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Offshoring: General Equilibrium Effects on Wages, Production and Trade

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Abstract
A simple model of offshoring is used to integrate the complex gallery of results that exist in the theoretical offshoring/fragmentation literature. The paper depicts offshoring as 'shadow migration' and shows that this allows straightforward derivation of the general equilibrium effects on prices, wages, production and trade (necessary and sufficient conditions are provided). We show that offshoring requires modification of the four HO theorems, so econometricians who ignore offshoring might reject the HO theorem when a properly specified version held in the data. We also show that offshoring is an independent source of comparative advantage and can lead to intra-industry trade in a Walrasian setting.

JEL: F02, F12, L22, R11
Keywords: Offshoring, Shadow migration, Inter-industry trade, Intra-industry trade, Trade theorems

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1. Introduction

The fragmentation and offshoring of production processes has been an important phenomenon for many years (Hummels, Ishii, and Yi 2001), having started in earnest in the mid-1980s in East Asia and across the US-Mexico border. Ando and Kimura (2005) and Urata (2001), for example, document the linked rise of foreign direct investment, offshoring, and parts and components trade by Japanese firms in East Asia. In North America, the 1980s saw the widespread emergence of 'twin plants' (one on either side of the US-Mexico border) under the Maquiladora programme (Dallas Fed 2002, Feenstra and Hanson 1996). More recently, offshoring has spread from the manufacturing to the service sector (Amiti and Wei 2005).

The empirical effects of offshoring on wages and production do not sit easily with simple partial equilibrium models that view one job shifted overseas as one job lost. For example, in both the US and Japanese cases, the widespread offshoring of unskilled manufacturing jobs that started in the mid-1980s was not accompanied by a general decline in manufacturing employment until the late 1990s (Debande 2006). Likewise, two recent studies of micro data find that find that expansion of employment in affiliates in low income countries raises the skill intensity of domestic production (see Head and Ries 2002 on Japanese data and Geishecker and Gorg 2004 on German data). Understanding such effects requires a general equilibrium framework where wages and prices adjust to offshoring. Responding to this need, some of the world's best trade economists have put forth general equilibrium models of offshoring/fragmentation. As we argue in the sequel, these models can be viewed as a collection of insightful special cases. In addition, many of them have a complex structure that forced their authors to rely on numerical simulations to study their equilibrium properties.

The purpose of our paper is to present a simple model of offshoring that integrates and extends the complex gallery of results that have been derived in the theoretical offshoring/fragmentation literature.[1] Our baseline model of offshoring finds firms unbundling the production process and putting fragments of it abroad to take advantage of low cost foreign factors of production. Importantly, our model avoids the analytic complexity of multi-cone models and factor-intensity reversals. Non-factor-price-equalisation exists under free trade due to Hicks-neutral technological differences among nations. Offshoring by the technologically advanced nation is cost saving since offshoring firms can

[1] In many instances, these papers do not provide the necessary and sufficient conditions for the effects they emphasize.

take their superior technology with them.[2] Since neither nation is specialised in production, our baseline model can be studied in the familiar setting of Jones (1965) and this allows us to consider a wide range of effects including the impact of offshoring on the four theorem of Heckscher-Ohlin trade theory. In particular, we show that offshoring leads to intra-industry trade in a perfectly competitive, Heckscher-Ohlin-like setting and that offshoring is, by itself, a source of comparative advantage. The general equilibrium incidences on production, prices and wages are shown to be ambiguous in general and we characterise the factors that lead the ambiguity to resolve itself in one direction or the other. Importantly, we find that the factor owners of the offshoring nation are typically better off as a result of fragmentation (controlling for terms of trade effects).

We also show how the model can be extended to allow intra-firm as well as international trade in fragmented production and how this implies that the gains from offshoring are shared more between nations and factor within nations. In this extension, the gains from offshoring are shared evenly between nations and factor within nations. Finally, we modify the model to allow for two-way intra-industry offshoring – an important extension since the largest importers and exporters of offshored services are the United States and other large OECD countries (Amiti and Wei 2005).

Review of the literature

Early on, the Heckscher-Ohlin (HO) theory saw a number of contributions that incorporated trade in intermediate goods (see Batra and Casas 1973, and Dixit and Grossman 1982), but the most commonly cited reference in the offshoring/fragmentation literature is Jones and Kierzkowski (1990). The Jones-Kierzkowski paper crystallised the insight that fragmentation/offshoring can be thought of as technological progress and thus should be expected – as per Jones (1965) – to have complex and ambiguous effects on wages, prices, production and trade. This line of modelling – which includes Jones and Findlay (2000, 2001), Jones and Kierzkowski (1998, 2000), Jones and Marjit (1992), and Jones, Kierzkowski and Leonard (2002) – is based on verbal, diagrammatic analysis (typically of small open economies) that assumes fragmentation occurs in only one sector and in one direction. See Francois (1990a,b,c) for formal, general-equilibrium modelling of the central mechanism in the Jones-Kierzkowski fragmentation story – the way in which the liberalisation of service links can promote the fragmentation of production blocks.[3]

[2] This assumption was inspired by one of the models in Grossman and Rossi-Hansberg (2006b), August 2006 version, specifically the Section 3.2 model.

[3] Francois (1990c) explicitly considers the impact of offshoring on the factor price equalization set.

The general equilibrium impact of Jones-Kierzkowski fragmentation varies according to the special case considered, with cases varying along three main dimensions: the factor intensity of the sector that is fragmented, the factor intensity of the process that is offshored, and the offshoring nation's relative endowment. The Jones and Kierzkowski (1998) diagrammatic analysis yields examples that suggest two important insights – what might be called the "Jones ambiguity" and the "anti-Stolper-Samuelson possibility." Using a pair of special cases, Jones and Kierzkowski (1998) argue that workers whose jobs are "lost" to offshoring may see their wages rise in one case, but fall in the other.[4] The "anti-Stolper-Samuelson" insight, which stems from viewing fragmentation as technological progress, notes that freer offshoring/fragmentation – unlike freer trade in goods – need not produce winners and losers among factor owners. The second insight is demonstrated when they show that offshoring can raise all real wages in certain special cases.[5]

Contributions that study the price, wage, production and trade effects of offshoring in explicit mathematical models include Venables (1999), Markusen (2005), and Deardorff (1989a, b). These papers present a gallery of special cases that firmly establish the ambiguous sign of the general equilibrium price, production, trade and factor price effects. A linchpin issue facing all general equilibrium models in this literature is the question of how offshoring can be cost-saving when international trade in goods naturally leads to factor price equalisation. To address this issue, these papers work in models marked by non-factor price equalisation. Since non-factor price equalisation typically prevents utilisation of the elegant Jones (1965) tools, the analysis in these papers is quite complex. To keep the analysis manageable, all these authors assume that offshoring/fragmentation occurs in only one sector and only in one direction.

Deardorff (1989a,b) studies fragmentation in a range of explicit models using graphical analysis. The main formal analysis, however, concerns a HO setting where cost-saving offshoring occurs since nations' endowments are assumed to lie in different diversification cones. Deardorff (1989a) argues that fragmentation/offshoring may or may not foster factor price convergence. Working with Lerner-Pearce diagrammatic analysis of a general model with fragmentation in a single sector, he notes "if you accept this argument, then such a move toward factor price equality is not at all assured. It depends crucially on … the factor intensities both of the fragments and of the original technology.

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[4] Referring to a HO model with capital and labour, Jones and Kierzkowski (1998, p. 373) write: "the charge that if international trade causes a nation to lose a production activity which is intensive in the use of labour, it will cause the wage to fall, need not be true – especially for relatively capital-abundant nations."

[5] Jones and Kierzkowski (1998, p. 380) write: "But even here the prognosis for a nation's labour supply need not be gloomy, since such fragmentation tends as well to work like technical progress in raising the returns to all factors."

There are many possibilities, including that relative factor prices move in the same direction in both countries and that they both move either together or further apart. (p. 14)" Necessary and sufficient conditions are not established. He then moves to explicit mathematical analysis using a 2-nation, 2-factor, many-good, multi-cone HO model with Cobb-Douglas tastes and technology. He derives explicit expressions for relative factor prices in the two nations, showing that the wage ratios depend upon the national capital-labour ratios and national weighted average of the factor intensity of produced goods. Fragmentation changes the latter and can thus lead to a convergence or divergence of relative factor prices (no expressions are given for the level of factor prices). The paper concludes by noting that "the effects on relative factor prices in the countries where the fragmentation takes place depend fairly systematically on the factor intensities of the fragments, as well as that of the original technology. What matters, however, is how these factor intensities compare to the average intensities of processes in use in each country before fragmentation, not their intensities compared to all goods produced globally." Necessary and sufficient conditions for relative factor price convergence are not derived but are implicit in the expressions.

Venables (1999) works with a standard 2x2x2 HO model and generates non-factor-price equalisation with a factor intensity reversal. Nations can thus have different factor prices without being specialised in production. As in the Jones-Kierzkowski tradition, fragmentation occurs in only one industry and offshoring occurs in only one direction (the labour-intensive segment is offshored to the labour abundant nation). Using numerical simulations and Lerner-Pearce diagrammatic analysis, he concludes that "production fragmentation does not necessarily lead to convergence of factor prices," and provides examples of both cases without developing necessary and sufficient conditions. The paper goes on to note that "fragmentation may change factor prices by changing the composition of Home exports, as well as imports" and that "it is possible to generate some curious cases in which it is the relatively capital intensive industry, not the labour intensive which leaves Home for Foreign," (curious since Home is capital-rich).

