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International Fragmentation of Value-added Chains: How Does it Affect Domestic Factor Prices?

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by

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Abstract

Economic globalization causes an increasing international fragmentation of value-added chains. A question often raised is whether such outsourcing affects domestic income distribution. The paper provides a theoretical treatment of this issue within a Heckscher-Ohlin framework. It extends beyond previous treatments by allowing for an arbitrary number of goods, factors, and fragments, and by formally specifying a “fragmentation technology”. It defines a “margin of international fragmentation” and shows how this margin shifts in response to economic globalization. Factor prices are driven by associated changes in “effective prices” of individual fragments of the value-added chain.

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1 Introduction

The high level of economic globalization that we observe today is not without historic precedence. Indeed, before the First World War, the national economies were in many respects no less integrated than they are today; see Temin (1999). However, this second wave of globalization is often claimed to feature new forms of internationalization that constitute new challenges for both policy makers and economists. Thus, a phenomenon that has recently caught much attention is firms in industrial countries seeking to exploit international factor price differences by moving labor intensive parts of their value-added chain to low wage countries, either relying on arms length transactions, or in connection with foreign direct investment. There is ample empirical evidence for this phenomenon which is now commonly referred to as “international fragmentation”, “outsourcing”, or “vertical specialization”.¹ It is quite natural that, from a policy perspective, this form of globalization should give rise to concern about painful consequences, either in the form of lost jobs or in the form of unwelcome wage effects.

From an economic theory point of view, the crucial question arising from this observation is whether the current wave of economic globalization may adequately be addressed using models of international trade which rely on a watertight distinction between value-added and intermediate goods, or which restrict attention to trade in final goods. The theoretical challenge, therefore, is to develop models which a) highlight the potential of fragmenting value-added processes into separate components, which b) focus on the incentives to do so across international borders and on how these are related to relevant scenarios of economic globalization, and which c) allow us to identify the effects of such fragmentation in terms of policy-relevant variables, such as factor prices, employment and welfare. The present paper tries to take a step in this direction, focusing on factor prices and following the lines of higher-dimensional trade theory.

It is interesting to note that the issue of fragmentation was actually taken up before the term globalization made its first headline appearance. Thus, Jones & Kierzkowski (1990) have pointed out that technological advances in various services that firms must rely on in order to link different stages of the value-added process may cause an increasing fragmentation of the

¹There is evidence both in terms of case studies, focusing on prominent examples such as the Maquiladoras in Mexico, and in more general terms, relying on certain characteristics of trade flows, such as the share of intermediate goods. See Feenstra & Hanson (1996,1997), Irwin (1996), Feenstra (1998), Hummels, Rapoport & Yi (1998), Hummels, Ishii & Yi (2000), Baier & Bergstrand (2000), and Görg (2000). In the empirical literature, subtle issues have arisen as regards the appropriate definition and measurement of the phenomenon in question, and different names have been used to highlight certain distinctions. In this paper, “outsourcing” and “fragmentation” are used synonymously. A precise definition will follow below.

production processes. Moreover, they note that such advances are particularly prone to ease *cross-border* fragmentation, thus generating a whole new pattern of international specialization. This new pattern of specialization is perhaps best characterized as being driven by worldwide arbitrage operating, not on well defined end products, but instead on ever smaller slices of the value-added chain. Generally, as noted by Jones & Kierzkowski (1990 and 2001a), one would expect that this also increases the scope for gains from trade.

However, in the second half of the 1990's the issue was readdressed on a somewhat less optimistic tone. Specifically, starting with Krugman (1995), outsourcing has been debated as a possible culprit in connection with the concern that had meanwhile arisen about the distributional consequences of economic globalization. In their seminal papers, Feenstra & Hanson (1996 and 1997) argue, both theoretically and empirically, that outsourcing in connection with US-foreign direct investment in Mexican Maquiladoras explains why wages for unskilled labor have declined relative to skilled labor in both countries, while at the same time production has become more skill-intensive.²

Reflecting the widespread public concern about wage effects of economic globalization, factor price implications have consistently remained a key focus of the literature that has since evolved around outsourcing and fragmentation. This literature suggests that international fragmentation may be associated with a remarkable variety of factor price changes, depending on a host of circumstances which appear very difficult to pin down in general terms. Thus, Arndt (1997 and 1999) argues that under certain conditions US labor will gain from Maquiladora-type outsourcing to Mexico. He employs a 2×2 Heckscher-Ohlin-type model with labor and capital, but his argument may easily be re-framed using skilled and unskilled labor instead, in which case his result is in stark contrast to that of Feenstra & Hanson (1996 and 1997).³ Using a somewhat more general framework, Jones & Kierzkowski (2001a and 2001b) discuss a host of different outcomes – “some rather surprising” – where fragmentation may be beneficial or harmful to low-skilled workers in relation to skilled workers or capital, depending on a complex interplay between the factor endowment position and output pattern of a country on the one hand, and the details of the fragmented activities on the other. In the same vein, Venables (1999) demonstrates that even in a two-sector model several different outcomes may arise, including “some curious

²It is worth mentioning that, in the model proposed by Feenstra & Hanson, this relative wage effect is consistent with a real income gain for all labor. Feenstra & Hanson (1999) discuss outsourcing in a more general approach which they employ in order to identify the different driving forces behind US wage movements. See also Leamer (1998).

³See Kohler (2001) for a more detailed discussion of this difference in results.

cases”.

The richness of possible results is further demonstrated in the work of Deardorff (1998 and 2001) where the focus lies on international factor price equalization, rather than domestic income distribution. In Deardorff (1998), he shows that fragmentation increases the likelihood of international factor price equalization in that it renders factor price equalization an equilibrium outcome for certain factor endowments which would otherwise rule this out. However, in Deardorff (2001) he warns against reading too much into this result, pointing out that under certain conditions fragmentation may actually increase international factor price differences.

In some sense, of course, it is not surprising that a phenomenon as generic as fragmentation should be associated with a variety of different factor price changes. But surely, we would not want to leave it with an agnostic attitude of “anything can happen”. While a casuistic discussion does offer important insights, we would at some stage want to have a concise formulation of a general principle which is at force in each special case. The literature so far does not yet seem to have reached this point.

The essential contributions of this paper are as follows. a) While previous treatments have been restricted to the two-factor case (often the 2×2 case), the analysis of fragmentation is carried out in a general $N \times M$ framework. b) The analysis is based on a formal description of an underlying technology of fragmentation which allows us to describe how the “margin of international fragmentation” shifts as a result of economic globalization. c) The paper focuses on both Ricardian and Heckscher-Ohlin-type forces that jointly operate on this “margin of international fragmentation”. d) The paper contains an explicit treatment of commodity-specific barriers, including in particular the cost of international fragmentation, which act as a counterforce to the Ricardian and Heckscher-Ohlin-type incentives for international fragmentation. e) Perhaps most importantly, the paper offers formal propositions in the spirit of higher-dimensional trade theory, stating how these forces affect international fragmentation and how this, in turn, affects domestic factor prices.

As always, there are a number of aspects that remain beyond the scope of analysis. Specifically, the two countries considered – a domestic country where international fragmentation is pursued by rational firms and a “neighboring” foreign country which is the potential host for offshore production of individual fragments of the value-added chain – are both assumed to face given prices for final goods on world markets. I.e., we rule out that international fragmentation as such affects world prices for final goods. Moreover, the analysis is restricted to the case of a constant returns to scale technology and perfect competition. This implies, among other things, that we do not address behavior of individual firms and, as in Venables (1999), issues related to multinational firms are only discussed in a more or less ad-hoc way.

