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# Offshoring: General Equilibrium Effects on Wages, Production and Trade

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# OFFSHORING: GENERAL EQUILIBRIUM EFFECTS ON WAGES, PRODUCTION AND TRADE

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**ABSTRACT**

A simple model of offshoring, which depicts offshoring as 'shadow migration,' permits parsimonious derivation of necessary and sufficient conditions for the effects on wages, prices, production and trade. We show that offshoring requires modification of the four classic international trade theorems. We also show that offshoring is an independent source of comparative advantage and can lead to intra-industry trade in a Walrasian setting. The model is extended to allow for two-way offshoring between similar nations and to allow for monopolistic competition. We also show that, unlike trade in goods, trade in tasks typically makes *all* types of workers better off in both the host and home countries (with some proviso).

## 1. Introduction

The fragmentation and offshoring of production processes has been an important phenomenon for many years (Hummels, Ishii, and Yi 2001; Berger 2006), 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 (Federal Reserve 2002, Feenstra and Hanson 1996). More recently, offshoring has spread from the manufacturing to the service sector (Amiti and Wei 2005), generating a renewed interest among academics (Krugman 1996, Grossman and Rossi-Hansberg 2006, Baldwin 2006, Rodriguez-Clare 2007) and raising fears among the general press.

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The observed empirical effects of offshoring 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 manufacturing jobs that started in the mid-1980s was not accompanied by a general decline in manufacturing employment until the late 1990s (Debande 2006). As for Europe, Barba-Naveretti et al. (2006) report that Italian and French firms that invest in developing countries subsequently expand production and domestic employment. Likewise, two recent studies of micro data 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); Autor et al. (2003) and Spitz-Oener (2006) report that occupations are shifting from routine to complex in the US and Germany, respectively.[1] Understanding such effects requires a general equilibrium framework where wages, prices, production and trade patterns adjust to offshoring. Responding to this need, some of the world's best trade economists have put forth general equilibrium models of offshoring/fragmentation (e.g. Jones and Kierzkowski 1990).[2] 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.

Viewing the production of goods (intermediate or final) as a 'bundle of tasks' (Autor et al. 2003, Baldwin 2006, Grossman and Rossi-Hansberg 2008) is helpful to understand the implications of the tradability of some tasks on factor rewards and how they differ from those of the tradability of goods and services. Traditional trade theory acknowledges the fact that, historically, domestic production factors were competing with foreign ones only indirectly—via trade in goods. In this paradigm, it could happen that the truck drivers and the call centre employees were working for the same sector, say a home PC delivery company. There was little wrong in 'lumping' the two tasks together as long as one could be fairly sure that the driving and call-answering jobs would remain bundled geographically. Put differently, it used to be the case that international competition was being felt almost exclusively at the sector-level (broadly defined), with all firms in a given sector being affected by import competition in a qualitatively similar way; ultimately, the Stolper-Samuelson theorem would provide a good guide as to which were the factors whose real reward would fall or rise as the result of trade. Recent technological breakthroughs in telecommunication technologies (as well as privatisations in the sector that allowed communication prices to fall substantially) rendered this view of the world incomplete making it important to look at the impact of globalisation on tasks in addition to sectors. As

[1] These developments are consistent with the adoption of skill-biased technologies, like IT (Autor et al. 2003), They are also consistent with offshoring (Grossman and Rossi-Hansberg 2008). In a model in which the purpose of organisations (hierarchies) is to allocate skills between production and communication and solving problems of various complexities, Garicano and Rossi-Hansberg (2006) show that an improvement in IT that reduces the cost of processing information results in an increase in the knowledge-intensity of all occupations (i.e. agents solve a larger fraction of problems and rely less on the hierarchy to solve them); this interpretation of their theoretical results is consistent with the findings of Spitz-Oener (2006).

[2] See e.g. Feenstra (1998) for a survey.

pointed out by Princeton economists Krugman (1996), Blinder (2006), and Grossman and Rossi-Hansberg (2006, 2008), 'trade in tasks' (a synonym for offshoring introduced by Grossman and Rossi-Hansberg) differs from trade in goods in two important ways. First, workers in a specific task are directly facing competition from their foreign kin in the former case but indirectly in the latter. Second, the key distinction lies in the tradability of services–not in the level of education. This indicates that the list of offshore-able tasks is unlikely to line up with educational attainment as neatly as it has in the past. Specifically, though high-skilled workers' real wages increased relatively to unskilled workers' in developed countries as a result of trade in goods, *some* skilled workers will be adversely affected by trade in tasks whereas *some* unskilled workers won't be directly affected. For instance, truck driving is completely unaffected by reduced international communication costs, while call centre services are highly affected. As we shall see, these subtle but crucial distinctions lead to amend well-known results in international trade theory

***Our model and preview of our contribution***

The purpose of our paper is to present a simple model of off shoring that allows us to examine its general equilibrium effects on wages, prices, production and trade patterns. The first main contribution of our exercise is that it allows us to develop *necessary and sufficient conditions* for signing these effects in source and host countries. Our baseline model finds firms in all sectors 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. Despite the resulting *effective* factor price equalisation, offshoring by the technologically advanced nation is cost-saving since offshoring firms can take their superior technology with them when they shift production abroad.[3] 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-Vanek trade theory* (Heckscher and Ohlin 1991, Vanek 1968). This is our second contribution. In particular, we show that offshoring is in many ways akin to *shadow migration*; it leads to intra-industry trade in a perfectly competitive, Heckscher-Ohlin-Vanek-like setting; and it 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); in other words, the welfare implications of trade no longer follow the standard Stolper-Samuelson logic and all factor owners might end up being better off (as also pointed out by Grossman and Rossi-Hansberg 2008). This is because

[3] This assumption follows the Section 3.2 model in Grossman and Rossi-Hansberg (2008), August 2006 version.

offshoring allows offshoring firms to cut on costs in a way that is similar to *factor-augmenting technological progress* in the canonical Jones (1965). In a perfectly competitive environment, these savings are fully distributed to primary factor owners at the general equilibrium.

We work with two main variants of the basic model. In the first, which we call the *service-task* case (mostly for terminological convenience) and which is similar to the case studied by Grossman and Rossi-Hansberg (2008), all offshored production is re-imported to the Home nation. In the second, which we call the *goods-task* case and which is original (to the best of our knowledge), local sales are possible in the sense that offshore production units can supply Foreign firms as well as Home firms. Our third contribution is to show that *the gains from offshoring are shared between nations* and factors within nations in the goods-task case, while Foreign wages are unaffected by offshoring in the service-task case (apart from possible terms of trade effects).

In addition, our basic model set-up is rich enough to permit simple extensions that address the limitations of the model. First, it might be argued that foreign sourcing by Home firms will eventually make the superior technology of the offshored tasks spill over the Foreign firms. This case would be modelled in exactly the same way as our 'goods-task' case mentioned in the previous paragraph. Thus, we can give two interpretations to this variant of the basic model.

Second, our model – as is common in the offshoring literature – is well suited to study North-South offshoring; however, most of the offshoring currently going on is probably among developed nations (Amiti and Wei 2005). A related concern stems from our use of the neoclassical paradigm, which sits uncomfortably with the exclusiveness of technology that Home firms use; if Home firms own intangible assets like better management techniques, then we need a framework in which the concept of a 'firm' is at least better defined than in a constant-return-to-scale, perfect-competition framework. To address these concerns, we provide two simple model extensions. The first allows for two-way intra-industry offshoring. The second allows for offshoring in a monopolistic competition model where the notion of a firm is better defined than it is in the Walrasian setting (but comparison with the four Heckscher-Ohlin-Vanek theorems is less evident), though the issue regarding the boundaries of the firm is beyond the scope of this paper.