Markusen (2005) also works with a 2x2x2 HO model where one sector fragments, and he, like Deardorff, generates non-factor-price equalisation by assuming the two nation are in different diversification cones (i.e. their endowments are so different that they produce no goods in common in equilibrium). Analytic results with multi-cone models are difficult (due to the inequality constraints), so the paper studies offshoring/fragmentation via numerical simulations. Fragmentation is assumed to occur in the skill-intensive sector and the offshored segment is assumed to be of middling skill-intensity. Offshoring therefore tends to increase the relative demand for skilled labour in both nations and thus the skill premium, but terms of trade effects can – depending upon the nations' relative sizes

– reverse this direct effect. One of the numerical simulations even shows the possibility of both factors losing in the offshoring nation (necessary and sufficient conditions are not established). Another simulation shows an anti-Stolper-Samuelson result whereby the skilled workers in the unskilled-labour-rich nation gain from offshoring in an absolute sense, but they gain less than their fellow unskilled workers. Markusen (2005) acknowledges the limitation of his examples: “In spite of doing countless runs of this model, I cannot guarantee that there are not other possibilities and, of course, reordering the factor intensities will change the results. What I can say is that it is easy to find ranges of parameters that generate these results, but we should all regard them as suggestive and not definitive.” The paper goes on to simulate four other models that vary in terms of the number of factors, the substitutability of factors in various sectors, and the factor-intensity of the offshored process and offshoring sector. The paper closes by noting “I view the paper as listing a number of plausible and empirically-relevant ways of modelling the offshoring of white-collar services…. Unfortunately, it is hard to offer robust conclusions.”

More recently, Grossman and Rossi-Hansberg (2006a) – GRH for short – present a formal model that highlights the case where offshoring unambiguously raises the wage of workers whose jobs are offshored (controlling for terms of trade effects). The unambiguous effect is driven by the fact that offshoring acts a technology progress – what they call the productivity effect. Grossman and Rossi-Hansberg (2006b) explore the issues in greater deep, confirming the unambiguous productivity effect on wages. GRH also identify an anti-Stolper-Samuelson effect. They argue (using ‘trade in tasks’ as a synonym for offshoring) that “reductions in the cost of trading tasks can generate shared gains for all domestic factors, in contrast to the distributional conflict that typically results from reductions in the cost of trading goods. (GRH 2006b, abstract)” GRH present an array of models to illustrate their findings, but the common core of their models is a technological specification akin to the Dixit and Grossman (1982) model. In Dixit-Grossman, final good production involves of continuum of intermediate production stages, each of which requires capital and labour; the production stages are strict complements in that producing the final good requires each one to be performed in fixed proportions. In GRH, final good production involves continuums of ‘tasks’ (rather than stages), with each task requiring only unskilled labour (*L*-tasks) or only skilled labour (*H*-tasks). Substitution between the *L*-task and *H*-task continuums is possible, but *L*-tasks are strict complements in that producing the final good requires each task to be performed in fixed proportions; the same holds for *H*-tasks.

Organisation of paper

The next section, Section 2, presents a modified Heckscher-Ohlin model and briefly lays out the four standard trade theorems in order to fix ideas and introduce notation. The next section presents our model of offshoring, characterises the equilibrium. Section 3 then shows how offshoring requires a modification of the four standard trade theorems; this section also integrates various special cases that we reviewed above. Section 4 presents our extensions. In one of them, we study two-way offshoring. The final section presents our concluding remarks.

2. Trade in goods in a modified HO model

To introduce our notation and normalisations, we introduce the familiar 2x2x2 Heckscher-Ohlin (HO) model and demonstrate the four theorems. The model assumes two nations, Home and Foreign, two final goods, X and Y, and two primary factors, human capital (K) and labour (L). Tastes are homothetic and identical across nations; Foreign is relatively abundantly endowed with labour, and Y is the K-intensive good, i.e.:

$$\kappa_Y > \kappa_X\,; \qquad \kappa_Y \equiv \frac{a_{KY}}{a_{LY}}, \quad \kappa_X \equiv \frac{a_{KX}}{a_{LX}} \tag{1}$$

where κ_i is the capital intensity of sector-i and the Leontief a_{ij}'s employ the standard factor- and sector-subscript notation.

Home is assumed to be technologically superior in the Hicks-neutral sense (Davis 1995, Trefler 1993). Specifically, all Foreign unit input requirements are $\gamma > 1$ times higher than Home's. Since $a_{ij}{*} = \gamma a_{\text{ij}}$ ("*" indicates Foreign variables), (1) also holds for Foreign technology. Note that the Hicks-neutral technology differences do not give rise to Ricardian motives for trade in our model. Indeed, we can mechanically transform the model into a standard HO model by defining Foreign factor supplies in 'effective units', i.e. dividing L^* and K^* by the technological-inferiority-factor γ.

In autarky, the Home or Foreign equilibriums are characterised by two pricing equations, two employment equations and a market clearing condition. The pricing equations in the two nations are:[6]

$$\begin{bmatrix} 1 \\ p \end{bmatrix} = \mathbf{A}^{\mathbf{T}} \begin{bmatrix} w \\ r \end{bmatrix}, \qquad \begin{bmatrix} 1 \\ p^* \end{bmatrix} = \gamma \mathbf{A}^{\mathbf{T}} \begin{bmatrix} w^* \\ r^* \end{bmatrix}; \qquad \mathbf{A} \equiv \begin{bmatrix} a_{LX} & a_{LY} \\ a_{KX} & a_{KY} \end{bmatrix} \tag{2}$$

[6] In general, these should be inequalities; we use equalities since we assume that parameters are such that both nations' production structures are diversified at the sectoral level with free trade, i.e. they share a diversification cone. This requires them to have sufficiently similar endowment ratios (the precise condition is listed below).

where X is numeraire, p denotes the price of Y, w and r are the rewards for unskilled labour (L) and skilled labour (K), respectively ('T' indicates the matrix transpose). The employment equations are:

$$\begin{bmatrix} L \\ K \end{bmatrix} = \mathbf{A}\begin{bmatrix} X \\ Y \end{bmatrix}, \qquad \begin{bmatrix} L^* \\ K^* \end{bmatrix} = \gamma\mathbf{A}\begin{bmatrix} X^* \\ Y^* \end{bmatrix} \tag{3}$$

Market-clearing conditions for Home and Foreign in autarky and the world (with free trade) are:

$$\frac{pY}{X} = \frac{\alpha E}{(1-\alpha)E}, \qquad \frac{p^*Y^*}{X^*} = \frac{\alpha E^*}{(1-\alpha)E^*}, \qquad \frac{pY^w}{X^w} = \frac{\alpha E^w}{(1-\alpha)E^w} \tag{4}$$

with Cobb-Douglas preferences (α is Y's expenditure share). The E's are GDP (expenditure) in terms of the numeraire.[7]

2.1. Free trade in goods and the 4 theorems

Assuming neither nation specialises, (2) and (3) yield the equilibrium wages and outputs:

$$\begin{bmatrix} w \\ r \end{bmatrix} = \left(\mathbf{A}^{\mathbf{T}}\right)^{-1}\begin{bmatrix} 1 \\ p \end{bmatrix}, \qquad \begin{bmatrix} w^* \\ r^* \end{bmatrix} = \frac{1}{\gamma}\left(\mathbf{A}^{\mathbf{T}}\right)^{-1}\begin{bmatrix} 1 \\ p \end{bmatrix}, \qquad \begin{bmatrix} X \\ Y \end{bmatrix} = \mathbf{A}^{-1}\begin{bmatrix} L \\ K \end{bmatrix}, \qquad \begin{bmatrix} X^* \\ Y^* \end{bmatrix} = \frac{1}{\gamma}\mathbf{A}^{-1}\begin{bmatrix} L^* \\ K^* \end{bmatrix} \tag{5}$$

Autarky and free trade equilibrium factor prices, which follow from (5) and (4), are:

$$\begin{aligned} &\text{Autarky:} \quad p = \frac{\alpha/(1-\alpha)}{a_{LX}/a_{LY}}\left(\frac{\kappa_Y - k}{k - \kappa_X}\right), \qquad p_Y^* = \frac{\alpha/(1-\alpha)}{a_{LX}/a_{LY}}\left(\frac{\kappa_Y - k^*}{k^* - \kappa_X}\right) \\ &\text{Trade:} \quad p = \frac{\alpha/(1-\alpha)}{a_{LX}/a_{LY}}\left(\frac{\kappa_Y - \tilde{k}^w}{\tilde{k}^w - \kappa_X}\right) \end{aligned} \tag{6}$$

where the lower-case k's are national endowment ratios, i.e. $k \equiv K/L$ and $k^* \equiv K^*/L^*$ and $\tilde{k}^w$ is the world capital-labour ratio measured in effective units, namely $\tilde{k}^w \equiv (K + K^*/\gamma)/(L + L^*/\gamma)$. We use "~" to denote factor supplies measured in effective units. The non-specialisation regularity condition – i.e. $\kappa_X < k^* < \tilde{k}^w < k < \kappa_Y$ – implies that all endogenous variables are positive in equilibrium.

The Factor Price Equalisation (FPE) theorem states that free trade equalises factor prices internationally by equalising goods prices. Here the FPE theorem holds but for 'effective' units of factors, i.e. counting an hour of Foreign labour as $1/\gamma$ times an hour of Home labour. From (5), the international ratio of wages in terms of the numeraire is γ.