2 An informal account

Before turning to the formal model, I present an informal account of the essential results. If we think about a given value-added process as composed of two fragments, then we may impute a value to any one fragment which depends on the price of the final good and the cost incurred to procure the other. In reference to the effective protection literature, we may call this the “effective price” of a fragment. An incentive to pursue international fragmentation across national borders arises if the opportunity cost of foreign procurement of any fragment, including the cost of fragmentation, is lower than its effective price. Barring artificial barriers to outsourcing, domestic production of this fragment is then no longer economically viable. The effect that such outsourcing has on the domestic economy is best understood by realizing that it acts like an increase in the effective price of the domestic fragment. This is the general principle behind all results obtained in this paper. The results, derived below in the form of 4 theorems in the spirit of higher-dimensional trade theory, may be informally stated as follows.

For a given cost of international fragmentation, the cost-advantage of moving production of a fragment to the foreign country is determined by that country’s technology and its factor prices. The first result derived below (*Theorem 1*) states that Ricardian differences in technology and the initial factor price differences between the two countries, together with the costs of international fragmentation, define hyperplanes in factor space, one for each final good, which separate components of value-added that are outsourced to the foreign country from those remaining at home. Scenarios of globalization involving technology changes and changes in trading and communications costs may change the position of these hyperplanes, whereby an increasing number of fragments shift from being tradeable in principle, but non-traded in practice, to actually being traded.

Any such shift in the margin of international fragmentation has the effect of changing effective prices for those activities that remain viable at home, i.e., for the fragments not yet reached by this shift. The magnitude of these effective price changes is determined a) by the respective cost shares of the fragments going offshore, b) by the cost-(dis)advantages implied by Ricardian technology gaps, c) by the costs of international fragmentation, d) by the interplay between factor intensities of individual fragments and international factor price differences, and finally, e) by the degree of substitutability between different factors in connection with this interplay. *Theorem 2* below describes in a single equation how these effects together determine the effective price change.

In general, the margin of international fragmentation may be shifted simultaneously for several value-added processes (industries). The Stolper-Samuelson logic leads us to expect, intuitively, that the attendant factor price changes are determined a) by which industries experience

particularly large effective price changes for their remaining domestic fragments, and b) by the factor intensities of these fragments, relative to the overall factor endowment of the economy. *Theorems 3 and 4* formulate these ideas in the spirit of correlation results familiar from general versions of the Stolper-Samuelson and Heckscher-Ohlin propositions.

3 Fragmentation technology and equilibrium

I now proceed to the formal model. For all final goods $i \in \{1 \dots N\}$, the home technology is described by concave minimum unit-cost functions $c_i(w)$, where w is a vector of domestic factor prices. To obtain a clear notion of the margin of international fragmentation, we need a general description of technology which permits fragmentation of the value-added process, independently of whether, and to what extent, such fragmentation will actually materialize. We thus assume that the underlying technology allows us to decompose these cost functions according to

$$c_i(w) = f_i [c_i^A(w), c_i^B(w)]. \quad (1)$$

For the sake of simplicity, we assume for a start that there are only two fragments A and B , with associated concave minimum unit-cost functions $c_i^A(w)$ and $c_i^B(w)$. The cost of the final good is determined by the unit-cost of individual fragments according to f_i . Using $\nabla c_i(w)$ to denote the gradient of the unit-cost function, and assuming a given world price p_i for the final good, the vector of cost-minimizing input requirements *per unit-value of final output* in the home economy is

$$\begin{aligned} a_i(w) &= \nabla c_i(w) / p_i \\ &= \left[\frac{\partial f_i}{\partial c_i^A} \nabla c_i^A(w) + \frac{\partial f_i}{\partial c_i^B} \nabla c_i^B(w) \right] / p_i \\ &= a_i^A(w) + a_i^B(w). \end{aligned} \quad (2)$$

I assume that there is a “neighboring” country, indicated by an asterisk, which is a potential host for offshore-production of individual fragments of the value-added chain initially located in the home-country. This country will henceforth be synonymously referred to as “the foreign country”, or as an “offshore” place of production. It features the same technology, except for a Hicks-neutral productivity difference which we capture by technological gap parameters τ_i . I assume that the two economies also have different *relative* factor prices, due to a difference in factor endowments which is too big for trade in goods to cause *relative* factor price equalization. The foreign economy, therefore, has cost-minimizing input requirements per unit-value of final

outputs according to

$$a_i^{*A}(w^*) = \tau_i a_i^A(w^*), \quad \text{and} \quad a_i^{*B}(w^*) = \tau_i a_i^B(w^*), \quad \text{with} \quad (3a)$$

$$a_i^*(w^*) = a_i^{*A}(w^*) + a_i^{*B}(w^*). \quad (3b)$$

For ease of notation, I henceforth use $a_i^A = a_i^A(w)$ and $a_i^{*B} = a_i^B(w^*)$, and analogously for fragment B and overall unit-input requirements. Notice that we focus on the Ricardian case of non-uniform technological differences, hence τ_i may differ across commodities. Although technological differences may just happen to be such that there are several goods that both economies produce in common, we rule this out by assumption. Thus, the home economy produces goods $j \in \{1 \dots K\}$, while the foreign economy produces goods $k \in \{K + 1 \dots N\}$. Notice that, because of technological differences, this ordering of goods does not mirror their ordering in terms of factor intensities.⁴ Unlike Deardorff (2001), therefore, we consider a case where countries are not located in separated cones of diversification. As pointed out above, an important assumption underlying this analysis is that foreign factor prices w^* are given independently of international fragmentation.

The zero-profit conditions of a competitive equilibrium are

$$w^T a_j = 1, \quad \text{and} \quad w^T a_k > 1, \quad (4a)$$

$$w^{*T} a_k^* = 1, \quad \text{and} \quad w^{*T} a_j^* > 1, \quad (4b)$$

where j and k , indicate a commodity which is produced in the home and foreign economy, respectively. In 4 and in what follows, a superscript T indicates a vector transposition. Cost minimization implies that

$$w^T a_i \leq w^T a_i^* / \tau_i, \quad \text{and} \quad (5a)$$

$$w^{*T} a_i^* \leq w^{*T} a_i \tau_i. \quad (5b)$$

Analogous equations hold for each individual fragment A and B . Using the cost-disadvantage equations 3a, 4 and 5 imply

$$(w - w^* \tau_j)^T a_j < 0, \quad \text{and} \quad (6a)$$

$$(w^* - w / \tau_j)^T a_k^* < 0. \quad (6b)$$

These are *necessary* conditions for the assumed pattern of specialization to obtain in the “pre-fragmentation” trading equilibrium.

⁴Technological differences here act much like tariffs on intermediates in Deardorff (1979).