To summarize, the contribution of our paper is threefold. First, in a way that complements Grossman and Rossi-Hansberg (2008), it integrates and generalises the results of a wide and diverse literature in a unified framework; in doing this, we are able to pinpoint the various channels and effects that lead to what might appear as a set of sometimes contradictory results. Second, we revisit the four canonical theorems of the Heckscher-Ohlin-Vanek paradigm in international trade. Most of our analysis works for a general number of sectors, factors and tasks. Third, we extend the model in a variety of original directions; among others, we study the wage and production effects of offshoring on developing countries.

***Organisation of paper***

The section in the immediate sequel provides an in-depth, albeit selective, review of the relevant literature; informed and hurried readers may skip it. Section 3 presents a simplified HOV model and briefly lays out the four standard trade theorems in order to fix ideas and introduce notation. The following section presents our model of offshoring, characterises the equilibrium, and then shows how offshoring requires a modification of the four standard trade theorems. Sections 5 and 6 present our extensions whereas section 7 discusses the normative implications of our theory. The final section presents our concluding remarks. An appendix provides necessary and sufficient conditions for the equilibrium to exist; to the best of our knowledge, our paper is the first to do so in the offshoring/fragmentation literature.

## 2. The literature

In this section we review first the trade literature on offshoring and then (more selectively) the labour economics literature on routine tasks.

***Offshoring, fragmentation and trade in tasks***

Early on, Heckscher-Ohlin-Vanek theory saw a number of contributions that incorporated trade in intermediate goods (see Batra and Casas 1973, Woodland 1977, Dixit and Grossman 1982 and Helpman 1984), 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 effects. This line of modelling – which includes Jones and Marjit (1992), Arndt (1997, 1999), Jones and Findlay (2000, 2001), Jones and Kierzkowski (1998, 2000), and Jones, Kierzkowski and Leonard (2002) – is based on verbal and 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 in which the liberalisation of service links can promote the fragmentation of production blocks.[4]

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 (with some abuse of language) 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

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

one case, but fall in the other.[5] 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.[6] In other words, the Stolper-Samuelson logic establishes that the real reward of at least one factor of production must fall as a result of trade in goods; with trade in tasks, *all* factor owners may be better-off, hence our terminology.

Contributions that study the price, wage, production and trade effects of offshoring in explicit mathematical models include Deardorff (1989a, b), Venables (1999), Kohler (2004a), Markusen (2006), Grossman and Rossi-Hansberg (2006, 2008) and Antràs et al. (2006).[7] 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 tools of Jones (1965), the analysis in these papers is quite complex. Most of these authors also assume that offshoring/fragmentation occurs in only one sector and only in one direction (to keep the analysis manageable).

Deardorff (1989a,b) studies fragmentation in a range of explicit models using graphical analysis. The main formal analysis, however, concerns a HOV setting where cost-saving offshoring occurs since nations' endowments are assumed to lie in different diversification cones (i.e. their endowments are so different that they produce no goods in common in equilibrium). 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 that "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. 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 HOV 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

[5] Referring to a HOV 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."

[6] 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."

[7] In a different vein, Yi (2003) emphasizes the role of fragmentation to reconcile the empirically large and growing elasticity of trade volumes with respect to trade barriers with the (relatively low) elasticity of substitution among broad categories of products as well as with the time series of measured average barriers to trade.

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 HOV 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).

Kohler (2004a) works with a specific factor model where fragmentation can only occur in one sector. Discussion of the source of non-factor price equalisation is avoided by assuming a small open economy where all goods prices and Foreign wages are immutably fixed (in the Jones-Kierzkowski tradition). The focus of the analysis is on the reward to the specific capital that moves offshore when fragmentation occurs, and the overall welfare effects on the small open economy.

Markusen (2006) works with a 2x2x2 HOV model where one sector fragments, and he, like Deardorff, generates non-factor-price equalisation by assuming the two nations are in different diversification cones. Analytic results with multi-cone models are difficult (due to the inequality constraints), so the paper studies offshoring/fragmentation via numerical simulations based on the complementary slackness approach. 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 – and thus the skill premium – in both nations, 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 (2006) points out the limitation of the analysis: “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. He then closes the paper 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."

Kohler (2004b) works with a small open economy where fragmentation/offshoring can only happen in one sector. He departs from other models, however, in using a radically different production structure – that of Dixit and Grossman (1982) where final good production involves of continuum of intermediate 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. At the cost of additional assumptions on the capital intensity of upstream versus downstream stages of production, the Dixit-Grossman production structure yields a very simple characterisation of the endogenous range of stages that are offshored given an exogenously specified range of offshoring costs for each stage of production. The focus of his analysis is on establishing a 'generalised factor price frontier' that takes account of the shifts in the range of stages that are offshored when prices or offshoring costs change exogenously. When prices change, he shows that offshoring can heighten or dampen the magnification aspect of the Stolper-Samuelson effects. He also shows that cheaper offshoring produces more offshoring and this raises or lowers factor prices according to the relative factor intensity of the two sectors and the fragments offshored. No formal results are presented on production and trade effects.

More recently, Grossman and Rossi-Hansberg (2006, 2008) – GRH for short – present a formal model where the wage effects of offshoring are unambiguous. GRH (2006), for example, 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 as technological progress – what they call the productivity effect. Grossman and Rossi-Hansberg (2008) explore the issues in greater depth, confirming the unambiguous productivity effect on wages in certain cases. GRH also identify an "anti-Stolper-Samuelson" effect. As they argue: "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 2008, 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. Unlike Kohler (2004b), however, the stages (called 'tasks') require 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. Rodriguez-Clare (2007) embodies the Grossman-Rossi-Hansberg approach to trade in tasks in a Ricardian model à-la Eaton and Kortum (2002) to study the impacts of offshoring on wages in both rich (i.e. home) and poor (i.e. host) countries. Since this is a Ricardian model, there are no distributional effects within nations. Also, the world as a whole is better off thanks to the productivity/technological progress effect. However, the rich/home nations may be hurt because the terms-of-trade effect (which redistributes incomes across nations) is necessarily detrimental to the offshoring nations in this model. This is because the cost-saving induced by offshoring is reflected in goods prices – and as the production of the offshoring nation expands as a result, its terms-of-trade deteriorate. By contrast, the terms-of-trade effect is ambiguous in our HOV framework.

Antràs et al. (2006, 2008) propose a model in which all tasks are potentially offshore-able. The accent in this paper is on the formation, composition and size of (cross-border) teams; workers have different abilities (skills); countries differ in the distribution of skills only (North's first-order stochastically dominates South's). Among other results, they show that improvements in the communication technology yield larger teams and larger wage inequalities among production workers. Their model also provides a trade-induced explanation for the rise in the returns to skills.

***Offshoring, routine tasks and codification***

Which tasks are "offshore-able"? The OECD classifies offshore-able jobs as those characterised by four features: IT intensity, output that is IT transmittable, tasks that are codify-able, and tasks that require little face-to-face interaction. It classifies about 20% of the US workforce in as being offshore-able.[8] In our view, a task can be offshored if two conditions are simultaneously fulfilled. The first condition is technological: communication costs must be low enough so that giving instructions to workers operating in distant countries is economical; the rise of the internet or the generalisation of the fibre optic cable and of satellite communications (developments that all dwarf the fall in transportation costs since WWII) contribute to make this technological constraint no longer binding. The second condition relates to the monitoring of agents; some tasks are easy to codify and it is also easy to verify whether the task has been performed according to the guidelines; assembly of a standard good is an example of such 'routine tasks'.[9] By contrast, other tasks are complex ('non-routine'). They require frequent face-to-face interactions ('non-routine interactive tasks'). Only part of the information necessary to carry out these tasks travels easily inside fibre optic cables and physical and cultural distances are impediment to the tradability of such tasks. The routine versus non-routine terminology is borrowed from Grossman and Rossi-Hansberg (2006). They draw on a five-way division of the US labour force prepared by Autor, Levy and Murnane (2003) from highly disaggregated data, aggregating the Autor-Levy-Murnane categories into 'routine' and 'non-routine' tasks.