[7] Specifically, preferences are given by $U=X^{1-\alpha}Y^{\alpha}$ and $E=X+pY=wL+rK$ in Home, with an isomorphic definition for E^*.

The Heckscher-Ohlin (HO) theorem states that the nation that is *L*-rich nation exports the *L*-intensive good and imports the *K*-intensive good. Home imports of *X*, using (5) and (6), are:

$$M_X = \frac{\alpha L}{a_{LX}}\left(\frac{k-\tilde{k}^w}{\tilde{k}^w-\kappa_X}\right) \tag{7}$$

where M_X is our notation for Home imports of *X*. Since the denominator is positive (the world's endowment is within the diversification cone), Home imports the *L*-intensive good if and only if its capital-labour endowment ratio exceeds the world's effective capital-labour endowment ratio. This demonstrates the Heckscher-Ohlin theorem since trade balance implies that the value of Home's exports of *Y* equals $-M_X$.

The Stolper-Samuelson theorem is a partial equilibrium result (*p* is exogenous) that connects goods and factor prices; a rise in the price of the *K*-intensive good raises *r* more than proportionally and lowers *w*. This can be seen from log differentiation of the solution for *w* and *r* in (5):

$$\frac{dw/w}{dp/p} = \frac{-p}{a_{KY}/a_{KX}-p} < 0, \qquad \frac{dr/r}{dp/p} = \frac{p}{p-a_{LY}/a_{LX}} > 1 \tag{8}$$

This means that *r* rise more than proportionally with p and *w* actually falls, so qualitatively the *w* and *r* changes are real wage changes. (The inequalities follow from our factor intensity assumptions as usual.)

The Rybczynski theorem is a partial equilibrium result (*p* is exogenous) which states, in its simple form, that a rise in a nation's endowment of *L* raises its production of the *L*-intensive good more than proportionally and lowers its production of the other good. By log differentiation of the solution for *X* and *Y* in (5):

$$\frac{dX/X}{dL/L} = \frac{\kappa_Y}{\kappa_Y-k} > 1, \qquad \frac{dY/Y}{dL/L} = \frac{\kappa_X}{\kappa_X-k} < 0 \tag{9}$$

3. A model of offshoring and trade in tasks

This section modifies the HO model to allow for offshoring/fragmentation. We model the production of *X* as involving three "tasks" labelled *X1*, *X2* and *X3*, which can be thought of segments of the production process (in which case the output of each task is an intermediate good), or service inputs. Likewise, *Y* production involves tasks *Y1*, *Y2* and *Y3*. In the HO model, the tasks were bundled into a_{LX} and a_{KX}. Here we allow them to be unbundled and their production potentially placed abroad, i.e. offshored. Each task involves some *L* and K, so the a_{ij}'s can be decomposed into task-by-task Leontief unit input coefficients:

$$a_{LX} \equiv a_{LX1} + a_{LX2} + a_{LX3}, \qquad a_{KX} \equiv a_{KX1} + a_{KX2} + a_{KX3} \tag{10}$$

where the L and K unit inputs for task-i in sector j denotes as a_{Lji} and a_{Kji}. The coefficients for Y are decomposed into task requirements in an isomorphic manner. In the spirit of the HO model, the international transportation of the fruit of each task is costless.

A key to offshoring is our assumption that firms that offshore a task (i.e. place its production abroad) can combine their own nation's technology with labour in the other nation, paying the local wage rather than marginal products. In this way, offshoring from the high-technology/high-wage nation to the low-technology/low-wage nation may be economic even with effective factor price equalisation. Offshoring from the low-technology nation to the advanced-technology nation, by contrast, will never be economic.

While offshoring tends to reduce costs, it may not occur if the costs of coordinating spatially separated tasks are too great. To be explicit about the coordination costs and the nature of tasks, we assume that individual tasks are not equally easy to separate spatially from the other two tasks. We model the coordination costs as being of the iceberg type. That is, production of a unit of *X1* by a Home firm in Foreign requires $\chi(X1)a_{LX1}$ and $\chi(X1)a_{KX1}$ units of L and K, where $\chi(X1) \geq 1$. Note that it is as if offshoring causes deterioration in the offshoring firm's production technology (due to the extra coordination costs). $\chi(i)$ varies according to the task and, without loss of generality, we order the tasks such that task *X1* is the cheapest to offshore, *X2* the next cheapest and *X3* the most expensive. We impose an isomorphic ordering on *Y*-sector tasks.

The per-unit offshoring costs χ related to the cost of coordinating spatially separate tasks within the same firm. Presumably, it is much harder to coordinate when tasks are performed by different firms. While it is possible to model this decision more precisely, doing so would make it difficult to compare offshoring as trade-in-tasks with traditional trade in goods. This leads us to introduce an extra set of coordination-cost parameters that simplify the problem. It costs $\chi(X1)$ to offshore task *X1* to Foreign when tasks *X2* and *X3* are undertaken by the same firm in Home, but is costs $\zeta(X1)$ to coordinate the three tasks when task *X1* is done in a separate firm from task *X2* and *X3* – and this regardless of whether they are undertaken in the same nation. (The same holds for all the other tasks.) For the time being, we assume that the outsourcing costs ζ's are sufficiently high to make inter-firm trade in tasks uneconomical (we relax this assumption later on). Thus even if Home firms offshore task *X1* to Foreign, they will not supply task *X1* to Foreign producers. An assumption that we maintain throughout is that both countries remain diversified.

Deviation analysis

Now consider the issue of whether offshoring a particular task would be economical for a Home firm. To find conditions under which offshoring occurs, we examine the problem facing an atomistic Home *X* producer that is considering offshoring a task, when no offshoring is yet occurring. Since no offshoring has occurred in this thought-experiment, but trade in goods is free, the analysis from the previous section implies that the low- and high-skill wage gap will be γ (i.e. $w = w^*\gamma$ and $r = r^*\gamma$). Offshoring is economical if:

$$wa_{LX1} + ra_{KX1} > \frac{wa_{LX1} + ra_{KX1}}{\gamma}\chi(X1) \qquad \Leftrightarrow \qquad \gamma > \chi(X1) \tag{11}$$

where the first sum is marginal cost of task *X1* without offshoring and the second is marginal cost with offshoring, i.e. when the Home firm uses Home technology but pays Foreign factor prices, taking account of the iceberg coordination costs. Plainly, task *X1* is offshored only if $\gamma > \chi(X1)$.

Many cases can arise since the firm might want to offshore tasks *X1* and *X2*, or *X2* and *X3*, or *X1* and *X3*, or even *X1*, *X2* and *X3*. To work through all of these, we would have to detail the coordination costs of each proposed bundle. Since the purpose here is to illustrate the fact that offshoring (i.e. trade in tasks) leads to some outcomes that are very different than those obtained with only trade in goods is allowed, we discipline the range of cases by making restrictive assumptions. Specifically, we assume that when trade in goods and tasks is allowed, the coordination costs for *X1* and *Y1* are nil while the coordination costs of offshoring *X2*, *X3*, *Y2* and *Y3* are prohibitive.

Given this simplifying assumption, the atomistic Home firm would find it profitable to offshore task *X1* to Foreign. Moreover, an atomistic Home firm in the *Y* sector would also find it profitable to offshore tasks *Y1* to Foreign. Of course, other firms would follow and the re-organisation of work would change prices, wages, production patterns and trade. We turn to working out the new international equilibrium with free trade in tasks and goods.

Note that Foreign firms would never offshore to Home since this would involve combining inferior Foreign technology with expensive Home factors of production.

3.1. **Offshoring: free trade in goods and tasks**

Given that tasks *X1* and *Y1* are offshored, the new employment and pricing equations are:

$$\begin{bmatrix} L \\ K \end{bmatrix} = (\mathbf{A} - \mathbf{A}_1)\begin{bmatrix} X_O \\ Y_O \end{bmatrix}, \qquad \begin{bmatrix} 1 \\ p_O \end{bmatrix} = (\mathbf{A}^{\mathbf{T}} - \mathbf{A}_1^{\mathbf{T}})\begin{bmatrix} w_O \\ r_O \end{bmatrix} + \mathbf{A}_1^{\mathbf{T}}\begin{bmatrix} w_O^* \\ r_O^* \end{bmatrix}$$
$$\begin{bmatrix} L* \\ K* \end{bmatrix} = \gamma\mathbf{A}\begin{bmatrix} X_O^* \\ Y_O^* \end{bmatrix} + \mathbf{A}_1\begin{bmatrix} X_O \\ Y_O \end{bmatrix}, \qquad \begin{bmatrix} 1 \\ p_O \end{bmatrix} = \gamma\mathbf{A}^{\mathbf{T}}\begin{bmatrix} w_O^* \\ r_O^* \end{bmatrix} \tag{12}$$

where the subscript '*O*' (for 'offshoring') indicates equilibrium variables with offshoring, and

$$\mathbf{A}_1 \equiv \begin{bmatrix} a_{LXI} & a_{LYI} \\ a_{KX1} & a_{KY1} \end{bmatrix}$$

and we have taken the coordinating costs of the offshored tasks to be zero.[8] The pricing equations for Foreign are unaltered by the offshoring (Foreign firms continue to use Foreign technology and Foreign labour as before).