Figure 1 illustrates such an equilibrium for two factors, capital (K) and labor (L), and four goods. Factor price lines w and w^* connect factor bundles costing one dollar at domestic and foreign factor prices, respectively. Goods 1 and 4 are produced by the foreign country, while the domestic economy produces goods 2 and 3. For this to be an equilibrium, the factor bundle a_2 , used by the home economy to produce a dollar's worth of good 2, has to lie to the south-east of the ray t_2 which passes through the intersection between the factor price lines w and $w^*\tau_2$; see equation 6a. Notice that by construction of the figure $\tau_2 > 1$, i.e., the foreign economy has a Ricardian cost-disadvantage in good 2. This disadvantage is large enough to compensate for the fact that the unit-value isoquant 2 which represents the domestic technology lies below the foreign unit-cost line w^* . By analogy, factor bundle a_4^* which is used abroad to produce a dollar's worth of good 4, must lie to the north-west of ray t_4 , which in turn passes through the intersection point of w^* and w/τ_4 ; see equation 6b. Figure 1 assumes that the foreign economy has a superior technology for good 4, i.e., $\tau_4 < 1$. For good 1, the home economy has a technological advantage ($\tau_1 < 1$) which is, however, not big enough to make production of good 1 viable, given its factor prices w . For good 3, on the other hand, the Ricardian advantage of the foreign economy ($\tau_3 < 1$) is not sufficient to make production viable there, given factor prices w^* . It is apparent from this figure that conditions 6 are necessary, but not sufficient for the assumed pattern of specialization. Specifically, the ray t_2 may lie to the left of a_2 , while at the same time the line $w^*\tau_2$ may intersect the unit-value isoquant 2. The latter implies that the minimum unit-cost of producing good 2 abroad, absent any fragmentation, is lower than its price. Under the assumed pattern of specialization, this violates the zero-profit condition. Only if the technology is of the Leontief-type, will conditions 6 be both necessary *and sufficient* for the assumed pattern of specialization. It will be seen below that graphical representations of this kind prove useful also for an illustration of how domestic factor prices are affected by international fragmentation.

4 The “margin of international fragmentation”

I now turn to a formal analysis of international fragmentation. A technology which permits fragmented production does not guarantee that fragmentation will actually occur. I will show, more generally, that there is a “margin of international fragmentation” which separates fragments of the value-added chain which may viably be produced in the home economy from those which are not, because they may more cheaply be procured via outsourcing. As will become apparent, if there is no outsourcing, it is because this margin does not yet reach the relevant range of fragments.

4.1 The simple case: two fragments

Even if there are cost-advantages abroad, there will be extra costs which must be incurred in order to link different fragments produced in different countries, in order to ensure a steady supply of the final product to the buyer. Such costs are discussed at great length in Jones & Kierzkowski (1990 and 2001a), as well as Harris (2001). Here, I employ a relatively simple representation of these costs by assuming that if the home firms carry out fragment A of good- j -production in the foreign country, they face trading and communications cost in the ad-valorem amount of $\alpha_j - 1 > 0$.⁵ Then, assuming for the moment that factor prices are constant, the cost-saving generated by foreign procurement of fragment A in sector j is equal to

$$s_j^A = w^T a_j - (\alpha_j w^{*T} a_j^{*A} + w^T a_j^B) = w^T a_j^A - \alpha_j w^{*T} a_j^{*A}. \quad (7)$$

For a better understanding of this effect, we decompose it such that

$$\begin{aligned} s_j^A &= (1 - \alpha_j \tau_j) w^T a_j^A + \alpha_j (\tau_j w^T a_j^A - w^{*T} a_j^{*A}) \\ &= (1 - \alpha_j \tau_j) w^T a_j^A + \alpha_j \tau_j (w - w^*)^T a_j^A + \alpha_j (\tau_j w^{*T} a_j^A - w^{*T} a_j^{*A}). \end{aligned} \quad (8)$$

Since by assumption $\alpha_j > 1$, and since conditions analogous to 5b hold for each individual fragment (and thus also for fragment A), the last term in equation 8 is non-negative. For a Leontief-technology it is zero.⁶ The first term captures the cost that a domestic firm faces if the factors available offshore are less efficient ($\tau_j > 1$), and if fragmentation is costly ($\alpha_j \geq 1$). The second term highlights the cost-effect arising from factor price differences. If factors used intensively in fragment A are “on average” cheaper offshore than at home, then $(w - w^*)^T a_j^A > 0$ which implies Heckscher-Ohlin-type cost-savings. Therefore, an incentive for international fragmentation obtains if this term offsets the first which requires

$$(w - \alpha_j \tau_j w^*)^T a_j^A > 0. \quad (9)$$

This is a *sufficient* condition and it gives rise to the following theorem.

Theorem 1 *Given factor prices w and w^* , as well as fragmentation costs α_j and a technology gap τ_j , $(w - \alpha_j \tau_j w^*)^T a = 0$ defines a hyperplane in factor space such that any fragment of good- j value-added with a factor bundle which lies above this plane is produced offshore. Any*

⁵The term a_j may in part also represent formal trade barriers like tariffs, but we shall henceforth assume that it represents real trading costs.

⁶For *infinitesimal* changes from the foreign input coefficients, this term is zero by the first-order conditions of cost-minimization. But such a local treatment is inadequate if we look at fragmentation.

change in the cost α_j and/or technology τ_j which moves this hyperplane into the cone defined by the individual fragments of good- j value-added causes international fragmentation.

Figure 2 illustrates this theorem by introducing the two fragments behind a_j in the pre-fragmentation equilibrium. In this figure, α_j is such that condition 9 is violated. This is reflected by the fact that the factor bundle a_j^A , which a domestic firm employs for its production of fragment A in the amount necessary to generate a dollar's worth of good 2, lies to the south-east of the ray t_2^α which, in turn, passes through the intersection point of the factor price lines w and $\alpha_j\tau_jw^*$. We can now readily see how globalization can cause international fragmentation by reducing the significance of formal as well as technical barriers to trade, thereby causing a fall in α_j . As α_j falls, the ray t_2^α starts to rotate in a clockwise manner, and once it crosses a_j^A condition 9 is met. If α_j falls all the way down to 1, t_2^α coincides with t_2 . A complete reduction of all barriers clearly creates an incentive for home firms to go offshore with fragment A of good-2-production. At the same time, locating the entire production of good 2 in the foreign economy remains unattractive, as we see from condition 6. In other words, the margin of international fragmentation is now positioned between fragments A and B .

There is an implicit upstream interpretation of fragment A behind this story. We still view the home economy as producing and exporting good 2, albeit with an imported intermediate good (fragment) A from abroad. But the above conditions, as such, are perfectly consistent with foreign firms producing fragment A , and importing fragment B as an “intermediate” from the home economy, in order to produce good 2 and sell it on world markets. This is, however, ruled out if fragment B is a downstream activity, such that the effective price of fragment A derives from a subsequent input of fragment B . The final good must then be produced in the home country where the downstream fragment B is produced. In this case, then, international fragmentation clearly increases the overall volume of trade. If there is some internalization advantage which prevents arms-length transactions, then this trade will be of an intra-firm nature, and the multinational firm emerging is of the vertical kind.⁷

4.2 Generalization: many fragments

With a little effort, theorem 1 can be generalized to the case of many fragments. Moreover, by introducing the above mentioned notion of “effective prices” for individual fragments we may establish a direct relationship to the case considered by Feenstra & Hanson (1996 and 1997).

⁷The analogy between fragmentation and to the Helpman-Krugman approach to the theory of multinational firms has been noted by Deardorff (2000a). See also Venables (1999).

Assume, then, that the value-added process permits fragmentation into F separate components. By complete analogy to a_j^A and a_j^B , we denote fragment J of good- j production by a_j^J , $J \in \{1 \dots F\}$. This is the factor bundle used for fragment J per dollar's worth of final good j , produced at factor prices w in the domestic economy. For ease of notation, I henceforth assume that F , the number of potential fragments, is same for all final goods. We may now impute a value of

$$\pi_j^C = 1 - \sum_{J \neq C} w^T a_j^J \quad (10)$$

to the factor bundle a_j^C representing fragment $C \in \{1 \dots F\}$. In reference to the theory of effective protection we call π_j^C the "effective price" of fragment C in production of good j .⁸ Next, we define

$$b_j^C = a_j^C / \pi_j^C \quad (11)$$

as the unit-value activity level of this fragment. The zero-profit condition then implies

$$w^T b_j^C = 1 \quad (12)$$

for each $j \in \{1 \dots K\}$ and $C \in \{1 \dots F\}$. It should be noticed, however, that the effective prices of different fragments within a given value-added chain are not independent from each other.

