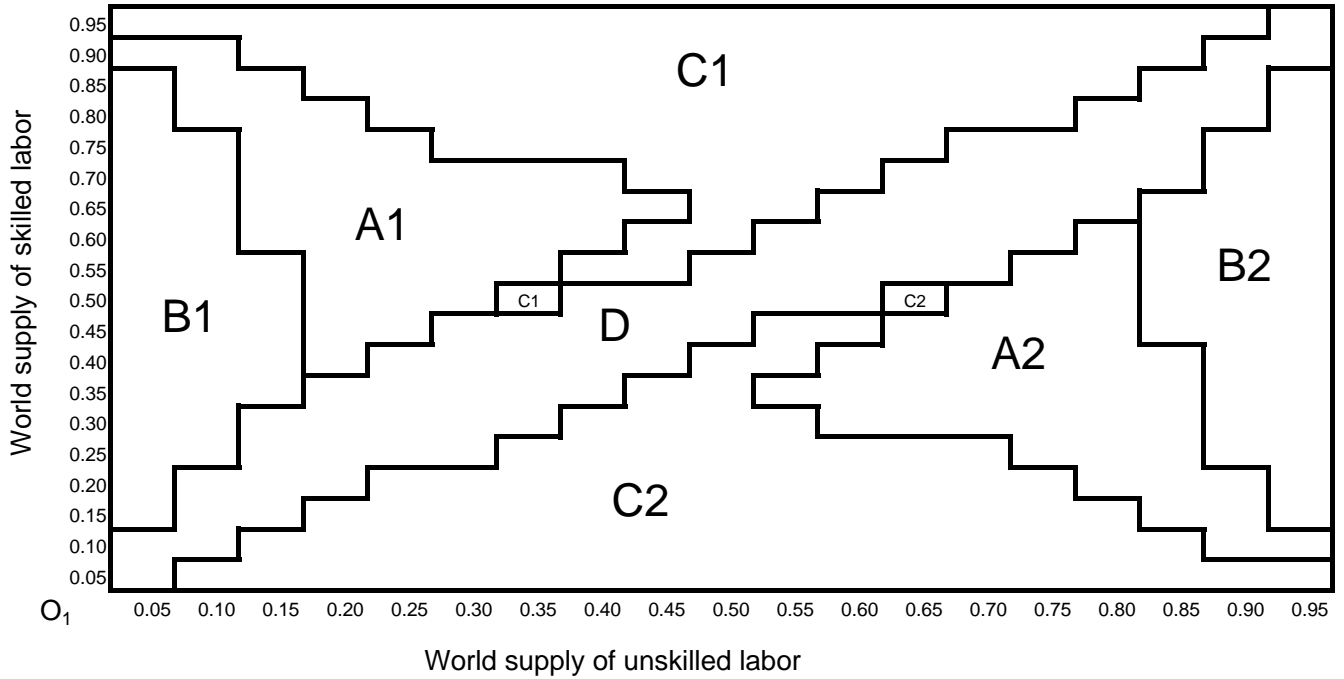
	<i>Coefficients</i>	<i>P-value</i>
SGDP	0.201 (2.182)	0.030
GDPDIFFSQ	-0.253 (-9.137)	0.000
SKDIFF	5.745 (20.381)	0.000
SKDIFFSQ	-6.999 (-14.695)	0.000
GDPDIFF*SKDIFF	-0.906 (-9.056)	0.000
Intercept	-0.188 (-1.144)	0.253

t-statistics in parentheses

<i>Regression Statistics</i>	
R Square	0.702
Adjusted R Square	0.698
Observations	361