Studying task changes within occupations, Spitz-Oener (2006) reports that occupations in Germany are more complex nowadays than in 1979. Crucially, Spitz-Oener (2006) reports "a sharp increase in non-

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[8] Bardhan and Kroll (2003) estimate that about 10% of the US labour force is employed in occupations that could be offshored; they include professions such as financial analysts, medical technicians, paralegals, and computer and math professionals.

[9] This second requirement is exposed clearly in Leamer and Storper (2001) who distinguish between 'codifiable' and 'tacit' information: while the former type of information can be fully described using words or symbolic languages and transmitted via the fibre optic cable, the telephone and or other means, the transmission and monitoring of the latter requires frequent face-to-face interactions. In other words, the former is technology-intensive whereas the latter requires mutual understanding that is trust-intensive and/or culture-intensive.

routine cognitive tasks … and a pronounced decline in manual and cognitive routine tasks…. Importantly, … most of the task changes have occurred within occupations, and they have been most pronounced in occupations in which computer technologies have made major headway." Using less disaggregated US data, Autor et al. (2003) report that whole occupations also experienced greater complexity. As pointed out by Grossman and Rossi-Hansberg (2006, 2008), the trend reported by Autor et al. (2003) is consistent with both skill-biased technological change and import competition at the *task* level. Spitz-Oener's paper is, to the best of our knowledge, unique in providing direct evidence that *routine* tasks have been displaced in a developed economy at a very finely defined microeconomic level—the one that we address in this paper.

## 3. Trade in goods in a modified HOV model

By way of introducing our notation and normalisations, we start by describing the familiar Heckscher-Ohlin-Vanek (HOV) model following Dixit and Norman (1980), Leamer (1980), Trefler (1993) and others, and then state the four theorems.

**Free trade in goods in the two-country model**

Let $f = 1,...,F$ index factors (primary inputs) and $i = 1,...,I$ index industries (sectors). We work with a world comprising two countries, Home and Foreign, and variables pertaining to Foreign are subscripted with a star '*' (variables pertaining to Home are subscript-free); aggregate variables are subscripted with a 'w' for 'world'. Thus vectors $\mathbf{w} \equiv \{w_f\}$, $\mathbf{p} \equiv \{p_i\}$, $\mathbf{V} \equiv \{V_f\}$, $\mathbf{X} \equiv \{X_i\}$ and $\mathbf{M} \equiv \{M_i\}$ denote, respectively, Home's factor prices, good prices, factor endowments, production and imports; also, the $I \times F$ matrix $\mathbf{A} \equiv \{a_{fi}\}$ denotes Home's technology with typical element $a_{fi}$ giving the cost-minimizing input requirement of factor *f* in industry *i*. Tastes are homothetic and identical across nations.[10]

Our first departure from the standard HOV model is the following:

**Assumption 1** (homothetic technologies). $\mathbf{A}^* = \gamma\mathbf{A}, \quad 1 < \gamma$.

That is, 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 ('gamma' is a mnemonic for 'gap'). 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 HOV model by defining Foreign factor supplies in 'effective units', i.e. dividing $V_f^*$ by the technological-inferiority-factor $\gamma$. By the same token, define the vector of world factor endowment in

[10] Two further remarks are in order regarding notation: vectors and matrices are denoted by bold letters, whereas individual variables and parameters are denoted using italics. We also adopt the convention that **Z** > **N** means that *each element* of the matrix or vector **Z** is larger than the corresponding element of **N** (which requires that the dimension of **Z** is equal to the dimension of **N**).

effective units as $\tilde{\mathbf{V}}^{\mathbf{w}} \equiv \mathbf{V} + \mathbf{V}^{*}/\gamma$, where we use "~" to denote factor supplies measured in effective units.

Let $E$ and $E^{*}$ denote respectively Home and Foreign GDP ('expenditure') and let $s$ denote Home's share of world income, $E^{w} \equiv E + E^{*}$, so $s \equiv E / E^{w}$. The HOV model with factor price equalisation and homothetic technologies implies $\mathbf{AM} = s\tilde{\mathbf{V}}^{\mathbf{w}} - \mathbf{V}$ (Heckscher-Ohlin-Vanek theorem) and $\mathbf{w} = \gamma \mathbf{w}^{*}$ (factor-price equalisation theorem), or:

$$M_f \equiv \sum_{i=1}^{I} a_{fi} M_i = s\tilde{V}_f^w - V_f, \qquad w_f = \gamma w_f^{*}; \qquad f = 1,...,F \tag{1}$$

where $M_f$ is Home's import-content of factor $f$. Home is defined to be abundant in factor $f$ if $s\tilde{V}_f^w < V_f$, so the HOV theorems predicts that Home imports the services of its scarce factors. Trade directly equalises good prices internationally; under some specific conditions (Assumption 2 below), trade also indirectly equalises factor prices (in effective units).

**The 2x2x2 model**

With appropriate qualifications, all the results we derive in this paper can be generalised to $I, F \geq 2$, but we sometimes streamline the exposition by working with the well-known 2x2x2 version of the HOV model.[11] To fix ideas, there are two types of labour, skilled labour $K$ (or human capital) and unskilled labour $L$, and two industries/sectors, $X$ and $Y$. We take $X$ as the numeraire and let $p$ denote the price of $Y$. Also, let $w$ and $r$ be the rewards for unskilled labour ($L$) and skilled labour ($K$), respectively. Thus, in the version of the model with $I = F = 2$, we write:

$$\mathbf{w} \equiv \begin{bmatrix} w \\ r \end{bmatrix}, \qquad \mathbf{p} \equiv \begin{bmatrix} 1 \\ p \end{bmatrix}, \qquad \mathbf{V} \equiv \begin{bmatrix} L \\ K \end{bmatrix}, \qquad \mathbf{X} \equiv \begin{bmatrix} X \\ Y \end{bmatrix}, \qquad \mathbf{A} \equiv \begin{bmatrix} a_{LX} & a_{KX} \\ a_{LY} & a_{KY} \end{bmatrix}$$

Foreign is relatively abundantly endowed with unskilled labour, which we write as $k^{*} < k$, where $k \equiv K / L$ and $k^{*} \equiv K^{*} / L^{*}$.

**Autarky, free trade and the 4 theorems**

In autarky, the Home or Foreign equilibriums are characterised by $I$ pricing equations (one for each sector), $F$ employment equations (one for each factor) and $I$ good markets clearing condition.[12] Using linear algebra, the pricing equations in the two nations are summarised by:

$$\mathbf{p} = \mathbf{Aw}, \qquad \mathbf{p}^{*} = \gamma \mathbf{Aw}^{*} \tag{2}$$

By the same token, the full-employment equations are ($\mathbf{A}^{\mathbf{T}}$ denotes the transpose of $\mathbf{A}$):

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[11] See Dixit and Norman (1980) for an exhaustive treatment of the issues related to generalizing the results.

[12] One of these conditions is redundant by Walras' law.

$$\mathbf{V} = \mathbf{A}^{\mathbf{T}}\mathbf{X}, \qquad \mathbf{V}^* = \gamma\mathbf{A}^{\mathbf{T}}\mathbf{X}^* \tag{3}$$

Together, these conditions imply that factors are fully employed worldwide, or $\tilde{\mathbf{V}}^{\mathbf{w}} = \mathbf{A}^{\mathbf{T}}\mathbf{X}^{\mathbf{w}}$, with $\mathbf{X}^{\mathbf{w}} \equiv \mathbf{X} + \mathbf{X}^*$.