Theorem 1 can now be applied to the factor bundles b_j^C . For each final good produced at home in the initial equilibrium, there is a chain of unit-value isoquants for individual fragments b_j^C , lined up in a tangent manner along the w -line. Figure 3 provides a graphical illustration, this time singling out final good 3 where the home economy has a Ricardian disadvantage, and assuming four instead of only two fragments. Good 4 is no longer depicted to avoid clutter. The unit-value isoquants for individual components are drawn with dotted lines. For instance, the one for fragment A is labeled 3^A , its position being determined by $\hat{\pi}_3^A$, as defined above. It is now evident that the ray t_3 separates fragments which are potential targets for outsourcing on the basis of factor price differences (to the left of this ray) from the rest (to the right of this ray). In our case, fragments A and B are potential targets for outsourcing. Within this group of fragments, the ray t_3^α separates those which are ruled out from outsourcing, due to the cost of international service links. Only fragments to the left of this ray are cost-savingsly moved offshore, in the present example only fragment A .

Given, international factor differences as depicted in figure 3, we can now distinguish the two forces determining the position of the margin of international fragmentation. One is the

⁸See Ethier (1977) for a general treatment of the analogy between effective prices and nominal prices which underlies the theory of effective protection.

cost of service links α_3 , and the other is the Ricardian technology advantage τ_3 . A reduction of α_3 initiates a clockwise rotation of t_3^α , thereby pushing out this margin. The same happens for a technological improvement in the foreign economy, i.e., for a reduction in τ_3 . In this case, we observe a simultaneous clockwise rotation of both t_3^α and t_3 , which again shifts the margin in favor of fragmentation. Notice that this is precisely the scenario which drives outsourcing in the model used by Feenstra and Hanson (1996 and 1997). They focus on North-South capital movements but exactly the same result obtains for a Ricardian technology improvement in the South relative to the North; see Feenstra & Hanson (1996, p. 100).⁹ The difference to the case depicted in figure 3 is that here the foreign economy has a Ricardian advantage in good 3 which gets bigger in the scenario considered, whereas in the Feenstra-Hanson case the South has a technology gap which is reduced.

5 The link between fragmentation and factor prices

Having established the margin of international fragmentation, we now ask how factor prices change if this margin moves. We know from the Stolper-Samuelson logic that factor prices are intimately related to the prices of domestic production activities. As a first step we therefore take a closer look at the magnitude of the change in effective prices for a domestic fragment that emerges from international fragmentation. The next step will then explore the factor price implications of a given pattern of such effective price changes, paying due attention to factor market clearing, in addition to the zero-profit conditions.

For step one, we resort to the simple case of two fragments. In this case

$$\pi_j^B = 1 - w^T a_j^A \quad (13)$$

is the imputed value, or effective price, that domestic producers receive per factor bundle a_j^B in their production of good j , prior to international fragmentation. Outsourcing of fragment A affects the domestic economy by changing this imputed effective price according to

$$d\pi_j^B = s_j^A, \quad (14)$$

where s_j^A is taken from 8 above. This implies, of course, that fragment A which is now produced in the foreign economy is imputed an effective price (and therefore also a cost) equal to

⁹In their model capital is a factor which is a substitute for a Leontief-aggregate of skilled and unskilled labor. An increase in the capital stock thus increases the productivity of this Leontief-aggregate and thus acts just like a technological improvement in our model.

$\alpha_j w^{*T} a_j^{*A}$. All of this is in line with the above mentioned downstream interpretation of fragment B . Remember once again our assumption of constant foreign factor prices w^* .

We can more easily draw on established results if the effective price change is expressed in relative terms. Relying on the familiar hat-notation, and noting that initially $\pi_j^B = w^T a_j^B$, we have

$$\begin{aligned}\hat{\pi}_j^B &= \frac{w^T a_j^A s_j^A}{w^T a_j^B w^T a_j^A} \\ &= \frac{w^T a_j^A}{w^T a_j^B} [(1 - \alpha_j \tau_j) - \alpha_j \tau_j \theta_j^{AT} \hat{w} + \alpha_j \gamma_j^* \theta_j^{*AT} \hat{a}_j].\end{aligned}\quad (15)$$

In this equation, α_j and τ_j must be interpreted as the fragmentation costs and the technology gap, respectively, that prevail after the hyperplane in theorem 1 has shifted such that (an increase in) fragmentation takes place. Moreover, following common notation, θ_j^A indicates a column vector of factor shares in the cost of fragment A at home, with superscript T again denoting vector transposition. A corresponding interpretation holds for θ_j^{*A} . A column vector \hat{w} denotes relative factor price differences between the home and the domestic economy, i.e., for factor m we have $\hat{w}_m = w_m^*/w_m - 1$. In the final term, we have $\hat{a}_{jm} = a_{jm}/a_{jm}^* - 1$, and $\gamma_j^* = (w^{*T} a_j^*) / (w^T a_j)$. This final term represents the factor intensity change that takes place when a fragment is outsourced. It is governed by the degree of substitutability among factors. For Leontief-technologies it is zero.

Equation 15 also applies to the case of many fragments. In that case, π_j^B must be interpreted as the effective price pertaining to the (composite) value-added activity remaining at home, while the term $(w^T a_j^A) / (w^T a_j^B)$ is interpreted as the cumulative cost of all fragments going offshore relative to those remaining at home. In turn, the bracketed term in 15 is replaced by weighted sums of the respective magnitudes for the individual fragments outsourced to the foreign economy, with their cost share in $w^T a_j^A$ serving as weights.

Since international fragmentation occurs only if condition 9 is satisfied, $\hat{\pi}_j^B$ is always positive. But for the factor price changes it is the *relative magnitude* of $\hat{\pi}_j^B$ across sectors that matters. It is thus important to see how this magnitude is determined. The determinants can be summarized by the following theorem, where a) through d) refer to the four consecutive terms of equation 15 above.¹⁰

Theorem 2 *Suppose the margin of international fragmentation shifts and some fragments of the industry j value-added chain are outsourced to the foreign economy. Then the remaining*

¹⁰Some of the channels highlighted by Theorem 2 are implicit in Deardorff (2001).

domestic fragments of industry j value-added will experience an increase in their effective price, the magnitude of which is determined as follows: a) The higher the initial cost of the fragments moved abroad relative to those staying behind, the higher the price increase. b) The costlier fragmentation and the bigger the Ricardian disadvantage of the foreign economy, the lower the price increase. The price increase is the larger, c) the more intensively the fragments outsourced use those factors that are relatively cheap abroad, and d) the easier it is for factors to be substituted for each other in the production of these fragments.