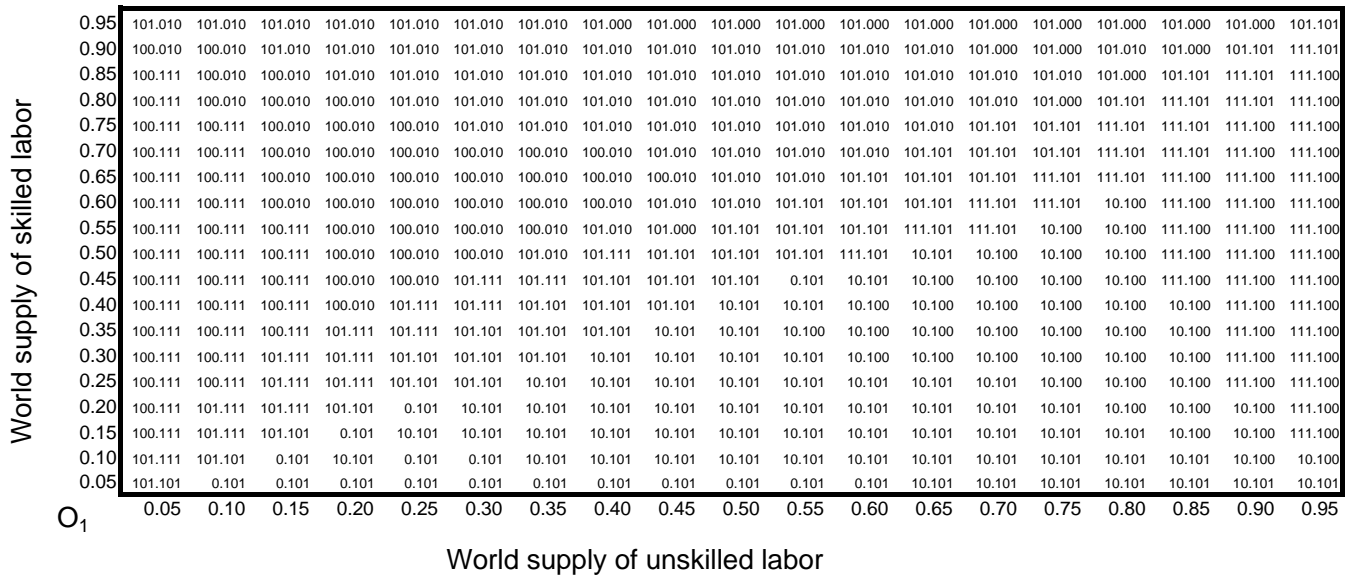
Figure 1: Production regimes (fixed coefficients in C and A, Y has the central factor intensity)

O₂



- A1 complete fragmentation: country 1 all components, country 2 all assembly (vice versa for A2)
- B1 country 1 some components, country 2 some components and all assembly (vice versa for B2)
- C1 country 1 all components and some/all assembly, country 2 some/zero assembly (vice versa for C2)
- D countries diversified

O₂



- 100 country 1 produces components
- 10 country 1 assembles X from imported components
- 1 country 1 assembles X from local components (integrated X production)
- 0.1 country 2 produces components
- 0.01 country 2 assembles X from imported components
- 0.001 country 2 assembles X from local components (integrated X production)

Figure 2: Volume of affiliate production (fixed coefficients in C and A, Y has central factor intensity)