Shadow migration

This offshoring-cum-tech-transfer acts like 'shadow migration.' Home firms use some Foreign L and K to produce goods using Home technology just as if the Foreign L and K migrated to Home and worked in the Home X and Y sectors (but got paid the foreign wages). We assume that the shadow migration is not large enough to move 'effective' endowment ratios outside of the diversification cone, so production remains diversified. Rearranging (12) Home, Foreign and world employment equations can be written as:

$$\begin{bmatrix} L_O \\ K_O \end{bmatrix} \equiv \begin{bmatrix} L + \Delta L \\ K + \Delta K \end{bmatrix} = \mathbf{A}\begin{bmatrix} X_O \\ Y_O \end{bmatrix}, \qquad \begin{bmatrix} L*-\Delta L \\ K*-\Delta K \end{bmatrix} = \gamma\mathbf{A}\begin{bmatrix} X_O^* \\ Y_O^* \end{bmatrix}, \qquad \begin{bmatrix} \tilde{L}_O^w \\ \tilde{K}_O^w \end{bmatrix} = \mathbf{A}\begin{bmatrix} X_O^w \\ Y_O^w \end{bmatrix} \tag{13}$$

where

$$\begin{bmatrix} \Delta L \\ \Delta K \end{bmatrix} \equiv \mathbf{A}_1\begin{bmatrix} X_O \\ Y_O \end{bmatrix} > \mathbf{0}; \quad \tilde{L}_O^w \equiv L + \frac{L*}{\gamma} + (1-\frac{1}{\gamma})\Delta L, \quad \tilde{K}_O^w \equiv K + \frac{K*}{\gamma} + (1-\frac{1}{\gamma})\Delta K \tag{14}$$

defines the equilibrium amounts of the shadow migration, ΔL and ΔK, and the world shadow effective endowments with offshoring. The definitions of $\tilde{L}_O^w$ and $\tilde{K}_O^w$ make it clear that offshoring is like an expansion in the world supply of factors (measured in effective units). The shadow migration amounts, ΔL and ΔK, are positive given our regularity condition that production remains diversified in both nations even after offshoring.

[8] It is simple to put in non-zero coordination costs, but doing so complicates the expressions without providing compensating insight.

Shadow-migration shows up in the price equations in (12) as cost-savings. Rearranging:

$$\begin{bmatrix} 1+S_X \\ p_O+S_Y \end{bmatrix} = \mathbf{A}^{\mathbf{T}} \begin{bmatrix} w_O \\ r_O \end{bmatrix}, \qquad \begin{bmatrix} 1 \\ p_O \end{bmatrix} = \gamma \mathbf{A}^{\mathbf{T}} \begin{bmatrix} w_O^* \\ r_O^* \end{bmatrix} \tag{15}$$

where

$$\begin{bmatrix} S_X \\ S_Y \end{bmatrix} \equiv \mathbf{A}_1^{\mathbf{T}} \begin{bmatrix} w_O - w_O^* \\ r_O - r_O^* \end{bmatrix}$$

defines the per-unit cost savings, S_X and S_Y, in the *X* and *Y* sectors, respectively.

General equilibrium incidence on prices, wages, output and trade

We turn now to determination of the post-offshoring prices, wages, output and trade flows.

Price effects

Solving (13) for world output and using the market-clearing condition, the post-offshoring price is:

$$p_O = \frac{\alpha/(1-\alpha)}{a_{LX}/a_{LY}} \left(\frac{\kappa_Y - \tilde{k}_O^w}{\tilde{k}_O^w - \kappa_X} \right) \tag{16}$$

Comparing this to (6), we see that *Y* becomes dearer ($p_O > p$), if and only if shadow migration lowers the world effective capital-labour ratio, i.e. $\tilde{k}_O^w < \hat{k}^w$.

Production effects

Combining the shadow-migration insight and Rybczynski logic, it is intuitively obvious that offshoring's general equilibrium incidence on production are ambiguous in sign and depend upon the relative shadow migration of L and K. Solving (12) for the post-offshoring production and using (5), the production effects of offshoring are:

$$\begin{bmatrix} X_O \\ Y_O \end{bmatrix} = \begin{bmatrix} X \\ Y \end{bmatrix} + \mathbf{A}^{-1} \begin{bmatrix} \Delta L \\ \Delta K \end{bmatrix} \tag{17}$$

This shows, as anticipated by the Rybczynski logic, that the relative shadow-migration of *L* and *K* induced by offshoring determines the impact on Home's output mix. Specifically, if $\Delta K/\Delta L$ is less than κ_Y, Home *X* output rises and the Home *Y* output either rises less or falls; the necessary and sufficient condition of Y output to fall is $\Delta K/\Delta L < k_X$.[9] Solving Foreign production (13) yields $\Delta X^* = -\Delta X/\gamma$ and $\Delta Y^* = -\Delta Y/\gamma$. Thus Foreign production effects have the opposite sign as Home production effects, but the magnitudes are mitigated by the Foreign technological disadvantage γ. A direct implication is that the change in the world relative output of Y and X will have the same sign as the shift in Home's production mix. As noted above, this links the ratio of shadow migration to the terms of trade effect via the market clearing condition. To summarise:

Proposition 1: Offshoring boosts Home X production if the offshoring implies a ratio of shadow L-migration to shadow K-migration that exceeds the L-intensity of K-intensive sector Y. Home Y production either rises by relatively less or actually falls; it falls if the ratio of shadow migration exceeds the L-intensity of the X sector. Foreign production changes have the opposite sign but are mitigated in magnitude. World production changes have the same sign as Home production changes but are mitigated in magnitude.

Wage effects

Combing the cost-savings aspect of the shadow-migration insight with Stolper-Samuelson logic, it is intuitively obvious that the general equilibrium incidence of offshoring on wages is ambiguous. For example, if offshoring leads to a great deal of cost-saving in the L-intensive sector – which act like a rise in the price of X as per (15) – then w rises and r tends to fall. More precisely, we solve (15) for the post-offshoring wages:

$$\begin{bmatrix} w_O \\ r_O \end{bmatrix} = \begin{bmatrix} w \\ r \end{bmatrix} + \left(\mathbf{A}^{\mathbf{T}}\right)^{-1} \begin{bmatrix} S_X \\ S_Y + \Delta p \end{bmatrix}, \qquad \begin{bmatrix} w_O^* \\ r_O^* \end{bmatrix} = \begin{bmatrix} w^* \\ r^* \end{bmatrix} + \frac{1}{\gamma}\left(\mathbf{A}^{\mathbf{T}}\right)^{-1} \begin{bmatrix} 0 \\ \Delta p \end{bmatrix} \tag{18}$$

where $\Delta p \equiv p_O - p$. This shows that the wage of Home L-workers rises (controlling for terms of trade effects Δp), if and only if the cost-savings is sufficiently greater in the L-intensive sector than in the K-intensive sector (the precise condition is $S_X/S_Y > a_{KX}/a_{KY}$). Additionally, r rises less or actually falls. The necessary and sufficient condition for r to fall (controlling for terms of trade effects), is that the ratio of cost-savings exceeds the ratio of L-input coefficients, $S_X/S_Y > a_{LX}/a_{LY}$. Conversely, the wage of K-workers rises and that of L-workers falls, if $S_X/S_Y < a_{KX}/a_{KY}$. Figure 1 illustrates the possibilities.

[9] The solutions are $X_O\text{-}X=(\kappa_Y\text{-}\Delta K/\Delta L)\ \Delta L/a_{LY}/(\kappa_Y\text{-}\kappa_X)$ and $Y_O\text{-}Y=(\Delta K/\Delta L\text{-}\kappa_X)\ \Delta L/a_{LX}/(\kappa_Y\text{-}\kappa_X)$. Since the denominators are positive, the sign of the production effect turns on the difference between $\Delta K/\Delta L$ and the κ's.

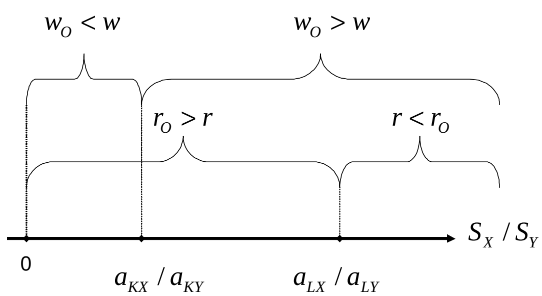

Figure 1: Sector-specific cost savings and offshoring's wage effects

Standard Jonesian magnification effects are in operation so the qualitative changes in *w* or *r* are also real changes. Apart from possible terms-of-trade effects, there is no change in the foreign wages as Foreign goods are produced with the unchanged Foreign technology.[10] To summarise:

Proposition 2: Offshoring raises the real wage of Home *L*-workers if the offshoring implies cost savings that are larger in the *L*-intensive sector than in the *K*-intensive sector; the real wage of *K*-workers rises less; it actually falls if the cost-savings are sufficiently skewed towards the *L*-intensive sector. Apart from terms of trade effects, wages of Foreign *L*- and *K*-workers are unaffected; in any case, Home owners of at least one type of labour (*L* or K) earn higher real wages with offshoring. The precise necessary and sufficient conditions are listed above.