6 Factor price effects: A general Result

Given a certain sectoral pattern of effective price changes $\hat{\pi}_j^B$ determined according to Theorem 2, what are the effects on domestic factor prices? Figure 4 gives an illustration for an isolated change in π_2^B . In this figure, $b_2^B = a_2^B / (1 - w^T a_2^A)$ is the factor bundle which cost-minimizing producers of fragment B would employ to generate a dollar's worth of value-added in the production of good 2; see equations 11 and 10 above. I have also drawn the associated isoquant, labeled 2^B . In this simple case, it is relatively easy to determine the factor price effect of fragmentation. The change in $\hat{\pi}_2^B$ due to fragmentation (according to 15) shifts isoquant 2^B inward to a position like 2_f^B . Notice that integrated production of good 2, represented by the non-fragmentation isoquant 2, is no longer relevant. Instead, in line with theorem 2, the cost savings must be interpreted as a change in the effective price of fragment B, which in this case is the only industry-2-activity surviving in the domestic economy. Since it is the relatively labor intensive of the two remaining domestic activities that has increased in value, the Stolper-Samuelson logic tells us that there is a real wage increase, and a real income loss for capital owners in the home economy. Since the price of both final goods have been kept constant by construction of the argument, the real wage increase is more pronounced than in the textbook case of the Stolper-Samuelson theorem, while the real income loss to capital is less severe. In figure 4, this is reflected by the new factor price line w_f .

But obviously, this is no general result. Assume, for instance, that fragment B is less labor intensive than good 3. In this case, b_2^B lies to the southeast of a_3 , and fragmentation increases the imputed value of a relatively capital intensive activity, and the factor price change is quite different. An important point to note here, however, is that for this to be a full employment equilibrium outcome, the endowment ratio must lie below a_3 , which can only be the case if there are further commodities that are less labor intensive than good 3. This suggests that the crucial question is not whether outsourcing happens in a relatively labor intensive or a capital intensive industry, but whether the fragments staying behind are labor or capital intensive,

relative to domestic endowment. This idea can be formalized more generally along the lines of higher-dimensional trade theory as follows.

In the initial equilibrium, factor prices are determined by the following minimization problem:

$$G = g(p, V) = \min_w \{w^T V \mid c_i(w) \geq p_i\}, \quad (16)$$

where the minimum-value function $g(p, V)$ is the dual version of the GNP function. Hence, G represents initial GNP. It is through $g(p, V)$ that the factor market clearing conditions enter our analysis at this stage. Given the underlying technology which permits fragmentation, the initial factor price vector w satisfies the following conditions, where $i \in \{1 \dots N\}$ denotes final goods and $C \in \{1 \dots F\}$ denotes fragments

$$w^T a_i^C(w) \geq \pi_i^C \text{ or, equivalently,} \quad (17a)$$

$$w^T b_i^C(w) \geq 1, \quad (17b)$$

In these expressions, equality obtains for $i = j \in \{1 \dots K\}$, i.e., for all goods produced in the domestic economy. The factor bundles $a(w)$ and $b(w)$ in 17 are defined as in 2 and 11. We now explicitly indicate dependence of input bundles on factor prices.

Suppose now that changes in either α_i or τ_i give rise to shifts in the margins of international fragmentation for several industries. Associated with these shifts there will be multiple changes in effective prices $\hat{\pi}_i^B$. Within each sector i , then, firms move further components of their value-added offshore. In line with the notation above, we use a superscript B to denote the remaining domestic factor bundle which, together with the fragments now obtained from abroad, produces final good i . This may be a single fragment, or it may itself be composed of several fragments. Then, using a superscript f to denote the new equilibrium with enhanced fragmentation, we have

$$G^f = \tilde{g}(\pi, V) = \min_w \{w^T V \mid w^T a_i^B(w) \geq \pi_i^B(w) + s_i^A\}. \quad (18)$$

GNP is now expressed as a function of effective prices for value-added components, and the factor bundles a are defined by complete analogy to 2 above. The cost saving from international fragmentation, s_i^A , is defined as in 8 above. In view of 17b and 15, the new factor price vector w_f satisfies

$$w^f b_i^B(w^f) \geq 1 + \hat{\pi}_i^B. \quad (19)$$

Let us now assume that j^* denotes the industry with the largest effective price increase of all domestic industries. I.e., j^* is defined such that for the underlying change in the margins of international fragmentation $\hat{\pi}_{j^*}^B \geq \hat{\pi}_i^B$ for all $i \in \{1 \dots K\}$. Then, since initially the restriction 4 was satisfied with equality for j^* , factor prices $w(1 + \hat{\pi}_{j^*}^B)$ would obviously satisfy 19. Defining

$v^f = V/G^f$, 18 implies $w^f T v^f = 1$. At the same time we have $w^T (1 + \hat{\pi}_{j^*}^B) v^f \geq 1$, and therefore

$$\left[w^f - w (1 + \hat{\pi}_{j^*}^B) \right]^T v^f \leq 0. \quad (20)$$

Since, by construction of our argument, industry j^* has experienced the greatest savings from outsourcing, 19 must be satisfied with equality for $i = j^*$.

We now define $\tilde{b}_{j^*}^B(w^f) = b_{j^*}^B(w^f) / (1 + \hat{\pi}_{j^*}^B)$. This is an input bundle used in industry j^* which generates an effective value equal to 1, and which also represents factor costs equal to 1 at factor prices w^f . Prior to the shift in fragmentation, the activities involved in bundle B were carried out at a level $b_{j^*}^B(w)$, representing a value equal to 1 as well as unit factor cost at factor prices w . At the new effective price $1 + \hat{\pi}_{j^*}^B$, therefore, a reduced factor bundle $\tilde{b}_{j^*}^B(w) = b_{j^*}^B(w) / (1 + \hat{\pi}_{j^*}^B)$ generates an output value equal to 1, as does $\tilde{b}_{j^*}^B(w^f)$, but given that $\tilde{b}_{j^*}^B(w^f)$ is cost-minimizing at w^f , $\tilde{b}_{j^*}^B(w)$ must cost at least 1 at factor prices w^f . We thus have

$$w^f T \tilde{b}_{j^*}^B(w^f) = 1 \text{ and} \quad (21a)$$

$$w^f T \tilde{b}_{j^*}^B(w) \geq 1. \quad (21b)$$

Conversely, if $\tilde{b}_{j^*}^B(w^f)$ generates an output value equal to 1 at new effective prices, then an input bundle $\tilde{b}_{j^*}^B(w^f) (1 + \hat{\pi}_{j^*}^B)$ would have generated a unit output value at (lower) initial effective prices, as did $b_{j^*}^B(w)$. But since $b_{j^*}^B(w)$ was cost-minimizing at w , the factor cost of $\tilde{b}_{j^*}^B(w^f) (1 + \hat{\pi}_{j^*}^B)$ at w would be at least equal to 1. We therefore have

$$w^T b_{j^*}^B(w) = 1 \text{ and} \quad (22a)$$

$$w^T \tilde{b}_{j^*}^B(w^f) (1 + \hat{\pi}_{j^*}^B) \geq 1. \quad (22b)$$

This gives us

$$\left[w (1 + \hat{\pi}_{j^*}^B) - w^f \right]^T \tilde{b}_{j^*}^B(w^f) \geq 0, \quad (23)$$

and, combining 23 with 20, we finally have

$$\left[w^f - w (1 + \hat{\pi}_{j^*}^B) \right]^T \left[\tilde{b}_{j^*}^B(w^f) - v^f \right] \geq 0. \quad (24)$$

The vector in the first bracket in this expression gives the difference between new factor prices and hypothetical factor prices that would obtain, if the highest of all effective price increases experienced by domestic industries for their respective remaining domestic value-added components were passed through proportionally to all factors. If this difference is positive (negative), we may say that the respective factor receives a more (less) than proportional rise in its rental. In other words, this vector is a measure of distributional changes between different factor owners, that is brought about by the underlying scenario of international fragmentation. In

turn, the second bracket gives the difference between domestic factor endowments, normalized by “post-fragmentation” GNP, and the respective amounts of factors used as inputs by industry j^* in their remaining domestic fragments to generate an effective value equal to 1. If this difference is negative (positive), we may say that the respective factor is used relatively intensively in the remaining value-added chain. We can state inequality 24 as the following Theorem:

Theorem 3 *Suppose there are multiple shifts in margins of international fragmentation for several industries, with associated changes in effective prices for remaining domestic value-added chains. Suppose, moreover, that the largest of all effective price increases is observed in industry j^* . Then, factors which are used intensively in the remaining domestic value-added chain of industry j^* , relative to domestic endowments, will on average receive a more than proportional increase in their rental.*

We may also state the same result in terms of a correlation coefficient. As is well known, the usual correlation coefficient between two variables has the same sign as the inner product of these variables if any of them has a zero mean. We now define

$$\omega_m = 1 - w_m (1 + \hat{\pi}_{j^*}^B) / w_m^f. \quad (25)$$

This expresses in relative terms the difference between the rental received by factor m in the new equilibrium and the factor price that it would receive if the effective price increase $\hat{\pi}_{j^*}^B$ had been passed through proportionally to all factors. This latter case is a notional situation which would preserve the initial income distribution. Notice that for some factors ω_m is negative. Moreover, we define

$$\phi_m = w_m^f \tilde{b}_{j^*m}^B(w^f) - w_m^f v_m^f, \quad (26)$$

which measures the difference between the share of factor m in the “post-fragmentation” domestic value-added chain of industry j^* and the share of this factor in GNP. Then, in view of equation 21a, and in view of the fact that $w^{fT} v^f = 1$, inequality 24 gives Theorem 4:

Theorem 4 *The correlation coefficient between ω_m and ϕ_m across factors is positive.*

Figure 5 illustrates the content of Theorems 3 and 4, focusing on the case of two factors and many commodities. The heavy line HH characterizes the initial situation, prior to a shift in the margins of fragmentation. It is the convex hull of all unit-value activities, including individual fragments evaluated at their respective effective prices defined, as in 13 above.¹¹ For instance,

¹¹Graphical reasoning akin to figure 5 has also been employed by Jones & Kierzkowski (2001b).

HH is tangent to the unit-value isoquant for final good j^* if the domestic economy features an integrated production of commodity j^* before the margin of fragmentation shifts. Isoquants j^{*A} and j^{*B} represent unit-value quantities for two fragments of industry j^* value-added, which are both produced domestically in the initial equilibrium. Their position reflects their effective prices as defined above. The various factor bundles a and b are as defined above. There are numerous further unit-value isoquants touching HH , of which I have only drawn (arbitrarily) fragment B of industry i . The initial factor price line must be tangent to HH , as drawn for w , with the domestic endowment being at point V . Notice that endowments are important here: The endowment ray OV must cross HH at a point where it touches the line w .

Suppose now that there is some change in α_i and τ_i , so that the margins of fragmentation shift simultaneously for several industries. Theorem 1 above allows us for each final good to separate the fragments that leave the home economy from those staying at home, and theorem 2 determines the effective price change for the remaining composite domestic value-added process. There will thus be a multitude of effective price changes $\hat{\pi}_i^B$, where B indicates for each value-added process i the (composite) value-added activity remaining to be produced domestically. For each final good, we may depict a unit value isoquant representing the remaining composite domestic value-added, and these isoquants will shift inwards in accordance with $\hat{\pi}_i^B > 0$. There will be an industry j^* with $\hat{\pi}_{j^*}^B \geq \hat{\pi}_i^B$ for all $i \in \{1 \dots K\}$. The factor price line $w(1 + \hat{\pi}_{j^*}^B)$ would obtain if this effective price increased were fully passed on to both factor prices (in proportional amounts). Given factor endowments V , however, it is clear that this cannot be a full employment equilibrium. Specifically, if $b_{j^*}^B$ lies below the ray OV , then the post-fragmentation factor price line w^f must be steeper than $w(1 + \hat{\pi}_{j^*}^B)$.

What the shifts in the margins of fragmentation have done in this figure is changing the position of the line HH to $H^f H^f$ which is for instance also tangent to a new “post-fragmentation” unit-value isoquant i^{Bf} . But by definition of sector j^* , the shift from i^B to i^{Bf} is smaller, proportionally, than that from j^{*B} to j^{*Bf} , hence the steeper new factor price line w^f . It is easy to see that the opposite effect obtains if $b_{j^*}^B$ is steeper than the endowment ray OV . This is the essence of Theorems 3 and 4.

It is worth pointing out that the factor intensity of the value-added chain that gets fragmented as a whole is irrelevant for the factor price change. So is the factor intensity of the fragments that move to the foreign country. Instead, factor prices are driven by the changes in effective prices for those value-added fragments that firms keep producing domestically after the margin of fragmentation has shifted. These effective price changes are driven by several forces, as highlighted in Theorem 2. Theorems 3 and 4, in turn, highlight how the factor intensities of the domestic fragments and domestic endowments together determine domestic factor price changes.

Notice also that the volume of fragmentation and trade brought forth by a change in the margins of fragmentation is immaterial, as such. In line with established results of trade theory, the story is essentially one of prices, not volumes.

7 Concluding remarks

International fragmentation, or outsourcing, is a relatively new phenomenon which is often thought to have quite dramatic effects on industrial countries, particularly on their factor prices and their internal distribution of income. In this paper, I have investigated the nexus of international fragmentation and domestic income distribution in a general trade-theoretic framework. I have highlighted the role that Ricardian productivity differences as well as factor price differences between countries play as incentives for international fragmentation. This role increases in significance if technological advances and international trade policies effectively move countries closer together, thus also reducing the cost of an international fragmentation of value-added processes. Economic globalization may thus be seen as shifting the margin of international fragmentation that separates components of a given value-added chain which are still economically viable to produce domestically from those which are not, because they can more cheaply be procured through production offshore.

A key result of the paper is that the factor price effect of international fragmentation is best understood as emerging from a change in effective prices for those fragments which remain in the domestic part of the value-added chain. However, international fragmentation, like globalization in general, does not affect all sectors equally. Hence, it is important to know the different forces that lie behind these effective price changes. This allows one to address sectoral differences. I have shown that the crucial forces generating such differences are the cost shares of the fragments that move offshore, as well as the interplay between factor price differences and the factor intensities of these fragments. Further channels of influence are opened up by Ricardian differences in productivity, as well as the cost of international fragmentation. The factor intensities of those fragments kept for domestic production, in turn, determine the domestic factor price and income distribution effects. More specifically, the crucial points are which industry observes the highest such effective price increase, and whether the domestic fragments of this industry are intensive in the use of labor of the skilled or unskilled type, or of capital, relative to the overall endowment of the economy. I have demonstrated how the workings of these factors can be pinned down in the spirit of modern higher-dimensional trade theory.