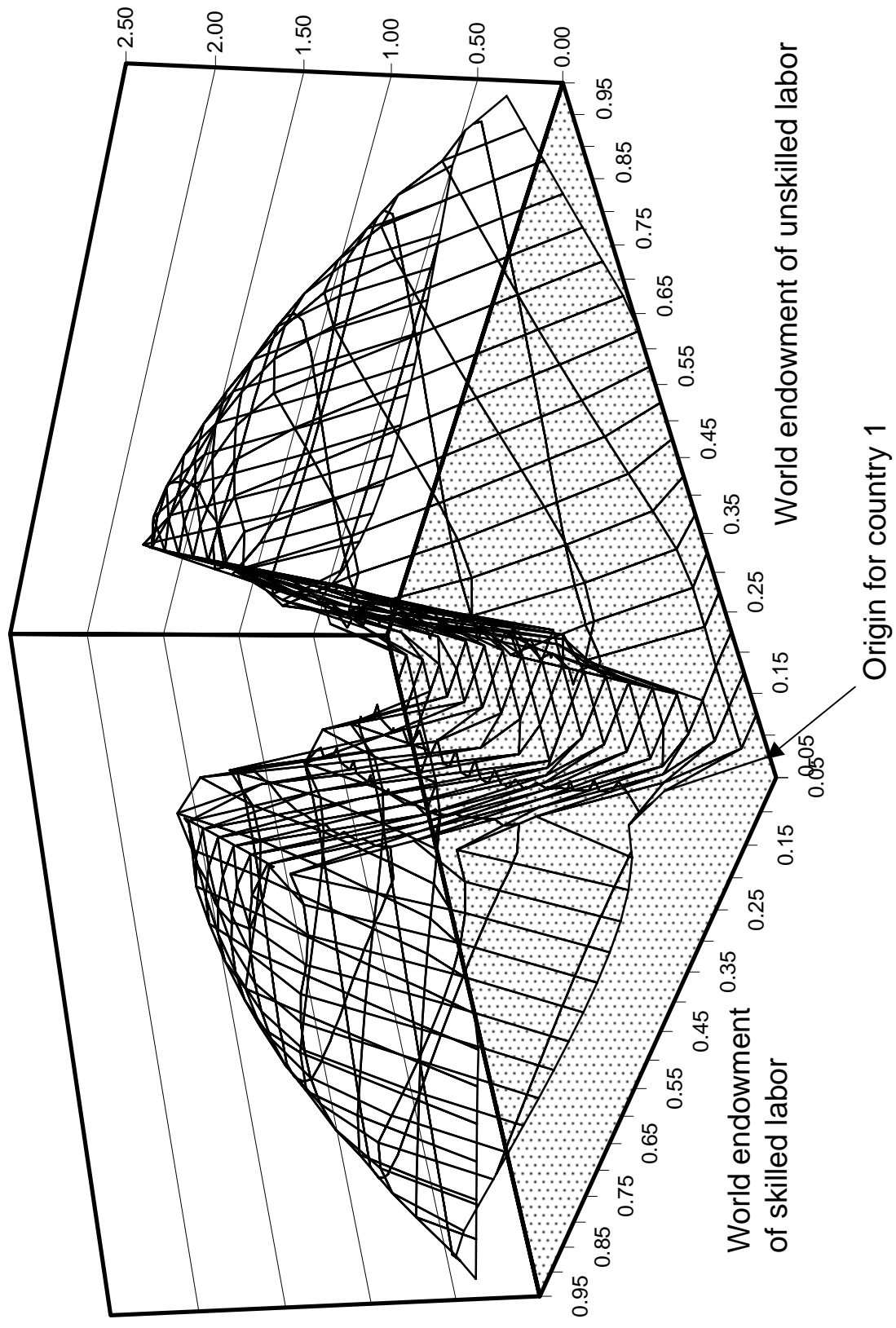


Figure 3: Affiliate production as a share of all X assembly (fixed coefficients in C and A, Y has central factor intensity)