The terms of trade effects are linked to the relative magnitudes of *L* and *K*-shadow migration (ΔL and ΔK), see (16), while wage changes are linked to the relative magnitudes of *X*- and *Y*-sector cost savings (S_X and S_Y), see (18). Because ΔL and ΔK and S_X and S_Y are both determined by the nature of offshored tasks, there are some cases where real wages changes are clear even when allowing for terms of trade effects. For instance, if the offshored tasks are primarily *L*-intensive, then $\Delta K/\Delta L$ will be small. If $\Delta K/\Delta L < \kappa_X$, world production of *Y* falls and *p* rises. Other things equal, this yields a real income gain for Home *L*-workers (Stolper-Samuelson). A sufficient condition that ensures the offshoring-induced cost-savings does not lower *w* enough to offset the Stolper-Samuelson effect is that the offshored tasks in the *L*-intensive industry are sufficiently important to ensure that $S_X / S_Y > a_{KX}/a_{KY}$ (see Figure 1). One simple case where all these conditions hold is $a_{LX1} > 0$ but $a_{LY1} = a_{KY1} = a_{KX1} = 0$. To summarise:

Proposition 3: Offshoring of either type of labour changes the world price of final goods. As a result, it changes the real returns of factors of production worldwide. If offshoring is mostly prevalent in unskilled labour intensive tasks and in the unskilled labour intensive sector, then the real wages of unskilled workers worldwide tends to rise.

[10] If offshoring involves a relatively large amount of shadow *L*-migration versus shadow *K*-migration, the price of the *L*-intensive goods will fall, as per (16); this implies a negative terms of trade effect for Foreign, so Foreign *L*-workers would lose and Foreign *K*-workers would gain according to standard Stolper-Samuelson reasoning.

Rent allocation

The source of the cost savings is the use of Home's superior technology with Foreign's cheap labour. This creates rents that accrue entirely to Home in this simple version of our offshoring model (the rents arise since Foreign workers in the offshoring sector are paid their reservation wage rather than their marginal product). The sectoral bias in the cost-savings determines how much of these rents go to Home *L*-workers as opposed to Home *K*-workers. The rent-sharing can be seen explicitly by writing (18) in terms of the Home-Foreign wage gaps using the definitions of the *S*'s:

$$\begin{bmatrix} w_O - w \\ r_O - r \end{bmatrix} = \left(\mathbf{A}^{\mathbf{T}}\right)^{\mathbf{-1}} \mathbf{A}_1^{\mathbf{T}} \begin{bmatrix} w_O - w_O^* \\ r_O - r_O^* \end{bmatrix} + \left(\mathbf{A}^{\mathbf{T}}\right)^{\mathbf{-1}} \begin{bmatrix} 0 \\ \Delta p \end{bmatrix} \tag{19}$$

This shows that the division of rents between Home *L*- and *K*-workers depends upon the relative labour savings in the *X* and *Y* sectors.

One interesting special case is where the coordination costs for all tasks are zero. In this case, all tasks are offshored and Home's superior technology completely displaces Foreign technology (all Foreign labourers work in the offshoring sector). The outcome is exactly like a technology transfer from Home to Foreign that brought the Foreign economy to the technology frontier. The wage effects in this case are extreme. There would be no change in Home wages from the free trade case (controlling for terms of trade effects) but Foreign wages would rise to Home levels. The wage-offshoring relationship is thus non-monotonic. A modest lowering of coordination costs produces offshoring that raises advanced-nation real incomes (as per Proposition 1), but a very large reduction could return them to the pre-offshoring level, while raising the backward nation's factor prices to those of the advanced nation.

Inter-industry and intra-industry trade effects

Since offshoring changes the Home technology matrix but does not affect Foreign's, we can no longer transform the equilibrium into free trade among nations with identical technology using the effective labour concept. This means that much of the elegance of the HO trade equation (7) disappears with offshoring, except in special cases. In particular, Home workers face the technology matrix $\mathbf{A}\text{-}\mathbf{A}_1$ while Foreign workers continue to face $\gamma\mathbf{A}$.

Home imports of *X* are (1-α) times its GDP minus its production of *X*. In the offshoring equilibrium, M_{XO} = (1-α)E_O - X_O, so we can express the change in imports in terms of the change in Home's GDP and its production of *X*, i.e. $M_{XO} - M_X = (1-\alpha)\Delta E - \Delta X$. Since offshoring's impact on *E* is driven by different factors than its impact on *X*, offshoring changes the pattern of trade in final goods (apart from knife-edge cases). For example, if the shadow migration is heavily biased towards *K* (so the impact on *X* is negative) and the per-unit cost-saving is heavily biased towards *Y* (so the wage of Home's abundant factor rises), then Home's imports of *X* will rise. More precisely, we calculate ΔE (which equals $L\Delta w + K\Delta r$, with $\Delta r \equiv r_O - r$ and $\Delta w \equiv w_O - w$) from (18) and ΔX from (17) to get:

$$M_{XO} - M_X = (1-\alpha)\begin{bmatrix} L \\ K \end{bmatrix}^{\mathbf{T}} \left(\mathbf{A}^{\mathbf{T}}\right)^{-1} \begin{bmatrix} S_X \\ S_Y + \Delta p \end{bmatrix} - \left(\kappa_Y - \frac{\Delta K}{\Delta L}\right)\frac{a_{LY}\Delta L}{\det(\mathbf{A})} \tag{20}$$

where $\det(\mathbf{A}) = a_{LX}a_{LY}(\kappa_Y - \kappa_X) > 0$ by (1). Plainly the outcome of (20) depends upon the sectoral cost-saving (the S_j's) and shadow migration, ΔK and ΔL, in complex ways. Except in knife-edge cases offshoring alters the pattern of trade in final goods. As such, it is then a source of comparative advantage. To summarise:

Proposition 4: Offshoring is a 'source of comparative advantage' in that it alters the pattern of trade in final goods. For instance, if Home and Foreign have identical endowments ratios there would be no HO motive for trade without offshoring, but trade in final good arises due to the 'shadow migration' associated with offshoring.

Intra-industry trade arises with offshoring if statisticians classify the output of tasks *X1* and *Y1* as *X*-sector and *Y*-sector trade respectively. Home imports the components or services produced abroad in its offshoring operations in both sectors. Since Home also imports either *X* or *Y* final goods (except in knife-edge cases), intra-industry trade must arise. To summarise:

Proposition 5: Offshoring typically creates intra-industry trade since Home imports the fruit of the offshored task *X1* and *Y1* and Home is, typically, a net exporter of either *X* or *Y* even if Home and Foreign have identical factor endowments.

A standard measure of the volume of intra-industry trade is the 'overlap' of a country's import and exports within a given sector. Here, there is no intra-industry trade in final goods (Home either exports *X* and imports *Y*, or vice versa), but Home imports the fruit of both tasks, so it engages in intra-industry trade in its export sector. Denoting 'IIT' as our measure of intra-industry trade and writing Home's imports of tasks in sector $J_O = X_O, Y_O$ as $M_J^{Tasks} \equiv (a_{LJ1}w^* + a_{KJ1}r^*)J_O$, $J = X, Z$:

$$IIT = \begin{cases} 2M_Y^{Tasks} & \text{if } M_{XO} < 0 \\ 2M_X^{Tasks} & \text{if } M_{YO} < 0 \\ M_X^{Tasks} + M_Y^{Tasks} & \text{if } M_{YO}, M_{XO} < 0 \end{cases}$$

(21)

A section in the appendix proposes a special case to elaborate further on intra-industry trade.

3.2. **Trade in tasks and the 4 theorems**

The effective Factor Price Equalisation theorem described above involved a pre- and post-trade comparison of wages in the absence of offshoring. Offshoring, in general, breaks the effective factor price equalisation since it changes Home wages. In other words, if a nation engaged in offshoring but the econometrician ignored it, a test of the effective factor price equalisation theorem would fail; the extra trade associated with offshoring widens the effective factor price gap between the technologically advanced nation and the technologically backward nation for at least one type of Home labour, as per Proposition 1.

The Heckscher-Ohlin theorem links trade in goods to relative factor endowments. The Heckscher-Ohlin theorem does not necessarily hold when there is free trade and offshoring. For instance, if nations have identical factor endowment ratios, free trade and offshoring would result in inter-industry trade when the HO theorem would predict none.[11] If the econometrician tested the HO theorem ignoring offshoring, the data might contradict the sign predictions of the HO theorem (the labour abundant nation might export the *K*-intensive good on net). If the econometrician used sector average factor intensities (e.g. a_{LX} and a_{KX}) to evaluate the factor content of the trade in tasks *X1* and *Y1* as well as the trade in final goods, the volume predictions of the HO theorem would be violated even if the sign predictions were correct. Depending upon the factor intensive of the offshored tasks, the data might be marked by a 'missing trade' paradox, i.e. show less net trade than predicted by the HO theorem, but equally well there might be too much net trade.

The correct version of the HO theorem in our model is rather involved. Since Home GDP is $X_O + p_O Y_O - w_O^* \Delta L - r_O^* \Delta K$, namely the output of final goods less the cost of imported intermediates, we can use the manipulations leading to (7), to write Home imports of *X* as:

$$M_{XO} = \frac{\alpha L_O}{a_{LX}} \left(\frac{k_O - \tilde{k}_O^w}{\tilde{k}_O^w - \kappa_X} \right) \quad - \quad (1-\alpha)(w_O^* \Delta L + r_O^* \Delta K)$$

The first term is isomorphic to the standard HO theorem formulation as in (7), except we use the shadow rather than the actual relative endowments (in effective units). The second term is proportional to two endogenous quantities that might be observable – the total wage bill in the offshoring sector in

[11] To see this, note that if actual relative endowments are the same in both countries (i.e. $k = \tilde{k}^w$) then without offshoring there is no trade in final goods by the Heckscher-Ohlin theorem, i.e. $M_X = 0$ in (7). With offshoring, Home imports of either *X* and *Y* (and both of them in general) are different from zero. This is true even in the knife-edge case where shadow migration does not change relative endowments (i.e. if $\tilde{k}_O^w = k_O$); see (22).