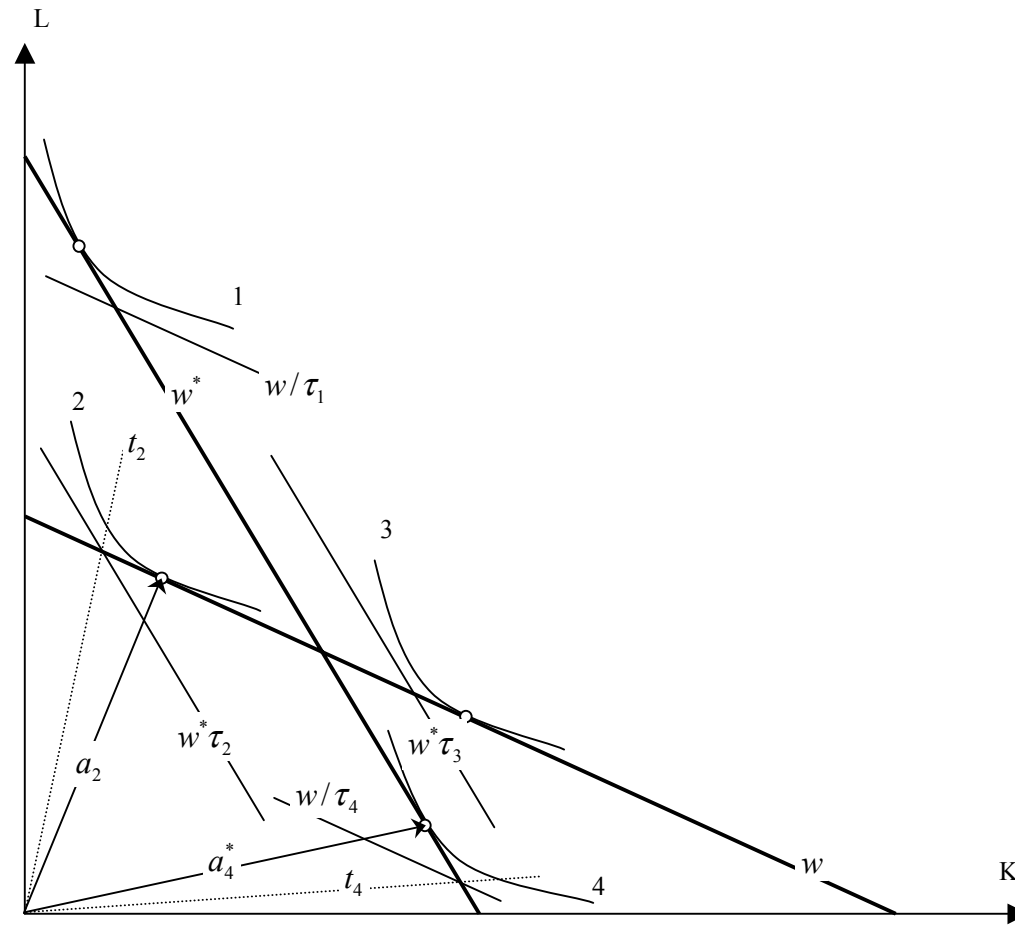


Figure 1: Pre-fragmentation trading equilibrium

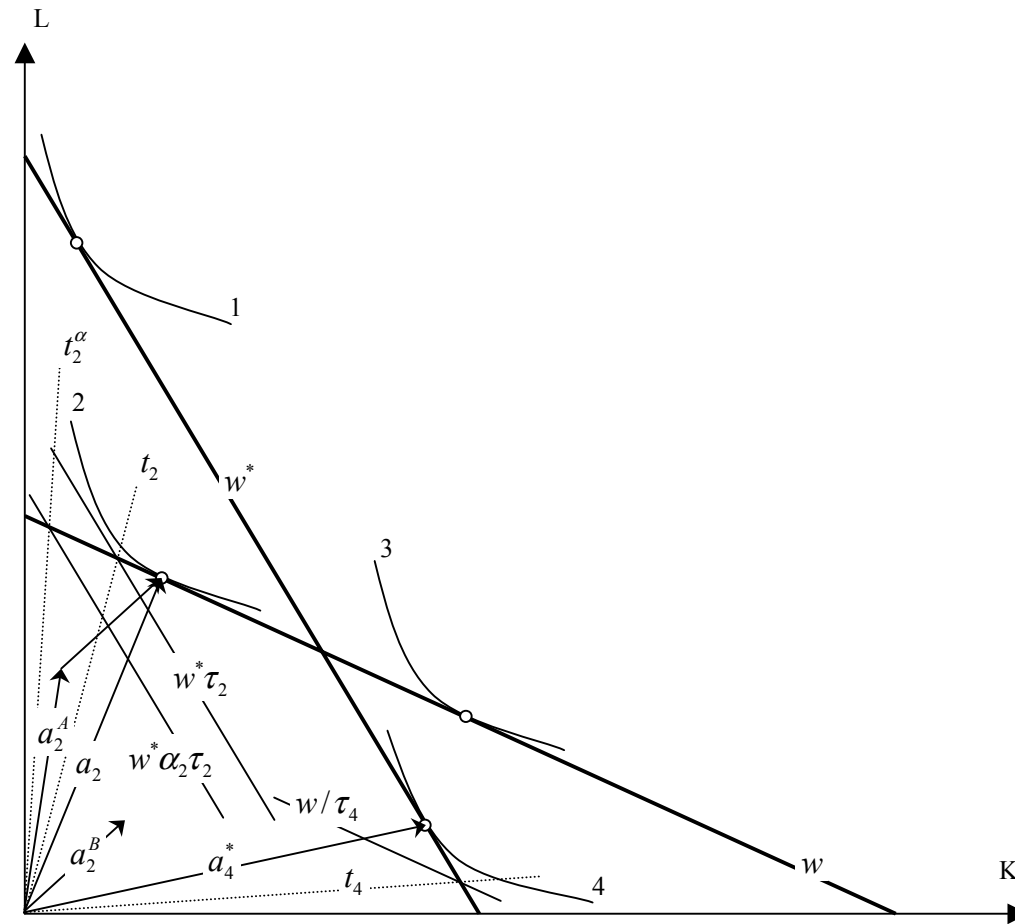


Figure 2: Costly, but cost-saving international fragmentation

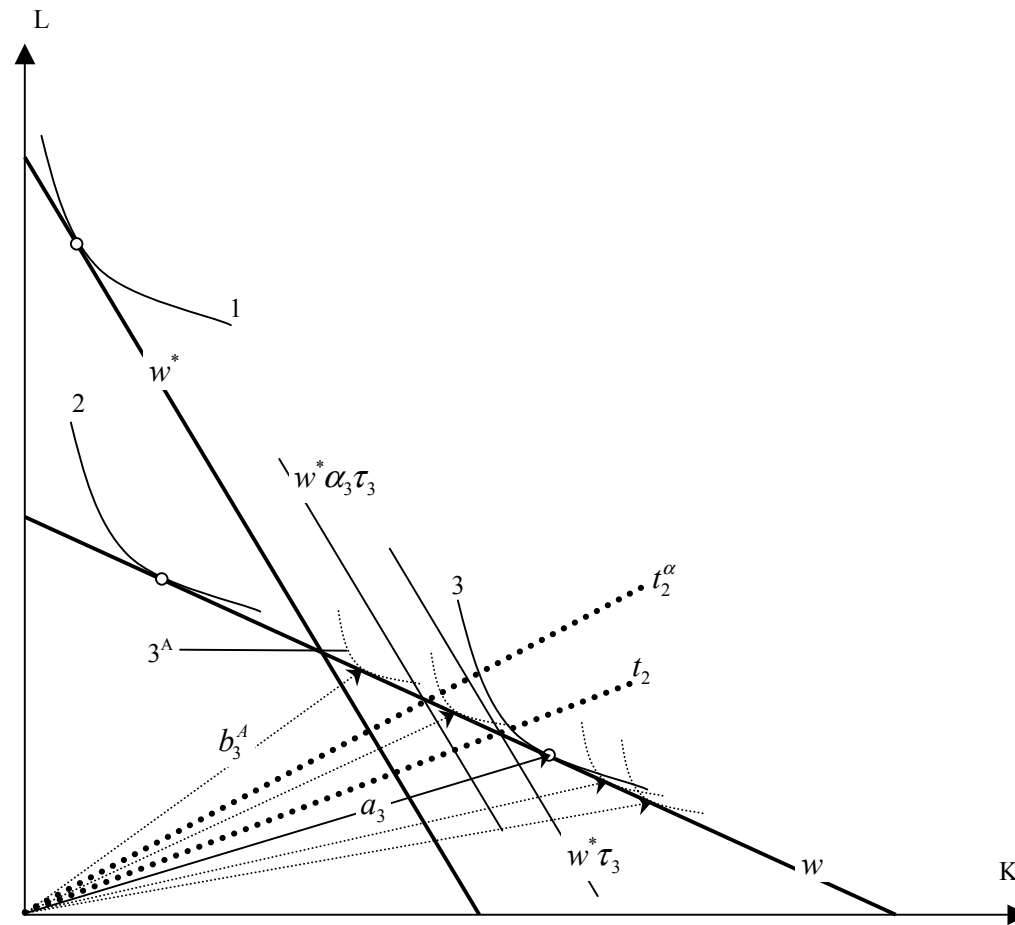


Figure 3: A demarcation line for international fragmentation