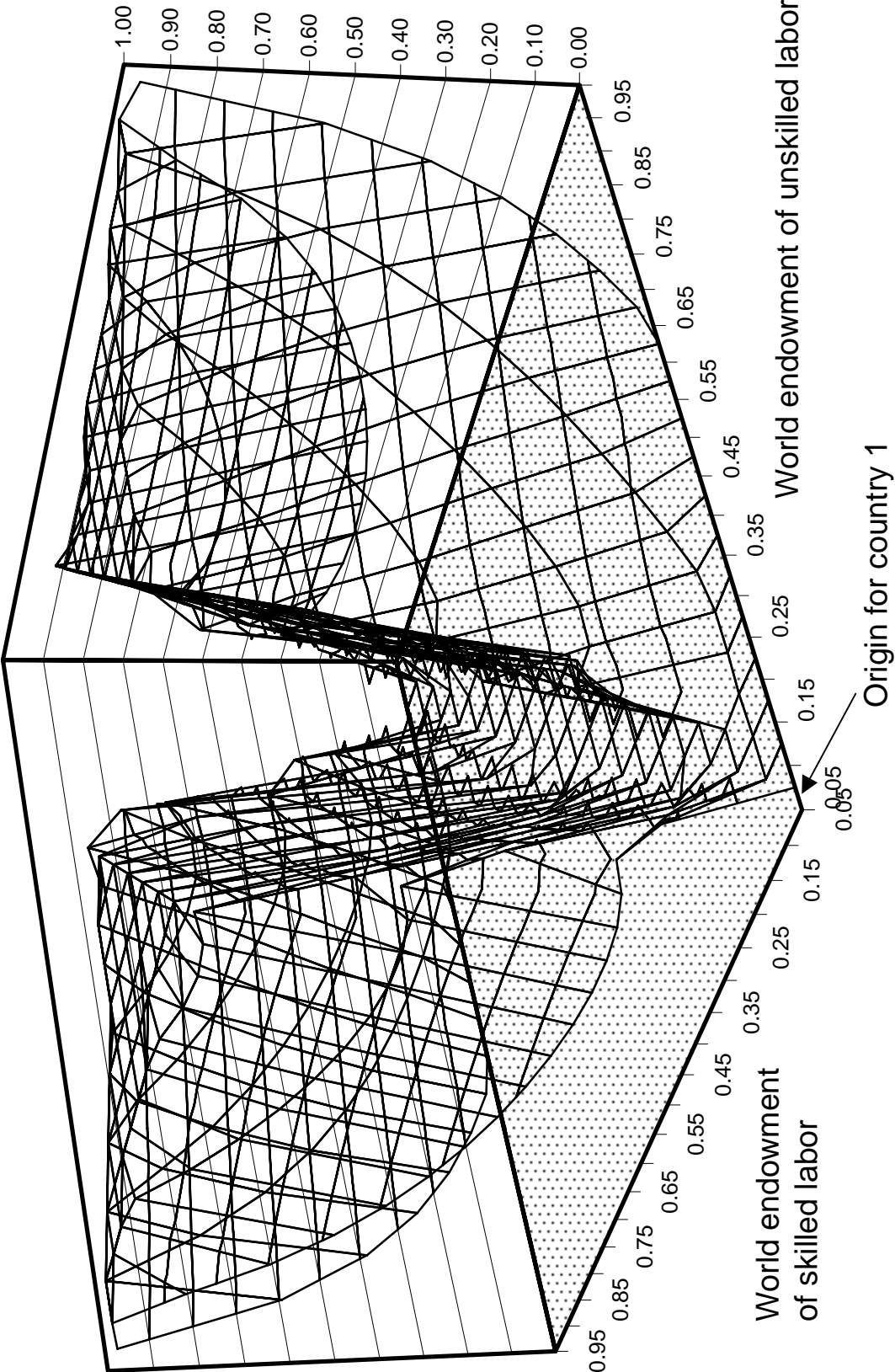


Figure 4: Change in the volume of trade in components and assembled