Let $\alpha(\cdot) \in (0,1)$ denote the equilibrium expenditure share on $Y$ (with Cobb-Douglas preferences $\alpha$ is a parameter). Market-clearing conditions for Home in autarky are $pY = \alpha E$ and $X = (1-\alpha)E$; these, together with their analogues for Foreign in autarky and for the world with free trade imply, respectively[13]:

$$\text{autarky:} \quad \frac{pY}{X} = \frac{\alpha}{1-\alpha}, \qquad \frac{p^*Y^*}{X^*} = \frac{\alpha}{1-\alpha}; \qquad \text{free trade:} \quad \frac{pY^w}{X^w} = \frac{\alpha}{1-\alpha}. \tag{4}$$

Let $\kappa_i$ denote the relative skilled-to-unskilled labour intensity of sector *i*, with *Y* being the *K*-intensive good, so $\kappa_Y > \kappa_X$, where $\kappa_i \equiv a_{Ki}/a_{Li}$, $i = X, Y$. We impose:

**Assumption** 2 (diversification). $\kappa_Y > k > k^* > \kappa_X$ (5)

so that neither nation fully specialises at equilibrium. Then inverting (2) and (3) yields the equilibrium wages and outputs:

$$\mathbf{w} = \mathbf{A}^{-1}\mathbf{p}, \qquad \mathbf{w}^* = \frac{1}{\gamma}\mathbf{A}^{-1}\mathbf{p}, \qquad \mathbf{X} = \left(\mathbf{A}^{\mathbf{T}}\right)^{-1}\mathbf{V}, \qquad \mathbf{X}^* = \frac{1}{\gamma}\left(\mathbf{A}^{\mathbf{T}}\right)^{-1}\mathbf{V}^*, \tag{6}$$

and world output is $\mathbf{X}^{\mathbf{w}} = \left(\mathbf{A}^{\mathbf{T}}\right)^{-1}\tilde{\mathbf{V}}^{\mathbf{w}}$. Autarky and free trade equilibrium factor prices, which follow from (6) and (4), are:

$$\text{autarky:} \quad p = \frac{\alpha/(1-\alpha)}{a_{LX}/a_{LY}}\frac{\kappa_Y - k}{k - \kappa_X}, \quad p^* = \frac{\alpha/(1-\alpha)}{a_{LX}/a_{LY}}\frac{\kappa_Y - k^*}{k^* - \kappa_X}; \quad \text{free trade:} \quad p = \frac{\alpha/(1-\alpha)}{a_{LX}/a_{LY}}\frac{\kappa_Y - \tilde{k}^w}{\tilde{k}^w - \kappa_X} \tag{7}$$

where $\tilde{k}^w \equiv (K + K^*/\gamma)/(L + L^*/\gamma)$ is the world skilled-unskilled endowment ratio measured in effective units. The non-specialisation regularity condition (5) implies that all endogenous variables are positive in equilibrium.

**FPE theorem**. The Factor Price Equalisation 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 (6), the international ratio of wages in terms of the numeraire is $\gamma$.

[13] Note that the *p* in the first equation is different from the *p* in the third one: in the former, it is the autarky price prevailing at Home whereas in the latter it is the terms-of-trade prevailing under free-trade.

**HOV theorem**. The Heckscher-Ohlin-Vanek theorem states that the relatively $L$-rich nation exports the $L$-intensive good and imports the $K$-intensive good. Using (6) and (7), Home imports of good $X$ are:

$$M_X = \frac{\alpha L}{a_{LX}} \frac{k - \tilde{k}^w}{\tilde{k}^w - \kappa_X} \tag{8}$$

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 skilled-unskilled endowment ratio exceeds the world's effective skilled-unskilled endowment ratio. This demonstrates the Heckscher-Ohlin-Vanek theorem since trade balance implies that the value of Home's exports of $Y$ equals -$M_X$.

We may also use (1) and (8) to get an expression for Home's import of unskilled labour services (i.e. the *factor content of trade*), $M_L = \alpha(k - \tilde{k}^w)(\kappa_Y - \kappa_X)(\tilde{k}^w - \kappa_X)^{-1}(\kappa_Y - \tilde{k}^w)^{-1}$, which is positive by (5).

**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 (6):

$$\frac{dw/w}{dp/p} = \frac{-p}{a_{KY}/a_{KX} - p} < 0, \qquad \frac{dr/r}{dp/p} = \frac{p}{p - a_{LY}/a_{LX}} > 1 \tag{9}$$

This means that $r$ rises more than proportionally with $p$ and $w$ actually falls, so qualitatively the $w$ and $r$ changes are like 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. Log differentiating (6):

$$\frac{dX/X}{dL/L} = \frac{\kappa_Y}{\kappa_Y - k} > 1, \qquad \frac{dY/Y}{dL/L} = \frac{-\kappa_X}{k - \kappa_X} < 0 \tag{10}$$

## 4. A simple model of offshoring

This section modifies the HOV model to allow for offshoring/fragmentation. We model the production of $X$ as involving $N_X$ "tasks" labelled $\{Xt\}_{t=1,\ldots,N_X}$, which can be thought of segments of the production process (in which case the task's output is an intermediate good) or service inputs. Likewise, $Y$ production involves tasks $Y1, \ldots, YN_Y$. In the HOV 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 $a_{fi}$'s can be decomposed into task-by-task Leontief unit input coefficients:

$$a_{LX} \equiv \sum_{t=1}^{N_X} a_{LXt}, \qquad a_{KX} \equiv \sum_{t=1}^{N_X} a_{KXt}; \qquad N_X \geq 2$$

where the $L$ and $K$ unit inputs for task-$t$ in sector $i$ denotes as $a_{Lit}$ and $a_{Kit}$. The coefficients for $Y$ are decomposed into task requirements in an isomorphic manner. In the spirit of the HOV model, the international transportation of the fruit of each task is costless. In the spirit of Grossman and Rossi-Hansberg (2008), some tasks *may* require only one type of labour, e.g. $a_{LXt} > a_{KXt} = 0$ for some $t$ and $a_{KX\tau} > a_{LX\tau} = 0$ for some $\tau \neq t$.

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 workers' marginal products.[14] In this way, offshoring from the high-technology/high-wage nation to the low-technology/low-wage nation may be economic despite the effective factor price equalisation. Offshoring from the low-technology nation to the advanced-technology nation, by contrast, will never be economic. One interpretation of this assumption is that Foreign workers are themselves as productive or as well educated as Home workers but that Foreign technology, institutions or management practices are inferior to Home's (Acemoglu et al. 2007, Bloom and Van Reenen 2007).

While offshoring tends to reduce costs, it may not occur if the cost of coordinating spatially separated tasks is 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 $\chi(X1) \geq 1$.[15] Note that it is as if offshoring causes deterioration in the offshoring firm's production technology (due to the extra coordination costs). $\chi(Xt)$ 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 $XN_X$ the most expensive. We impose an isomorphic ordering on $Y$-sector tasks.

The per-unit offshoring costs $\chi$ relates to the cost of coordinating spatially separate tasks within the same firm. In addition, depending upon the nature of the task, it may be much harder to coordinate the $N$ tasks when tasks are performed by different firms – especially when the task involves firm-specific services, many of which may be idiosyncratic, such as accounting services (which involves firm-specific peculiarities) or telephone help-lines (which involve firm-specific training). While it is possible to model this decision more precisely, doing so would make it difficult to compare offshoring

[14] The concept of what constitutes a firm does not seat easily with our otherwise Walrasian model. Section 6 shows that our results all got through in a monopolistic competition trade model where firms are well-defined; we stick with the HOV setting to improve comparison with the four theorems and the main offshoring/fragmentation literature.