Foreign, and the value of Home's imports of intermediates (all in terms of the numeraire). The closed form solution for $w_O^*\Delta L + r_O^*\Delta K$, employing the definitions of ΔK and ΔL, (12) and (13), is:

$$w_O^*\Delta L + r_O^*\Delta K \equiv \begin{bmatrix} w_O^* & r_O^* \end{bmatrix} \begin{bmatrix} \Delta L \\ \Delta K \end{bmatrix} = \gamma^{-1} \left[\left(\mathbf{A}^{\mathbf{T}}\right)^{-1} \begin{bmatrix} 1 \\ p_O \end{bmatrix} \right]^{\mathbf{T}} \mathbf{A}_1 \mathbf{A}^{-1} \begin{bmatrix} L_O \\ K_O \end{bmatrix}$$

where p_O is defined in (16). Combining these elements, the HO theorem with offshoring can be written as

$$M_{XO} = \frac{\alpha L_O}{a_{LX}} \left(\frac{k_O - \tilde{k}_O^w}{\tilde{k}_O^w - \kappa_X} \right) \quad - \quad \frac{1-\alpha}{\gamma} \left[\left(\mathbf{A}^{\mathbf{T}}\right)^{-1} \begin{bmatrix} 1 \\ p_O \end{bmatrix} \right]^{\mathbf{T}} \mathbf{A}_1 \mathbf{A}^{-1} \begin{bmatrix} L_O \\ K_O \end{bmatrix} \tag{22}$$

Plainly this is far more complex that the usual HO theorem. The reason is that offshoring alters the relative technology matrices in ways that prevent us from using the effective-labour concept to cleanly restate the equilibrium as trade between nations with identical technology.

The Stolper-Samuelson theorem is a partial equilibrium result linking factor and goods prices. In the partial equilibrium spirit, we take the extent of offshoring – as measured by S_X and S_Y – to be exogenous when formulating the equivalent theorem for the case of free trade in tasks and goods. Inspection of (18) shows that the theorem would be unaltered for Foreign, but the transmission of changes in p to Home w and r is altered by the S_X and S_Y terms. Using (18), the theorem's analogue in our model is:

$$\left.\frac{dw_O / w_O}{dp_O / p_O}\right|_{S_X, S_Y} = \frac{-p_O}{a_{KY}/a_{KX} - p_O}\left(\frac{w}{w_O}\right) = \frac{-p_O}{(1+S_X)a_{KY}/a_{KX} - (p_O + S_Y)},$$

$$\left.\frac{dr_O / r_O}{dp / p}\right|_{S_X, S_Y} = \frac{p_O}{p_O - a_{LY}/a_{LX}}\left(\frac{r}{r_O}\right) = \frac{p_O}{(p_O + S_Y) - (1+S_X)a_{LY}/a_{LX}}$$

Comparing this to (8), we see that the impact on w would be dampened (less negative) and the impact on r would be magnified (more positive), if and only if under the offshoring regime w_O rises and r_O falls for any given change in p. As we know from the discussion above, a necessary condition for this to be the case is that the relative cost saving is skewed towards the L-intensive sector so that $S_X / S_Y > a_{KX} / a_{KY}$, as per Figure 1.

The Rybczynski theorem states that a rise in a nation's endowment of K raises its production of the K-intensive good more than proportionally and lowers its production of the other good. The analogue with trade in tasks is (evaluated at $L = L_O$ and $K = K_O$, thus $k = k_O$):

$$\left.\frac{dX_O/X_O}{dL_O/L_O}\right|_{\Delta L,\Delta K}=\frac{\kappa_Y}{\kappa_Y-k_O}\cdot\frac{X}{X_O},\qquad \left.\frac{dY_O/Y_O}{dL/L}\right|_{\Delta L,\Delta K}=-\frac{\kappa_X}{k_O-\kappa_X}\cdot\frac{Y}{Y_O}$$

Comparison of this and (9) provides two main results. First, under the assumption that offshoring does not reverse the ranking of relative factor intensities, the proportional increase in *X* from a given proportional increase in *L* would be smaller under trade in tasks, but the drop in *Y* production would be more marked if and only if $X_O > X$ and $Y_O < Y$; a sufficient for these conditions to hold is that $\kappa_X > \Delta K/\Delta L$. If $\Delta K/\Delta L > \kappa_Y$, then the proportional increase in *X* is more marked and the proportional drop of *Y* would be dampened. Second, if as a result of offshoring *X* becomes capital intensive, then the output of *X* decreases as a result of an increase in *L* by the usual Rybczynski logic. To summarise:

Proposition 6: Offshoring alters the four HO theorems. An econometrician who tested the HO theorem's sign and volume predictions ignoring offshoring would reject the theorem even though a modified form the HO theorem holds. The same can be said for the factor price equalisation theorem since the extra trade induced by offshoring tends to widen international factor price gaps. The Stolper-Samuelson and Rybczynski theorems would also appear to be rejected in their strict forms although properly modified versions of the theorems hold.

3.3. Integrating special cases

The fragmentation/offshoring literature has focused on special cases. Many of the papers assume that offshoring occurs in only a single sector while others present cases where offshoring only involves a single factor. Here we illustrate how our offshoring model can integrate the various cases. To keep our synthesis manageable, we limit our focus to Home wage effects and ignore terms of trade effects.

Starting with the papers that assume only one sector experiences fragmented/offshoring, the wage changes (ignoring terms of trade effects) are, from (18):

$$\Delta w=\frac{a_{KY}S_X-a_{KX}S_Y}{\det(\mathbf{A})},\qquad \Delta r=\frac{a_{LX}S_Y-a_{LY}S_X}{\det(\mathbf{A})} \tag{23}$$

The "Jones ambiguity" (see Introduction) can be seen by noting that if offshoring occurs only in the *X*-sector, then $S_Y = 0$ and Home unskilled wages rise, but *w* falls if offshoring occurs only in the *Y*-sector. The anti-Stolper-Samuelson effect can be seen in fact that both Δw and Δr can rise if S_X/S_Y lies between a_{KX}/a_{KY} and a_{LX}/a_{LY}. As GRH (2006a) points out in footnote 16, the Jonesian literature works with offshoring that acts like sector-specific Home technical progress, since fragmentation occurs in only one sector. The GRH set-up, by contrast, results in factor-specific technical progress, since offshoring occurs in both sectors but only in one factor (in the main body of their analysis). Since the formulation of S_X and S_Y in (15) allows for both sector-specific and factor-specific cost savings, we can illustrate the essence of the well-known GRH result that offshoring unambiguously boosts the wage of workers' whose jobs are offshored (controlling for terms of trade effects).

GRH (2006a) assume production functions where each task uses only *L*-labour (*L*-tasks) or only *K*-labour (*K*-tasks) and they undertake most of the analysis assuming that only *L*-tasks are offshored.[12] In this case, $S_X = a_{LX1}(w_O - w_O^*)$ and $S_Y = a_{LY1}(w_O - w_O^*)$, so:

$$\Delta w = \frac{a_{KY}a_{LX1} - a_{KX}a_{LY1}}{\det(\mathbf{A})}(w_O - w_O^*), \qquad \Delta r = \frac{(a_{LY1}/a_{LX}) - (a_{LX1}/a_{LY})}{\det(\mathbf{A})}a_{LY}a_{LX}(w_O - w_O^*) \tag{24}$$

Due to GRH (2006a,b) normalisations involving the size of tasks and the equality of offshoring costs across sectors, the numerator of Δr is zero, while Δw is positive.[13] GRH (2006b) also consider the case where tasks that involve only *K*-labour can also be offshored and this case S_X and S_Y regain their general formulation as in (15), so the Jones ambiguity is restored. The sign of the wage changes then depends upon the relative magnitudes of *L*-task offshoring and *K*-task offshoring, as per (23).

4. Extending the basic model

In this section, we extend the basic trade-in-tasks model in two directions. First, we relax the assumption that inter-firm trade-in-tasks is prohibitively expensive, so Home firms offshoring a task in Foreign can sell the offshored task to Foreign firms. Second, we allow for Ricardian differences among nations and show that this can result in the two-way offshoring that is common among OECD nations (Amiti and Wei 2005).

4.1. Local sales of offshored tasks: sharing the rents

The analysis above assumed that the cost of coordinating tasks across firms was prohibitive, so Foreign *X* and *Y* producers continued to use the inferior technology despite the presence of efficient task *X1* and *Y1* producers in the Foreign nation. Here we relax this by assuming the inter-firm

[12] GRH (2006a, b) focus on the case where only tasks involving *L* can be offshored but they do consider the possibility that tasks involving *K* can be also be offshored. The main restriction in their formal analysis is that every task is performed only by *L* or only by *K*.