X following liberalization

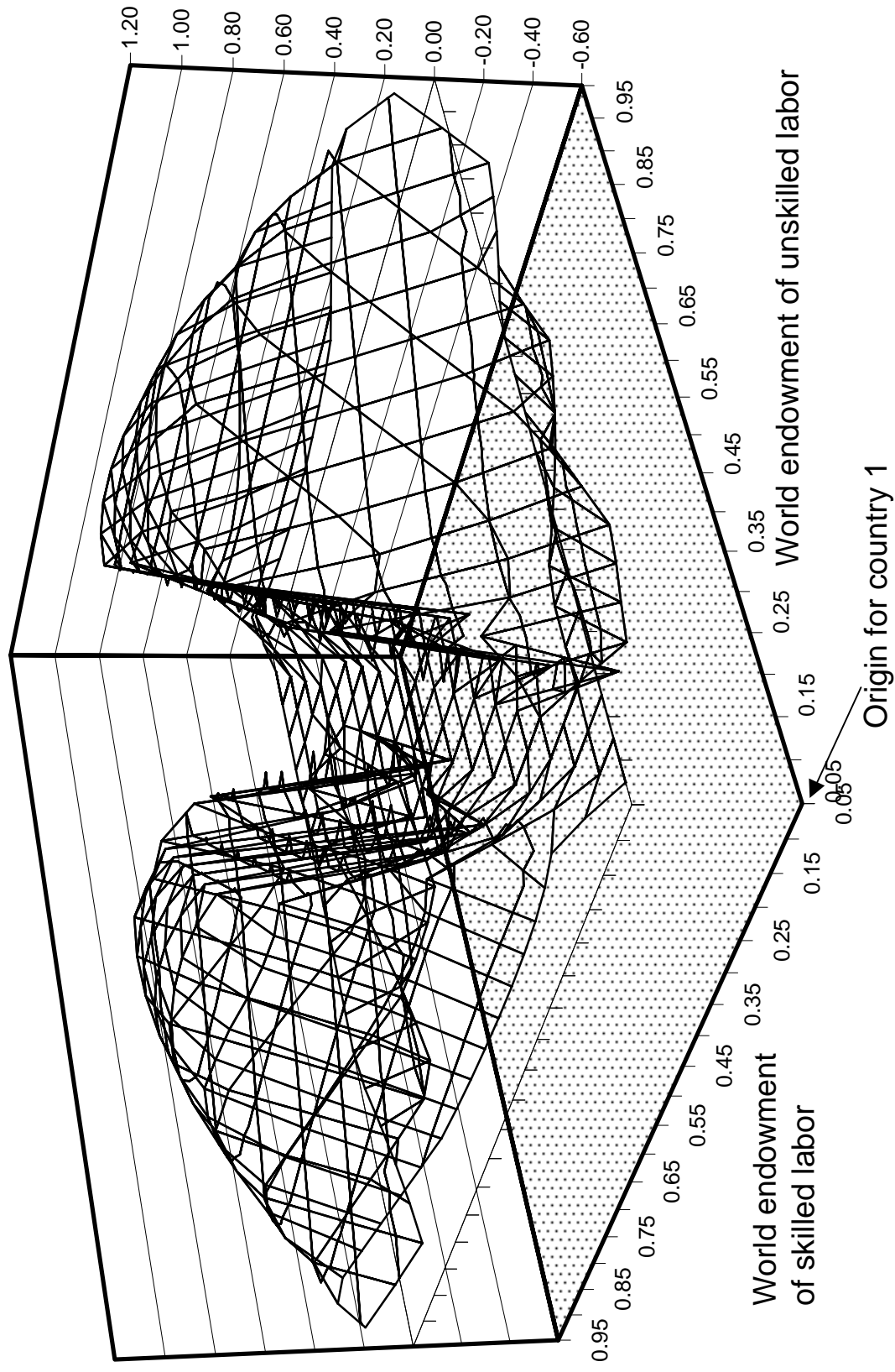
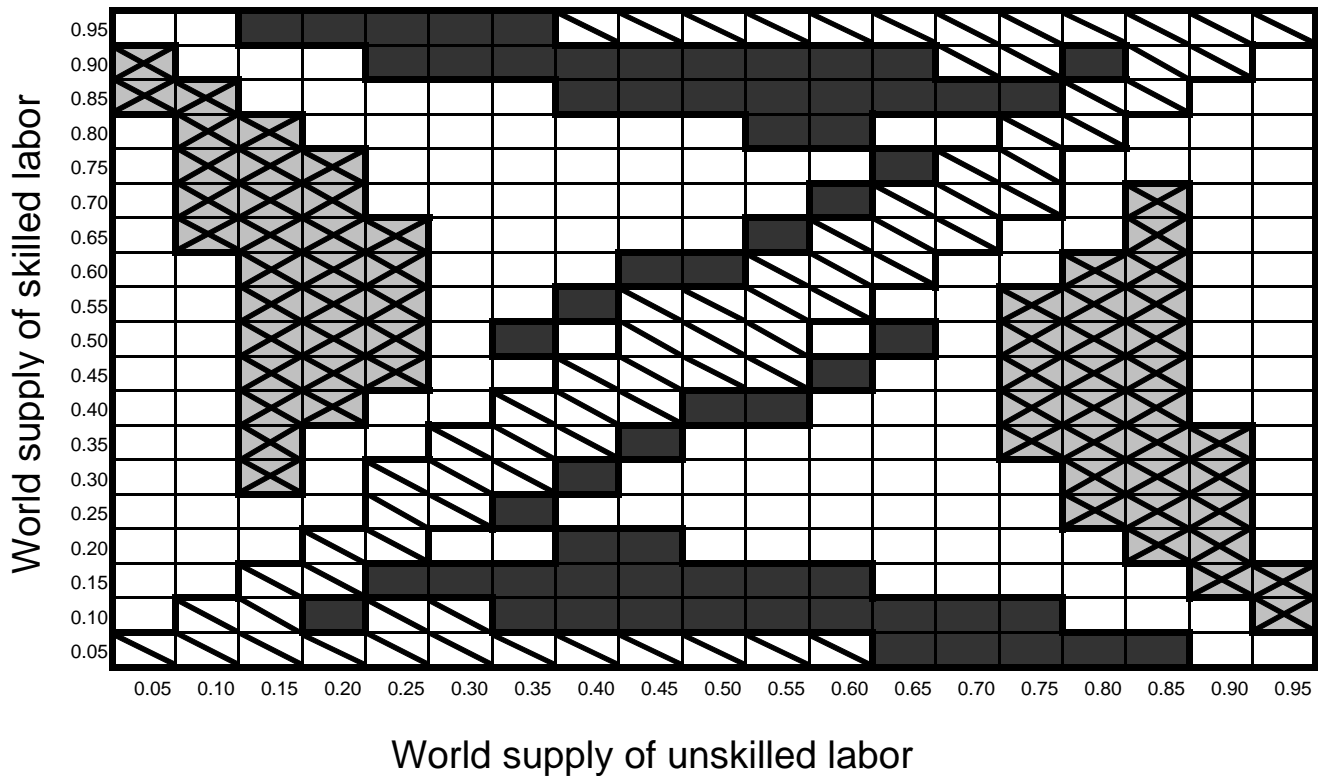