[15] Hence the monitoring/coordination costs are borne in foreign-labour units. This assumption is immaterial for our results, for we shall solve the model for $\chi(.) \in \{0,\infty\}$. See footnote 18 below.

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 $X2$ through $XN_X$ 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 $X2$ through $XN_X$ – and this regardless of whether they are undertaken in the same nation.[16] (The same holds for all the other tasks.)

For the sake of analytic clarity, we consider two cases. The first case takes the $\zeta$'s as sufficiently high to make inter-firm trade in tasks uneconomical. Thus even if Home firms offshore task $X1$ to Foreign, they will not supply task $X1$ to Foreign producers. The second takes the $\zeta$'s as zero so inter-firm trade in tasks becomes economical. For the sake of terminological clarity, we refer to the first case (i.e. no local sale of offshored production) as offshoring of the service-tasks case (although it could also hold for the offshoring of some firm-specific intermediate goods) and the second case (i.e. local sales as economical) as manufacturing- or goods-tasks case. We study the former case in the remainder of the section; we address manufacturing-tasks in section 5.

***Deviation analysis: Service task offshoring***

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 $\gamma$ (i.e. $w = w^*\gamma$ and $r = r^*\gamma$). Offshoring is economical if:

$$wa_{LXt} + ra_{KXt} > \frac{wa_{LXt} + ra_{KXt}}{\gamma}\chi(Xt) \qquad \Leftrightarrow \qquad \gamma > \chi(Xt)$$

where the first sum is the marginal cost of task $Xt$ without offshoring and the second is the 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 $Xt$ is offshored only if $\gamma > \chi(Xt)$.

Many cases can arise since the firm might want to offshore any subset of tasks $\{Xt\}_{t=1,\ldots,N_X}$. To work through all of these, we would have to detail the coordination costs of each proposed bundle and this could be complex since coordination costs are unlikely to be separable. 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, we discipline the range of cases by making restrictive assumptions. Specifically, we assume that when trade in both goods and tasks is allowed, the

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[16] Thus the decision to 'make or buy' a given task is left in a 'black box'. The same is true about the boundaries of tasks. In the model developed by Garicano and Rossi-Hansberg (2006) and extended to an open economy by Antràs et al. (2006, 2007), we may interpret the various layers of the hierarchies as various 'tasks'. This way, their model provides some microeconomic foundations to the 'boundaries of tasks', i.e. as to what constitutes a task. In their model, a reduction in communication costs changes also the *scope* of each task. By contrast, we keep the boundaries of tasks $t = 1, \ldots, N_i$ exogenous in our model.

coordination costs for $X1$ and $Y1$ are nil while the coordination costs of offshoring $\{Xt\}_{t=2,...,N_X}$ and $\{Yt\}_{t=2,...,N_Y}$ are prohibitive. Thus, unless otherwise mentioned, we impose $N_i = 2$ throughout the rest of the paper, that is, there are two sets of tasks: those that are offshoreable and those that are not; this is without further loss of generality.

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 both 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.

**Service task offshoring**

In the remainder of this section, as in section 3, the expressions written using linear algebra are general (in the sense that they usually hold for $I, F \geq 2$). We often focus our discussion on the case with $I = F = 2$ to ease economic interpretation. Also, from now on we explicitly assume that the cost-minimising input-output coefficients are fixed, thus the results we derive below are generically a reasonable first-order approximation by the envelope theorem.[17] As discussed above, we roughly associate service-sector offshoring with the case where all offshore production is re-imported to Home because no $X1$ or $Y1$ can be sold to Foreign firms by assumption. Given that tasks $X1$ and $Y1$ are offshored, the new employment conditions are

$$\mathbf{V} = (\mathbf{A}^{\mathbf{T}} - \mathbf{A}_{\mathbf{1}}^{\mathbf{T}})\mathbf{X}_{\mathbf{O}}, \qquad \mathbf{V}^* = \gamma \mathbf{A}^{\mathbf{T}}\mathbf{X}_{\mathbf{O}}^* + {}_{\chi}\mathbf{A}_{\mathbf{1}}^{\mathbf{T}}\mathbf{X}_{\mathbf{O}}$$

where the subscript 'O' (for 'offshoring') indicates equilibrium variables with offshoring, $\mathbf{A_1} \equiv \{a_{fi1}\}$ and ${}_{\chi}\mathbf{A}_1 \equiv \{\chi(i1)a_{fi1}\}$ define the unit input coefficients of the tasks being offshored from the perspective of the home and host countries, respectively; more explicitly (in the 2x2x2x2 case):

$$\mathbf{A_1} \equiv \begin{bmatrix} a_{LX1} & a_{KX1} \\ a_{LY1} & a_{KY1} \end{bmatrix}, \qquad {}_{\chi}\mathbf{A_1} \equiv \begin{bmatrix} \chi(X1)a_{LX1} & \chi(X1)a_{KX1} \\ \chi(Y1)a_{LY1} & \chi(Y1)a_{KY1} \end{bmatrix}$$

The difference between $\mathbf{A_1}$ and ${}_{\chi}\mathbf{A_1}$ results from the iceberg offshoring costs. Likewise, the new pricing equations are:

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[17] Thus the loss of a generality is minimal. Interestingly, this specification allows us to derive sufficient conditions for the equilibrium to exist (see Appendix), which is non-existent in this literature. We also note that this simplifying assumption is frequent in the literature and many papers that relax this assumption consider marginal changes instead (e.g. Grossman and Rossi-Hansberg 2008). Expressions that include flexible production become more convoluted but the effects we describe below still exist and generalise easily (details are available from the authors upon request). Conversely, looking at discrete changes allows us to uncover infra-marginal effects that are absent otherwise (for instance, offshoring e.g. *L*-tasks will entail a factor-saving effect that will also benefit factor *K* in general, unlike in e.g. Grossman and Rossi-Hansberg 2008).

$$\mathbf{p_O} = (\mathbf{A} - \mathbf{A_1})\mathbf{w_O} +_\chi \mathbf{A_1}\mathbf{w_O^*}, \qquad \mathbf{p_O} = \gamma\mathbf{A}\mathbf{w_O^*}$$

Note that the pricing equation for Foreign is unaltered by offshoring (Foreign firms continue to use Foreign technology and Foreign labour as before). In order to work with explicit solutions for **X** or **w**, we take the coordination costs to be zero, i.e. $\chi(X1) = \chi(Y1) = 1$.[18] In this case ${}_\chi\mathbf{A_1} = \mathbf{A_1}$, or:

$$\begin{aligned} &\mathbf{p_O} = (\mathbf{A} - \mathbf{A_1})\mathbf{w_O} + \mathbf{A_1}\mathbf{w_O^*}, && \mathbf{V} = (\mathbf{A^T} - \mathbf{A_1^T})\mathbf{X_O}, \\ &\mathbf{p_O} = \gamma\mathbf{A}\mathbf{w_O^*}, && \mathbf{V}^* = \gamma\mathbf{A^T}\mathbf{X_O^*} + \mathbf{A_1^T}\mathbf{X_O}. \end{aligned} \tag{11}$$

From these, it follows that offshoring implies that the countries have no-longer access to the same technology, so that inverting the zero profits conditions yields $\mathbf{w_0} \neq \mathbf{w_0^*}/\gamma$ whilst summing Home and Foreign full employment conditions yields $\tilde{\mathbf{V}}^{\mathbf{w}} \neq \mathbf{A^T X_0}$. In particular, Home firms face the technology matrix **A-A₁** while Foreign firms continue to face γ**A**. These considerations imply the following:

**Proposition 1.** Offshoring implies that the FPE and the HOV theorems break down.

*Proof.* The proof follows from (1). Start with the FPE theorem. Unless $\exists\phi \in (0,1) : a_{fi1} = \phi a_{fi}$ so that we can write $\mathbf{A_1} = \phi\mathbf{A}$ (i.e. a common fraction $\phi$ of each $a_{fi}$ can be offshored), it is not possible to find a real number $\tilde{\phi} \in (0,1)$ such that $\forall f : w_f^* = \tilde{\phi} w_f$, i.e. there exist no 'effective units' so that factor prices can be considered to be equalised. Turn now to the HOV theorem. In the sense of (1), the HOV theorem holds only if the FPE theorem holds. A sufficient condition for the HOV theorem to hold under more general conditions is that the trading countries face the same technology. Inspection of (11) reveals that this is no-longer the case with offshoring. *QED.*

Two implications of this proposition are noteworthy. First, it implies that the *K*-abundant country might end up importing the *K*-intensive good for reasons that are conceptually different from the exogenous Ricardian differences suggested by Leontief (1953) and confirmed by Trefler (1993). Second, 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 HOV trade equation (8) disappears with offshoring, except in special cases. This is the main reason why the existing literature on fragmentation/offshoring is so fragmented: solving the model under general conditions is technically not difficult but the outcome is so unwieldy that the cognitive cost of interpreting them is prohibitive.[19] However, we introduce two 'tricks' that allow us to move forward: we show that offshoring is in many ways analogous to factor migration and to technical progress.

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[18] This is also in line with the spirit of standard neoclassical modelling whereby transaction costs are either prohibitive or zero.

[19] The result is a ratio of two expressions of the parameters of the model that contain tens of terms each, even after all the possible factorisations have been undertaken.

***Shadow migration and technical progress***

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. The exhaustive set of necessary and sufficient conditions analogous to (5) is way too unwieldy to be revealing; however, the appendix provides a set of sufficient conditions that have a natural economic interpretation. Rearranging (11), the employment equations are:

$$\mathbf{V_O} \equiv \mathbf{V} + \mathbf{\Delta V} = \mathbf{A^T X_O}\,, \qquad \mathbf{V_O^*} \equiv \mathbf{V^*} - \mathbf{\Delta V} = \gamma \mathbf{A^T X_O^*}\,, \qquad \mathbf{\tilde{V}_O^w} = \mathbf{A^T X_O^w} \tag{12}$$

with

$$\mathbf{\Delta V} \equiv \mathbf{A_1^T X_O} > \mathbf{0}\,, \qquad \mathbf{X_0^w} \equiv \mathbf{X_0} + \mathbf{X_0^*}\,, \qquad \mathbf{\tilde{V}_0^w} = \mathbf{\tilde{V}} + (1 - \frac{1}{\gamma})\mathbf{\Delta V} > \mathbf{\tilde{V}}. \tag{13}$$

Above, $\mathbf{\Delta V} \equiv [\Delta L \quad \Delta K]'$ defines the equilibrium amounts of the shadow migration, $\mathbf{X_0^w}$ is the world output with offshoring and $\mathbf{\tilde{V}_0^w}$ denotes the world shadow effective endowments with offshoring. The definition of $\mathbf{\tilde{V}_O^w}$ makes it clear that offshoring is akin to an expansion in the world supply of factors (measured in effective units).[20] The shadow migration amounts, $\Delta L$ and $\Delta K$, are positive. Shadow-migration shows up in the price equations in (11) as cost-savings. For Home and Foreign:

$$\mathbf{p_O} + \mathbf{S} = \mathbf{A w_O}\,, \qquad \mathbf{p_O} = \gamma \mathbf{A w_O^*}\,; \qquad \mathbf{S} \equiv \mathbf{A}_1(\mathbf{w_O} - \mathbf{w_O^*}) > \mathbf{0} \tag{14}$$

where $\mathbf{S} \equiv [S_X \quad S_Y]'$ and $S_X$ and $S_Y$ are the per-unit cost savings in the $X$ and $Y$ sectors, respectively. Thus, offshoring is akin to factor-augmenting technological progress (Jones and Kierzkowsi 1990, Grossman and Rossi-Hansberg 2008).

**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 (12) for $X_O^w$ and $Y_O^w$, and using the market-clearing condition, the post-offshoring price is:

$$p_O = \frac{\alpha/(1-\alpha)}{a_{LX}/a_{LY}} \frac{\kappa_Y - \tilde{k}_O^w}{\tilde{k}_O^w - \kappa_X} \tag{15}$$

[20] Thus, this shadow migration is conceptually quite different from the shadow migration implied by the factor-content of trade in final goods. Another difference between the two is that shadow migration implied by trade in tasks is one-way (from Foreign to Home) whereas implicit migration in the standard Heckscher-Ohlin framework is two-way (balanced trade). Finally, the 'shadow immigrants' are being paid the wage prevailing in their country of origin, not the one in the host country.

Comparing this to (7), we see that $Y$ becomes dearer ($p_O > p$), if and only if shadow migration lowers the world effective skilled-unskilled labour ratio, i.e. $\tilde{k}_O^w < \hat{k}^w$. From (12), $\tilde{k}_O^w < \hat{k}^w$ holds when the shadow $L$-migration is proportionally greater than shadow $K$-migration relative to the pre-offshoring world effective labour supplies, i.e. if $\Delta L / \tilde{L}^w > \Delta K / \tilde{K}^w$. To summarise (proof in the text):

**Proposition 2** (Terms of trade). Offshoring of either type of labour changes the world price of final goods. The relative price of $K$-intensive good $Y$ rises if the shadow $K$-migration is proportionally less than the shadow $L$-migration.

***Production effects***

From (12), (13) and $\forall f, \forall j: a_{fi} > 0$, it follows that $\tilde{\mathbf{V}}_\mathbf{O}^\mathbf{w} > \tilde{\mathbf{V}}^\mathbf{w}$ establishes that the world output must rise in at least one industry (precise conditions to follow) though production might fall in some industries. More generally, combining the shadow-migration insight and Rybczynski logic, the general equilibrium incidence of offshoring on production are ambiguous in sign and depend upon the relative shadow migration of $L$ and $K$. Solving (11) for the post-offshoring production and using (6), the production effects of offshoring are:

$$\Delta \mathbf{X} = (\mathbf{A}^\mathbf{T})^{-1} \Delta \mathbf{V}, \qquad \Delta \mathbf{X}^* = -\frac{1}{\gamma} (\mathbf{A}^\mathbf{T})^{-1} \Delta \mathbf{V}, \qquad \Delta \mathbf{X}^\mathbf{w} = (1 - \frac{1}{\gamma}) (\mathbf{A}^\mathbf{T})^{-1} \Delta \mathbf{V} \tag{16}$$

where

$$\Delta \mathbf{X} \equiv \mathbf{X}_\mathbf{O} - \mathbf{X}, \qquad \Delta \mathbf{X}^* \equiv \mathbf{X}_\mathbf{O}^* - \mathbf{X}^*, \qquad \Delta \mathbf{X}^\mathbf{w} \equiv \mathbf{X}_\mathbf{O}^\mathbf{w} - \mathbf{X}^\mathbf{w}$$

and **X** and **X*** are defined in (6). This shows, as anticipated by the Rybczynski logic, that Home $X$ output rises if $\Delta K/\Delta L$ is lower than $\kappa_Y$ and Home $Y$ output either rises less or falls. Let us illustrate this point in the 2x2x2x2 case[21]:

$$\Delta X \equiv X_O - X = \frac{\Delta L}{a_{LY}} \frac{\kappa_Y - \Delta K / \Delta L}{\kappa_Y - \kappa_X}, \qquad \Delta Y \equiv Y_O - Y = \frac{\Delta L}{a_{LY}} \frac{\Delta K / \Delta L - \kappa_X}{\kappa_Y - \kappa_X}. \tag{17}$$