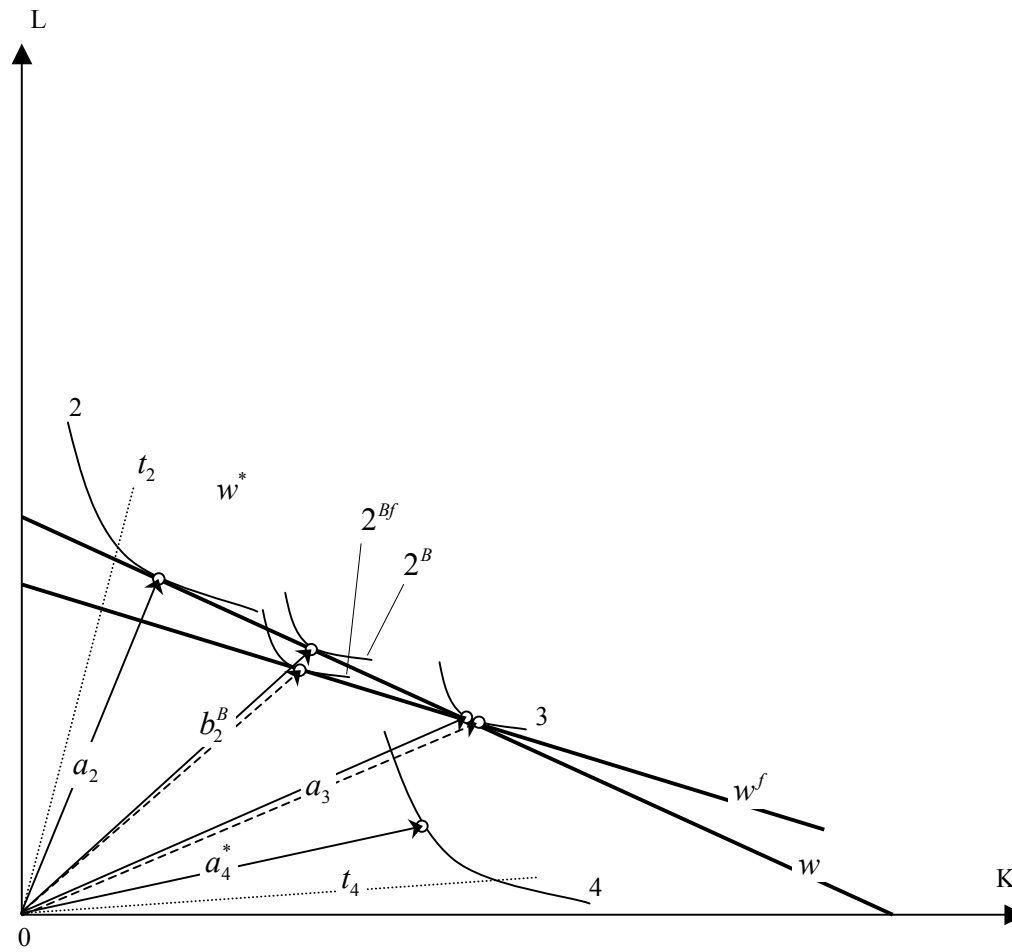


Figure 4: Effective price change through fragmentation

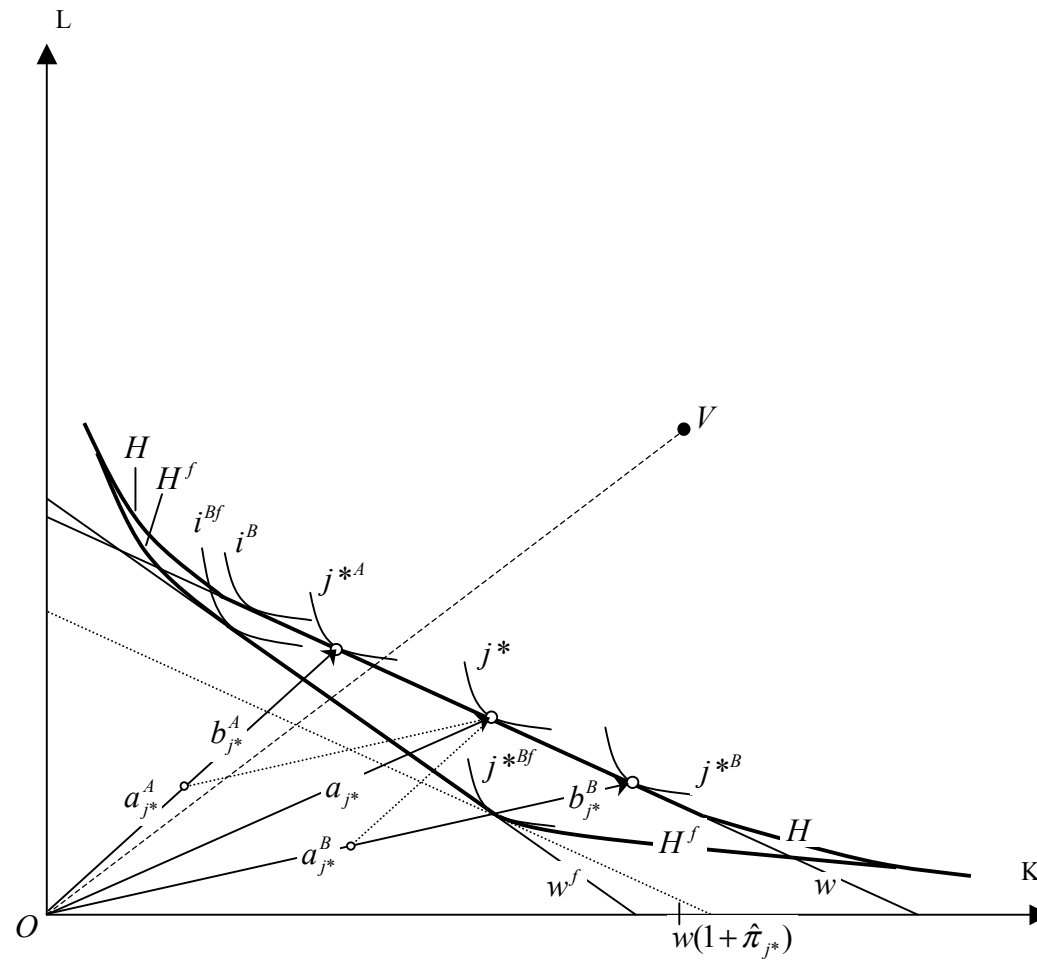


Figure 5: Factor price effect of international fragmentation

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