Figure 5: Proportional change in the volume of trade in components and assembled X following liberalization







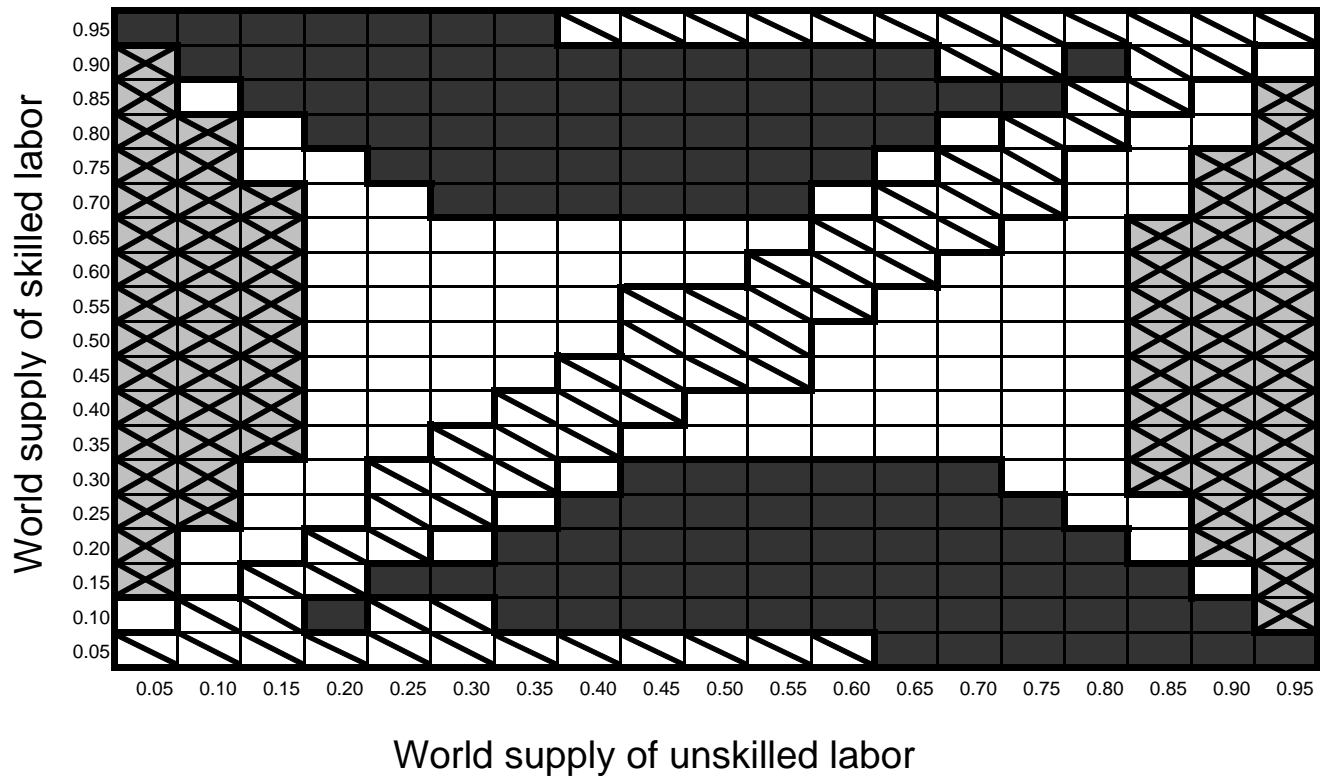
-  No change
-  Proportional increase positive, < 0.75
-  Proportional increase positive, > 0.75
-  Volume of trade falls

Figure 6: Changes in wage-rental ratios following liberalization







-  No change
-  w/r falls in capital-abundant country, rise in labor-abundant country
-  w/r rise in both countries
-  w/r falls in both countries