The necessary and sufficient condition for $Y$ output to fall is $\Delta K/\Delta L < \kappa_X$. From (16), the change in Foreign product has the opposite sign of the change in Home production effects, but the magnitudes are mitigated by the Foreign technological disadvantage $\gamma$. Specifically, $\Delta X^* = -\Delta X / \gamma$ and $\Delta Y^* = -\Delta Y / \gamma$. The various outcomes are depicted in the right-panel of Figure 1. The usual Jonesian magnification effects are in operation.[22] To summarise (proof in the text):

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[21] Since the denominators are positive, the sign of the production effect turns on the difference between $\Delta K/\Delta L$ and the $\kappa$'s. Note that the production of at least one good must rise; the proof of this statement is by contradiction. Assume $\Delta X < 0$ and $\Delta Y < 0$ both hold simultaneously; these imply $\kappa_Y < \Delta K/\Delta L < \kappa_X$, which violates the ranking $\kappa_Y > \kappa_X$.

[22] For example, $\Delta X/X = \{(\Delta L/L) / (1 - k/\kappa_Y) - (\Delta K/K)/(\kappa_Y/k - 1)\}$ and $k/\kappa_Y < 1$ since both economies' product is diversified.

**Proposition 3** (Shadow migration). Offshoring can be viewed as shadow migration of Foreign factors. The impact on Home production follows a Rybczynski-like pattern; the production of at least one good rises but the production of one good may fall if offshoring implies a very unbalanced migration of factors. Standard Jonesian magnification effects occur.

**Figure 1 about here**

As an illustration of this, the output of *K*-intensive good *Y* may fall if the ratio of *K* versus *L* shadow migration is low enough, but the output of both sectors would rise if the amounts of *L* and *K* shadow migration are fairly similar. The exact limits are shown in Figure 1. Changes in world production follow changes in Home production; more precisely:

**Corollary 3.1**. World production of good $X_i$ increases if (and only if) Home production of good $X_i$ rises ($i = 1,...,I$).

*Proof*. From (16), we may write $\mathbf{\Delta X^w} = (1-\gamma^{-1})\mathbf{\Delta X}$, which establishes the result. *QED*.

***Wage effects***

From (14), it is clear that it cannot be that all Home factor prices fall (controlling for $\mathbf{\Delta p}$), though the reward of some Home factor owners may fall. Combing the cost-savings aspect of the shadow-migration insight with Stolper-Samuelson logic, it is intuitive that the general equilibrium incidence of offshoring on wages is generally ambiguous. For example, if offshoring leads to a great deal of cost-saving in the *L*-intensive sector – which acts like a rise in the price of *X* as per (14) – then *w* rises and *r* tends to fall. More precisely, we solve (14) for the post-offshoring wages:

$$\mathbf{w_O} = \mathbf{w} + \mathbf{A^{-1}}(\mathbf{S} + \mathbf{\Delta p}), \qquad \mathbf{w_O^*} = \mathbf{w^*} + \frac{1}{\gamma}\mathbf{A^{-1}\Delta p}, \qquad \mathbf{\Delta p} \equiv \mathbf{p_O} - \mathbf{p} \tag{18}$$

with $\Delta p \equiv p_O - p$, and where $\mathbf{w}$ and $\mathbf{w^*}$ are defined as in (6). This shows that the wage of Home *L*-workers rises (controlling for terms of trade effects $\Delta p$), if and only if the cost-saving is sufficiently greater in the *L*-intensive sector than in the *K*-intensive sector. Using well-know solutions for (18) (see Jones 1965), the precise necessary and sufficient 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, $S_X / S_Y > a_{LX} / a_{LY}$. If the cost-savings ratio lies between the skilled-unskilled endowment ratios, then both wages may rise. Figure 1 (left panel) illustrates the possibilities. The usual Jonesian magnification effects are in operation.

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.[23] To summarise (proof in the text):

**Proposition 4** (Cost saving). Controlling for terms of trade effects, offshoring raises the real wage of Home *L*-workers if the offshoring implies cost savings that are sufficiently larger in the *L*-intensive sector than in the *K*-intensive sector; the real wage of *K*-workers rises less or actually falls; it falls if the cost-savings are sufficiently skewed towards the *L*-intensive sector. The precise necessary and sufficient conditions are illustrated in Figure 1. Apart from terms of trade effects, wages of Foreign *L*- and *K*-workers are unaffected.

Notice that shadow migration can widen or narrow the international wage gap for each type of labour, so offshoring may increase or decrease the pressure for real migration. In this sense, *shadow migration need not be a substitute for real migration*.

### *Rent allocation*

The cost savings arises from the use of Home's superior technology with Foreign's cheap labour. This creates rents (Foreign workers in the offshoring sector are paid their reservation wage rather than their average product) that accrue entirely to Home in the services-version of our offshoring model. The sectoral bias in the cost-savings determines how much of these rents go to Home *L*-workers as opposed to Home *K*-workers. This can be seen explicitly by writing (18) in terms of the Home-Foreign wage gaps using the definitions of **S** in (14):

$$\Delta\mathbf{w} \equiv \mathbf{w} - \mathbf{w_O} = \mathbf{A}^{-1}\mathbf{A}_1(\mathbf{w_O} - \mathbf{w_O^*}) + \mathbf{A}^{-1}\Delta\mathbf{p}$$

The first term on the right-hand side of this expression shows that the division of rents between Home *L*- and *K*-workers depends upon the relative labour savings in the *X* and *Y* sectors. The second term illustrates that Home factors' rewards also depend on the change in the terms-of-trade $\Delta\mathbf{p}$ (what Grossman and Rossi-Hansberg 2008 call the 'relative-price effect').

### *Extreme offshoring*

One interesting special case is where the coordination costs for all tasks are zero (all $\chi$'s are unity). In this case, all tasks are offshored (potentially) 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 brings the Foreign economy to the technology frontier. In this extreme case, Home wages are unchanged (controlling for terms of trade effects) but Foreign wages rise to Home levels. This tells us that the wage-offshoring relationship is thus non-monotonic. A modest lowering of coordination costs produces offshoring that raises incomes in the advanced-nation

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[23] 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 (15); 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.

(as per Proposition 4), 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*

Home imports of $X$ are (1-$\alpha$) times its GDP minus its production of $X$. In the offshoring equilibrium, $M_{XO} = (1-\alpha)E_O - X_O$, so we can express the change in imports in terms of the change in Home's GDP and its production of $X$, i.e. $\Delta M_X \equiv M_{XO} - M_X = (1-\alpha)\Delta E - \Delta X$. Since the impact of offshoring on $E$ is driven by factor price changes – and thus $S_X$ and $S_Y$ as per (18) – while its impact on $X$ is driven by $\Delta L$ and $\Delta K$ as per (16), 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 $\Delta E$ (which equals $L\Delta w$+ $K\Delta r$) from (18) and $\Delta X$ from (17) to get:

$$\Delta M_X = (1-\alpha)\mathbf{V}\mathbf{A}^{-1}(\mathbf{S}+\mathbf{\Delta p}) - (\kappa_Y - \frac{\Delta K}{\Delta L})\frac{a_{LY}\Delta L}{\det(\mathbf{A})}$$

Plainly this depends upon the sectoral cost-saving (**S**) and shadow migration ($\Delta K$ and $\Delta L$) in complex ways. Thus offshoring alters the pattern of trade in final goods. To summarise:

**Proposition 5** (Comparative advantage). 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 HOV motive for trade without offshoring, but trade in final goods can arise due to the 'shadow migration' associated with offshoring. Recall that Home firms face the technology matrix $\mathbf{A}$-$\mathbf{A_1}$ while Foreign firms face $\gamma\mathbf{A}$, thus in this sense offshoring creates a form of *Ricardian* comparative advantage in final goods.