[13] GRH (2006b) normalize the measure of a task so that *L*-tasks in both industries all have the same unit input coefficients, i.e. $a_{LX1} = a_{LY1}$, in our notation. They also assume that the offshoring cost for the tasks that have been thus normalised are identical across sectors (i.e. $t_x(i) = t_y(i) = t(i)$ in their notation). This interaction between the normalisation of task 'sizes' within each sector and the cross-sector assumption on offshoring costs implies that the labour cost-saving in both sectors is proportional to the pre-offshoring unit-labour input coefficient, which, in our notation implies $a_{LX1}/a_{LX} = a_{LY1}/a_{LY}$. Footnote 12 in GRH (2006b) suggests that $a_{LX1} = a_{LY1}$ could be relaxed by allowing more general substitution among tasks but the mapping to offshoring costs in this a case is not made explicit.

coordination costs ζ(*X1*) and ζ(*X1*) are zero. In this case, the offshoring Home firms would also supply *X1* and *Y1* to Foreign producers. This would change the pricing equations to:

$$\begin{bmatrix} 1+S_X \\ p_1+S_Y \end{bmatrix} = \mathbf{A^T} \begin{bmatrix} w_1 \\ r_1 \end{bmatrix}, \qquad \begin{bmatrix} 1+S_X^* \\ p_1+S_Y^* \end{bmatrix} = \gamma \mathbf{A^T} \begin{bmatrix} w_1^* \\ r_1^* \end{bmatrix} \tag{25}$$

where the subscript '1' indicate the new wages (note that S_X and S_Y are different from the previous section). In this case:

$$\begin{bmatrix} S_X \\ S_Y \end{bmatrix} \equiv \mathbf{A}_1^{\mathbf{T}} \begin{bmatrix} w_1-w_1^* \\ r_1-r_1^* \end{bmatrix}, \qquad \begin{bmatrix} S_X^* \\ S_Y^* \end{bmatrix} \equiv (\gamma-1)\cdot \mathbf{A}_1^{\mathbf{T}} \begin{bmatrix} w_1^* \\ r_1^* \end{bmatrix}$$

Solving (25) for wages and using Δp to denote p_1-p:

$$\begin{aligned} \begin{bmatrix} w_1-w \\ r_1-r \end{bmatrix} &= \left(\mathbf{A^T}\right)^{\mathbf{-1}} \mathbf{A}_1^{\mathbf{T}} \begin{bmatrix} w_1-w_1^* \\ r_1-r_1^* \end{bmatrix} + \left(\mathbf{A^T}\right)^{\mathbf{-1}} \begin{bmatrix} 0 \\ \Delta p \end{bmatrix}, \\ \begin{bmatrix} w_1^*-w* \\ r_1^*-r* \end{bmatrix} &= (1-\frac{1}{\gamma})\cdot\left(\mathbf{A^T}\right)^{\mathbf{-1}} \mathbf{A}_1^{\mathbf{T}} \begin{bmatrix} w_1^* \\ r_1^* \end{bmatrix} + \frac{1}{\gamma}\cdot\left(\mathbf{A^T}\right)^{\mathbf{-1}} \begin{bmatrix} 0 \\ \Delta p \end{bmatrix} \end{aligned} \tag{26}$$

Three aspects of this are noteworthy. First, note that the expression for Home factor prices is similar to (19) so our analysis in the previous section also applies in this model extension. Second, what is new is that Foreign workers also benefit from the technology transfer that results from offshoring. Indeed, in both expressions the first term in the right hand side shows how the rent is being split; the second term shows the offshoring-induced terms of trade effect on factor rewards. There is a crucial difference, though. For Home labour, it is *offshoring* that generates the rents; for Foreign factor owners, it is the *technology* transfer that is the source of these rents. Third, given that at equilibrium $w_1 \geq w_1*$ and $r_1 \geq r_1*$ must hold, controlling for the terms of trade effect, w_1* is larger than $w*$ (respectively r_1* is larger than $r*$) if, and only if, w_1 is larger than w (respectively r_1 is larger than r). To see this, note that the effects on wages depend on $\mathbf{(A^T)^{-1}A_1^T}$ in both cases. Also, the offshoring-induced terms of trade effect affects *L*-workers in qualitative the same way worldwide; it also affects world *K*-workers in qualitative the same way (formally, the effects on wages depend on $\mathbf{(A^T)^{-1}}$ in both cases).

This is useful to generalise Proposition 3: as follows:

Proposition 7: When Home offshoring firms also supply Foreign producers, then offshoring generates rents that accrue to both Home and Foreign factor owners in a way that is qualitatively similar to the case in Section 3.1 .Qualitatively, the offshoring-induced Stolper-Samuelson and Rybczynski effects are the same as those summarised in Proposition 3:.

4.2. **Intra-industry two-way offshoring** [14]

To focus on the essential differences between trade in goods and tasks, it proved convenient to eliminate Ricardian motives for trade by assuming that the international technology differences were of the Hicks neutral type. One result of this assumption was that Foreign never offshored tasks to Home. The extensive empirical literature on fragmentation, however, documents the importance of two-way trade in parts and components. This notation is also confirmed by a much smaller number of studies of service sector offshoring which indicates that two-way services trade is an important in the data.

Here we modify the basic model in a way that creates two-way, intra-industry offshoring. We shall do so in a highly specific model. As the analysis above made clear, there are a wealth of cases that could be considered (e.g. various combinations of factor abundance and technology superiority, factor intensity of the offshored tasks, etc.). However it is not really necessary to formally consider all the cases. Most of the cases can be dealt with simply using the core intuition that trade in tasks can be viewed as 'shadow migration'.

The model we work with assumes 'mirror image' Ricardian superiority. Home has inferior technology in tasks *X3* and *Y3*, while Foreign has inferior technology for tasks *X1* and *Y1*. Moreover, we assume that the task-level technological advantages exactly offset each other so that the two nations have the same sector-level unit input coefficients. Formally, let the input-output matrices be $\mathbf{B}\equiv\{b_{ij}\}$ and $\mathbf{B^*}\equiv\{b_{ij}^*\}$, $i = L,K$ and $j = X,Y$. We assume:

$$b_{ij} \equiv a_{ij1} + a_{ij2} + \gamma a_{ij3}, \quad b_{ij}^* \equiv \gamma a_{ij1} + a_{ij2} + a_{ij3}, \quad b_{ij} = b_{ij}^*, \quad \gamma > 1; \qquad i = K, L, \quad j = X, Y$$

so $\mathbf{B^*}=\mathbf{B}$. Thus:

$$a_{ij} < b_{ij}\ , \qquad \frac{b_{ij}}{a_{ij}} = \frac{b_{ij}^*}{a_{ij}} \equiv \eta_{ij} > 1; \qquad i = K, L, \quad j = X, Y,$$

Finally, we assume that the nations have the same factor endowment ratios.

Given the analysis above, the outcome without trade-in-tasks is obvious. The two nations will have identical wages and will not trade with each other. Specifically, by analogy with (18) and (17):

$$\begin{bmatrix} 1 \\ p \end{bmatrix} = \mathbf{B^T} \begin{bmatrix} w \\ r \end{bmatrix} = \mathbf{B^T} \begin{bmatrix} w^* \\ r^* \end{bmatrix}; \qquad \begin{bmatrix} L \\ K \end{bmatrix} = \mathbf{B} \begin{bmatrix} X \\ Y \end{bmatrix} = \mathbf{B} \begin{bmatrix} X^* \\ Y^* \end{bmatrix} = \begin{bmatrix} L^* \\ K^* \end{bmatrix} \tag{27}$$

---

[14] We would like to thank Toshi Okubo for providing the idea for this section.

Once we allow free trade-in-tasks – by assuming the coordination costs, the χ's and ζ's drop to zero – then trade in tasks occurs. Specifically, the offshoring will allow Home's superior technology in tasks *X1* and *Y1* to displace Foreign's technology in these tasks while Foreign's superior technology in tasks *X3* and *Y3* displaces Home's technology. In this case, the offshoring (and the fact that tasks can be sold at arm's length among firms, i.e. the ζ's are zero) imply that both nations move to the technology frontier. In symbols, the shadow input-output matrices are **A** as defined in (2) for both countries. As a result, the pricing and production equations with two-way offshoring turn out to be

$$\begin{bmatrix} 1 \\ p_2 \end{bmatrix} = \mathbf{A}^{\mathbf{T}} \begin{bmatrix} w_2 \\ r_2 \end{bmatrix} = \mathbf{A}^{\mathbf{T}} \begin{bmatrix} w_2^* \\ r_2^* \end{bmatrix}; \qquad \begin{bmatrix} L \\ K \end{bmatrix} = \mathbf{A} \begin{bmatrix} X_2 \\ Y_2 \end{bmatrix} = \mathbf{A} \begin{bmatrix} X_2^* \\ Y_2^* \end{bmatrix} = \begin{bmatrix} L^* \\ K^* \end{bmatrix} \tag{28}$$

where the subscript '2' stands for 'two-was offshoring'. An observation immediately emerges: since **B**>**A** (i.e. each b_{ij} is larger than the corresponding a_{ij}), it is immediate from (27) and (28) that, first, the real reward of at least one factor of production has risen and, second, (world and domestic) production of at least one of the two final goods has risen. In symbols:

$$\begin{bmatrix} w_2 - w \\ r_2 - r \end{bmatrix} = [\mathbf{I} - (\mathbf{B}^{\mathbf{T}})^{-1} \mathbf{A}^{\mathbf{T}}] \begin{bmatrix} w_2 \\ r_2 \end{bmatrix} + (\mathbf{B}^{\mathbf{T}})^{-1} \begin{bmatrix} 0 \\ \Delta p \end{bmatrix}; \qquad \begin{bmatrix} X_2 - X \\ Y_2 - Y \end{bmatrix} = [\mathbf{I} - \mathbf{B}^{-1}\mathbf{A}] \begin{bmatrix} X_2 \\ Y_2 \end{bmatrix}. \tag{29}$$

Let

$$\mathbf{I} - (\mathbf{B}^{\mathbf{T}})^{-1} \mathbf{A}^{\mathbf{T}} = \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix} \quad \text{and} \quad \mathbf{I} - \mathbf{B}^{-1}\mathbf{A} = \begin{bmatrix} \beta_{11} & \beta_{12} \\ \beta_{21} & \beta_{22} \end{bmatrix}$$

We provide the closed form solution to the *b*'s and to the β's in the appendix. The interpretation of (29) revolves around the same considerations as before; for instance, assume that $\eta_{ij} = \eta_i$ (all *i*,*j*), which is a sufficient condition for offshoring not to switch the sectors' relative factor intensities; in this case, $b_{11} = 1 - 1/\eta_L$, $b_{22} = 1 - 1/\eta_K$ and $b_{21} = b_{12} = 0$. In this case, *L*-workers capture 100% of the offshoring-generated unskilled-labour rents whereas *K*-workers capture 100% of the offshoring-generated skilled-labour rents.