Figure 7: Production by affiliates of country 1 firms in country 2

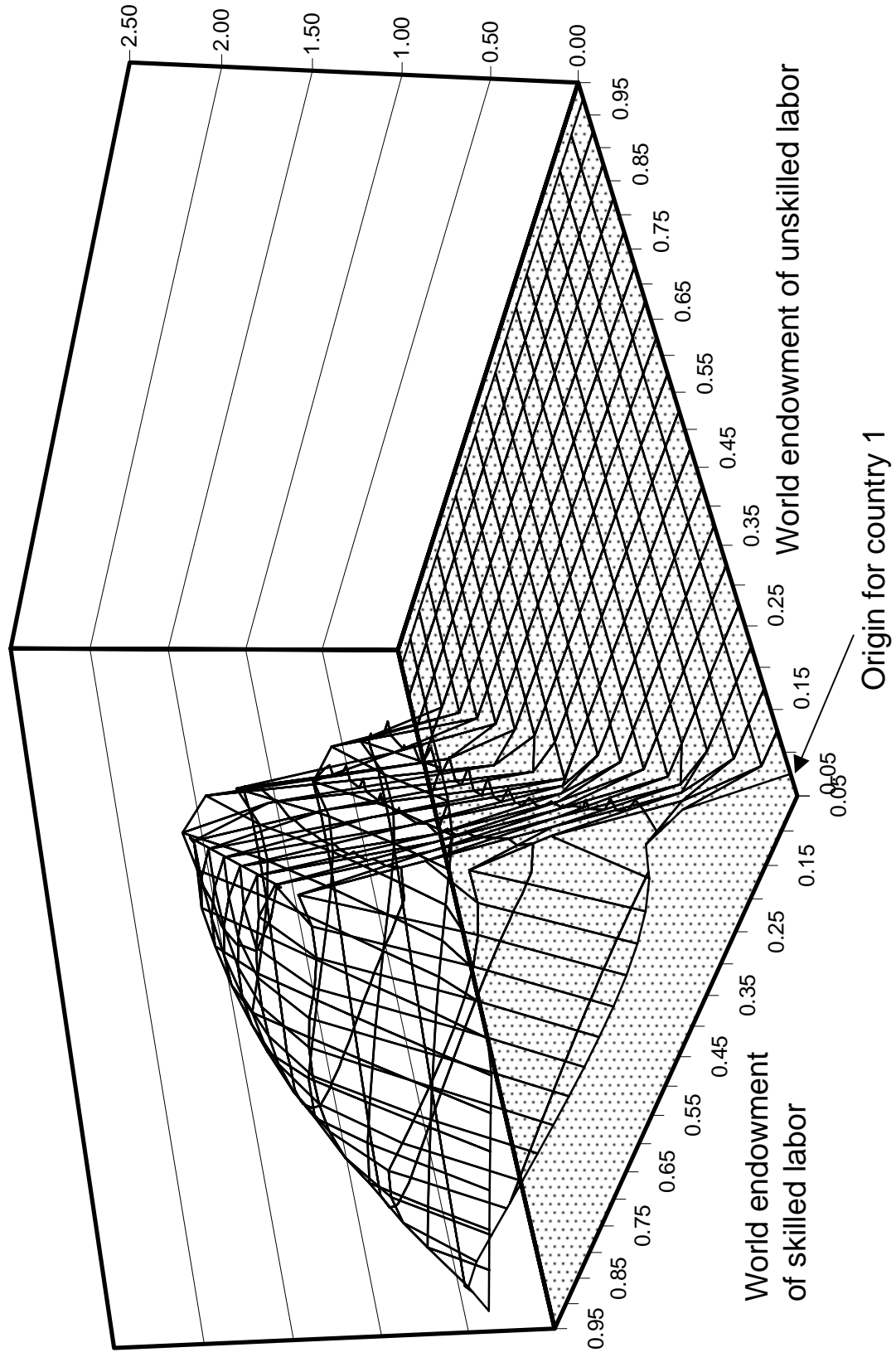
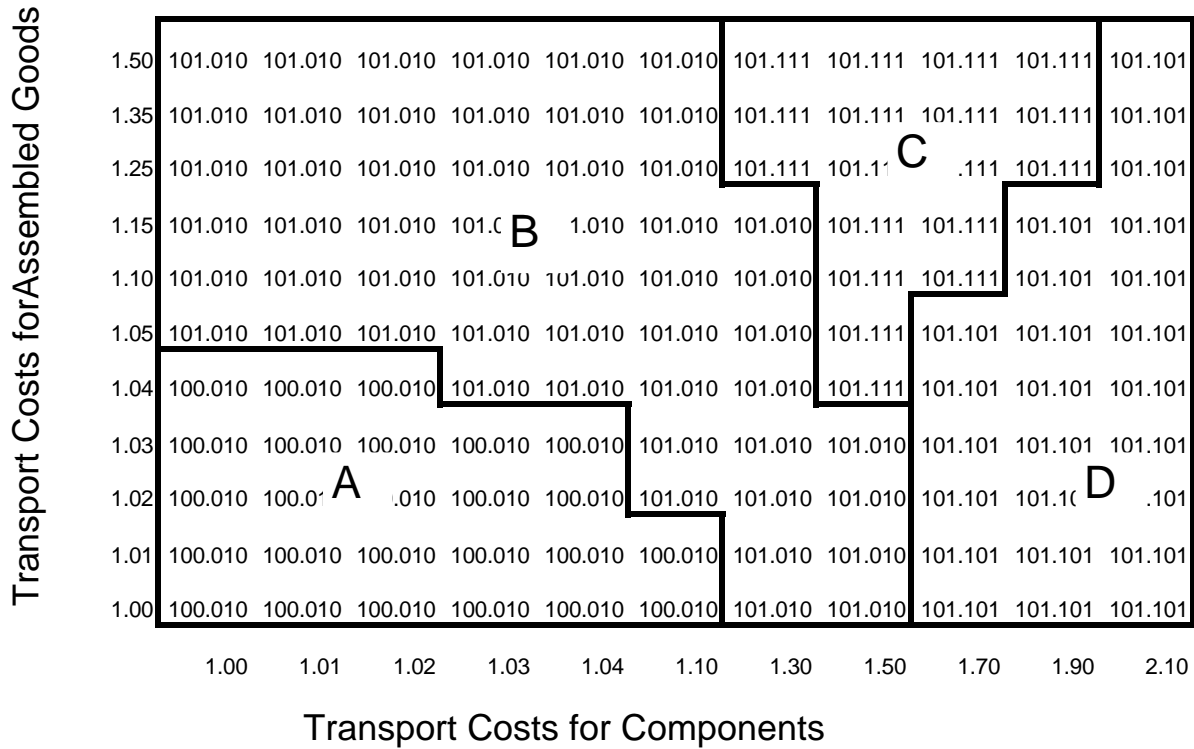


Figure 8: Equilibrium regime as a function of trade costs: countries similar in size, country 1 has a 0.75 capital share and 0.25 labor share of the world endowment



- 100 country 1 produces components
- 10 country 1 assembles X from imported components
- 1 country 1 assembles X from local components (integrated X production)
- 0.1 country 2 produces components
- 0.01 country 2 assembles X from imported components
- 0.001 country 2 assembles X from local components (integrated X production)

regions

- A complete fragmentation: country 1 produces components, country 2 assembles
- B country 1 produces components and assembles, country 2 assembles only
- C country 1 produces components and assembles, country 2 assembles only from both local and imported components
- D both countries diversified, and autarky in extremely northeast

Figure 9: Affiliate production as a function of trade costs

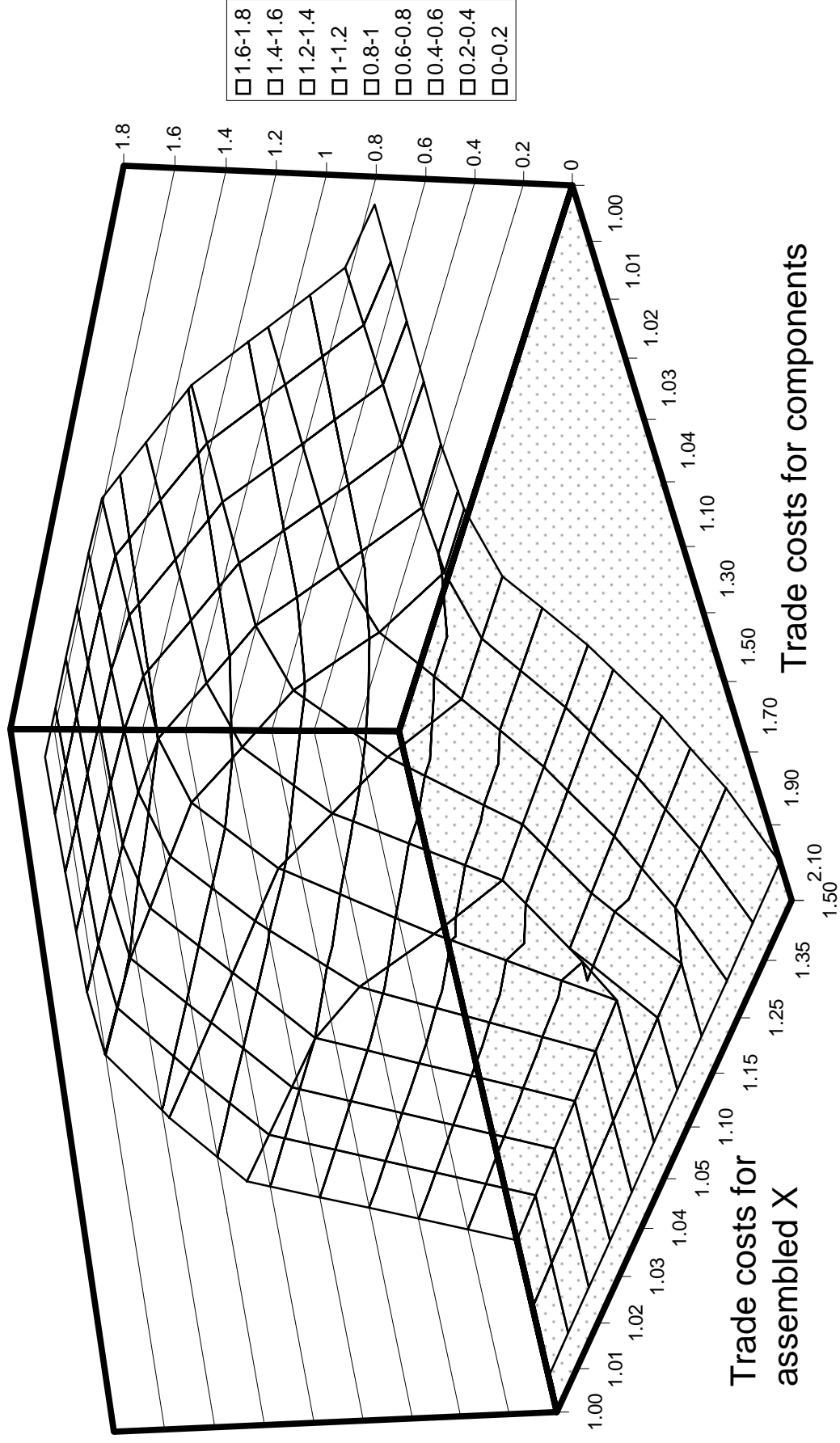


Figure 10: Volume of trade in components and assembled X as a function of trade costs