The production effects are simple to work out. The two-way offshoring is like 'shadow migration' but due to the symmetry we imposed, there is no net shadow migration, so there is no Rybczynski effect in either nation. By contrast, the move of both nations towards the technology frontier as a result of two-way offshoring will be isomorphic to a labour saving productivity improvement in both sectors in both nations by the factor η_{ij}. Given the ex ante symmetry of the nations at the sector level and the ex post symmetry of the nations at the task level, it is clear that there will be no trade in final goods either before or after the freeing up of trade in tasks. All trade would be intra-industry trade in the sense that Home would export the fruit of tasks *X1* and *Y1* to Foreign in exchange for the fruit of tasks *X3* and *Y3.* If the tasks represent manufacturing stages, this would be parts and components trade. If they are service inputs, this would be intra-industry services trade.[15]

To be more specific, assume first that $\eta_{ij} = \eta_j$ (all *i,j*) holds. In this case, both the production of both X and Y increases: indeed, in this case in this case, $\beta_{11} = 1 - 1/\eta_X$, $\beta_{22} = 1 - 1/\eta_Y$ and $\beta_{21} = \beta_{12} = 0$. Next, assume again that $\eta_{ij} = \eta_i$ (all *i,j*) holds. Assume without further loss of generality that $\eta_L / \eta_K > a_X / a_Y$. This, of course, results in a rise in *X* production relative to *Y* production in both nations (Jones 1965).

Finally, consider the price side of the expansion of world *X* production relative to *Y* production: this will raise the relative price of *Y* and this will have all the standard Stolper-Samuelson effects. The novel effect will be that the two-way offshoring will act like economy-wide labour-saving technological progress in both nations. Given the reasoning above, the general equilibrium net incidence of this effect falls entirely on low-skilled workers (with $\eta_L > \eta_K = 0$ to streamline the exposition). That is, *w* rises in both nations (and it also rises relative to *r*), controlling for terms-of-trade effects. Since the terms of trade effects work in the opposite direction, the net effect on *w* and *r* (and on real wages alike) are ambiguous.

5. Concluding remarks

Our paper has presented a simple model of offshoring that integrates the complex gallery of results derived in the extensive theoretical literature on offshoring/fragmentation. We view offshoring as 'shadow migration' that brings with it cost-savings that act as technological changes. This permits us to use the elegant analysis of Jones (1965) in specifying the necessary and sufficient conditions for offshoring's impact on wages, prices, production and trade. We also show that offshoring requires a modification of the four classic HO theorems, that it produces intra-industry trade in a Walrasian setting, and it is an independent source of comparative advantage in that it alters the pattern of trade in final goods.

[15] This is consistent with the evidence in Schott (2004) insofar as we observe two-way trade at finely disaggregated levels and that the differences in productivity at the task level are re-interpreted as differences in the quality of the fruit of the task.

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Appendix: Closed form solutions with offshoring

The closed-form solutions for wages and production with offshoring are simple to derive but tend to be too complex to be revealing, so the text works with aggregates of parameters – S_X, S_Y, ΔL, and ΔK.

Here we provide the closed-form solutions in matrix notation. These all follow from straightforward manipulation of (12) and the definitions of S_X, S_Y, ΔL, and ΔK. Foreign wages and Home production are simple to calculate since there is no interaction with the other pricing and employment equations:

$$\begin{bmatrix} w_O^* \\ r_O^* \end{bmatrix} = \gamma^{-1}\left(\mathbf{A}^{\mathbf{T}}\right)^{-1}\begin{bmatrix} 1 \\ p_O \end{bmatrix}, \qquad \begin{bmatrix} X_O \\ Y_O \end{bmatrix} = \left(\mathbf{A}-\mathbf{A}_1\right)^{-1}\begin{bmatrix} L \\ K \end{bmatrix}$$

where p_O is given in (16). Home wage and Foreign production vectors involve both pricing and employment condition and are thus more complex:

$$\begin{bmatrix} w_O \\ r_O \end{bmatrix} = \left(\mathbf{A}^{\mathbf{T}}-\mathbf{A}_1^{\mathbf{T}}\right)^{-1}\left(I-\frac{1}{\gamma}\mathbf{A}_1^{\mathbf{T}}\left(\mathbf{A}^{\mathbf{T}}\right)^{-1}\right)\begin{bmatrix} 1 \\ p_O \end{bmatrix}, \qquad \begin{bmatrix} X_O^* \\ Y_O^* \end{bmatrix} = \frac{1}{\gamma}\mathbf{A}^{-1}\left(\begin{bmatrix} L^* \\ K^* \end{bmatrix}-\mathbf{A}_1\left(\mathbf{A}-\mathbf{A}_1\right)^{-1}\begin{bmatrix} L \\ K \end{bmatrix}\right)$$

ITT—a special case

In general, the closed form solution to M_j^{Task} and M_{Tasks} are not very revealing; however, we can actually say a bit more about their shape at the cost of some generality. To avoid a topology of cases, let us consider the special case in which the same proportion of all tasks are 'offshorable' in each sector and for each factor. In symbols, we write $\mathbf{A}_O = \delta\mathbf{A}$, where $0<\delta<1$ is a scalar. In this case, Home and world endowments simplify to

$$L_O = \frac{L}{1-\delta}, \quad K_O = \frac{K}{1-\delta}; \quad L_O^w = \frac{L(\gamma-\delta)+(1-\delta)L^*}{\gamma(1-\delta)}, \quad K_O^w = \frac{K(\gamma-\delta)+(1-\delta)K^*}{\gamma(1-\delta)}.$$

In this case, standard algebra reveals that $\gamma>1$ and $k>k^*$ imply $\tilde{k}_O^w > k^w$, i.e. in effect offshoring makes the world relatively more capital abundant. when offshoring does not reverse the ranking of the relative factor abundance between countries, in which case $M_{XO}>0$ typically holds, then ITT is given by the first line in (21). In this case, provided that $k_O > \tilde{k}_O^w$ holds, ITT as a fraction of shadow Heckscher-Ohlin trade in final goods M_X is given by

$$\frac{2M_Y^{Tasks}}{M_X} = \frac{2\delta}{\gamma(1-\alpha)}a_{KY}a_{LX}\,\frac{(\tilde{k}_O^w-\kappa_X)(k_O-\kappa_X)}{\kappa_X(k_O-\tilde{k}_O^w)\det(\mathbf{A})}$$

Three features of this expression are noteworthy: first, as δ increases relative to γ, the volume of ITT relative to trade in final goods increases. This is intuitive, for δ is the fraction of offshorable tasks and γ affects both trade in final goods and trade in tasks. Second, as det(**A**) increases, the Heckscher-Ohline motives for trade increase (at the limit det(**A**)=0, both sectors have the same factor intensity) and, as a result, of measure of relative ITT falls. Finally, this measure is decreasing in k_O and increasing in $\tilde{k}_O^w$; again, this is intuitive given that we have $k_O > \tilde{k}_O^w$: as home and world (shadow) endowments become more similar, then the HO motives for trade disappear.

Two-way offshoring: closed form solutions

In this section we provide the closed form solution for the factor price and production effects of two-way offshoring:

$$\mathbf{I}-(\mathbf{B}^{\mathbf{T}})^{-1}\mathbf{A}^{\mathbf{T}}=\begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix} \equiv \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} - \frac{1}{a_X\eta_{LX}\eta_{KY}-a_Y\eta_{LY}\eta_{KX}} \begin{bmatrix} a_X\eta_{KY}-a_Y\eta_{KX} & \eta_{KY}-\eta_{KX} \\ \eta_{LX}-\eta_{LY} & a_X\eta_{LX}-a_Y\eta_{LY} \end{bmatrix}$$

and

$$\mathbf{I}-\mathbf{B}^{-1}\mathbf{A}=\begin{bmatrix} \beta_{11} & \beta_{12} \\ \beta_{21} & \beta_{22} \end{bmatrix} \equiv \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} - \frac{1}{a_X\eta_{LX}\eta_{KY}-a_Y\eta_{LY}\eta_{KX}} \begin{bmatrix} a_X\eta_{KY}-a_Y\eta_{LY} & (\eta_{KY}-\eta_{LY})a_{LY}/a_{KX} \\ (\eta_{LX}-\eta_{KY})a_{LX}/a_{KY} & a_X\eta_{LX}-a_Y\eta_{KX} \end{bmatrix}$$

From these expressions, the statements made in the text can be more easily verified**.**

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