If one uses aggregated data, some trade would be measured as Intra-industry trade (IIT). Indeed, IIT arises with offshoring if statisticians classify the output of tasks $X1$ and $Y1$ as $X$-sector and $Y$-sector trade, respectively. Home imports the fruit of tasks $X1$ and $Y1$. Since Home also exports either or both of final goods, intra-industry trade must arise. To summarise:

**Proposition 6** (IIT). Offshoring typically creates intra-industry trade since Home imports the fruit of the offshored task $X1$ and $Y1$ and is, typically, a net exporter of either $X$ or $Y$ even if Home and Foreign have identical factor endowments.

*Proof.* A standard measure of the volume of intra-industry trade is the 'overlap' of a country's import and exports within a given sector. Denoting 'IIT' as our measure of intra-industry trade and writing Home's imports of tasks in $i$ as $M_{X_i}^{Tasks} \equiv X_{iO}\sum_f a_{fi1}w_f^*$, we get (for $I = 2$ and thus $i = X, Y$):

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

*QED.*

**Trade in tasks and the 4 theorems**

The effective **FPE** 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. Moreover, *the direction of causality goes both ways*. Offshoring, which arises because the wage gap creates opportunities for arbitrage, widens the international wage gap (for at least one type of labour and possibly all of them as per Proposition 4) and thus creates extra trade.

The **HOV** theorem links trade in goods to relative factor endowments. It 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 HOV theorem would predict none.[24] By opening a gap between effective and actual endowments, offshoring may also lead to a Leontief-like paradox (the $L$-abundant nation might become a net exporter of the $K$-intensive good as per Proposition 5).

The correct version of the HOV theorem in our model is rather involved. Since Home GDP is the output of final goods less the cost of imported intermediates $\mathbf{p_O X} - \mathbf{w^*_O \Delta V}$, we can use the manipulations leading to (8) to write Home imports of $X$ as:

$$M_{XO} = \frac{\alpha L_O}{a_{LX}} \frac{k_O - \tilde{k}_O^w}{\tilde{k}_O^w - \kappa_X} \quad - \quad (1-\alpha)\mathbf{w^*_O \Delta V}.$$

The first term is isomorphic to the standard HOV theorem formulation as in (8), 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 Foreign, and the value of Home's imports of intermediates (all in terms of the numeraire). The closed form solution for $\mathbf{w^*_O \Delta V} \equiv w^*_O \Delta L + r^*_O \Delta K$, employing the definitions of $\mathbf{\Delta V}$ in (13), the solution for $\mathbf{w^*_O}$ in (14) and the solution for $\mathbf{X_O}$ in (11), is:

$$\mathbf{w^*_O \Delta V} = \frac{1}{\gamma} \mathbf{A^{-1} p_O A_1^T (A^T - A_1^T)^{-1} V}.$$

[24] Depending upon the factor intensity of the offshored tasks, the data might be marked by a 'missing trade' paradox, i.e. it might show less net trade than predicted by the HOV theorem as in Trefler (1995), but equally well there might be 'too much' net trade.

Combining these elements and using the two-sector definitions of $\mathbf{p_O}$ and $\mathbf{V}$, the HOV theorem with offshoring can be written as

$$M_{XO} = \frac{\alpha L_O}{a_{LX}} \frac{k_O - \tilde{k}_O^w}{\tilde{k}_O^w - \kappa_X} \quad - \quad \frac{1-\alpha}{\gamma} \mathbf{A}^{-1} \begin{bmatrix} 1 \\ p_O \end{bmatrix} \mathbf{A}_1^{\mathbf{T}} (\mathbf{A}^{\mathbf{T}} - \mathbf{A}_1^{\mathbf{T}})^{-1} \begin{bmatrix} L \\ K \end{bmatrix}$$

where $p_O$ is defined in (15). Plainly this is far more complex that the usual HOV 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** – 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:

$$\left.\frac{dw_O / w_O}{dp_O / p_O}\right|_{S_X, S_Y} = \frac{-p_O}{a_{KY}/a_{KX} \ - \ p_O} \frac{w}{w_O}, \qquad \left.\frac{dr_O / r_O}{dp / p}\right|_{S_X, S_Y} = \frac{p_O}{p_O \ - \ a_{LY}/a_{LX}} \frac{r}{r_O}$$

Comparing this to (9), 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 $w_O$ rises and $r_O$ falls with offshoring (controlling for terms of trade effects). 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 $S_X / S_Y > a_{LX} / a_{LY}$, as per Figure 1.

The **Rybczynski theorem** analogue with trade in tasks is (taking the extent of shadow migration as given):

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

Comparison of this and (10) 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 goods only, but the drop in $Y$ production would be more marked, if and only if $X_O > X$ and $Y_O < Y$; for these conditions to hold, it is sufficient 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 skilled-labour intensive, then the output of $X$ decreases as a result of an increase in $L$ by the usual Rybczynski logic. To summarise (proof in the text):

**Proposition 7** (Offshoring and the four theorems). Offshoring alters the four HOV theorems. In particular, shadow migration implies that the sign and volume predictions of the HOV theorem violate the theorem based on actual endowments. 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 violated in their strict forms although properly modified versions of the theorems hold.

**Integrating special cases in the literature**

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. From (18):

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

In the papers that assume only one sector experiences fragmented/offshoring (so $\min\{S_X, S_Y\} = 0$), offshoring acts like sector-specific Home technical progress, so the wage changes (ignoring terms of trade effects) are simple and the "Jones ambiguity" (see Section 2) arises. If offshoring/fragmentation occurs only in the unskilled-labour intensive $X$-sector, then $S_Y = 0$ and Home unskilled wages rise, but $w$ falls if offshoring occurs only in the $Y$-sector. Likewise, $r$ rises and $w$ falls if the offshoring occurs only in the skilled-labour intensive sector.

In papers where offshoring involves only one factor, offshoring acts like a factor-specific cost saving and the well-known GRH result that offshoring unambiguously boosts the wage of workers' whose jobs are offshored (controlling for terms of trade effects) can arise. GRH (2006) assume production functions where each task uses only $L$-labour or only $K$-labour and they undertake most of the analysis assuming that only $L$-tasks are offshored.[25] In this case, $S_X = a_{LX1}(w_O - w_O^*)$ and $S_Y = a_{LY1}(w_O - w_O^*)$, so:

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

Due to GRH normalisations involving the size of tasks and the equality of offshoring costs across sectors, the numerator of $\Delta r$ is zero, while $\Delta w$ is positive.[26] GRH (2008) also consider the case where

[25] GRH (2006) focus exclusively on the case where only tasks involving $L$ can be offshored; GRH (2008) also consider the possibility that tasks involving $K$ can be also be offshored. The main restriction in their formal analysis in both papers is that every task is performed only by $L$ or only by $K$.

[26] GRH (2008) 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' (formally, their measure) 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

tasks that involve only $K$-labour can also be offshored and in this case $S_X$ and $S_Y$ regain their general formulation as in (14), so the Jones ambiguity is restored as per Proposition 3.

## 5. Manufacturing task offshoring

In the previous section, all output of the offshored sector was 'sold' to Home even though offshored production units produce tasks $X1$ and $Y1$ at a lower cost than the Foreign producers. Here we allow local sales of $X1$ and $Y1$. For the sake of terminological clarity, we refer to this case (where the ζ's are zero) as the 'manufacturing goods case' even though it could apply to some types of services. As we mentioned in the introduction, this version of the model also captures 'long run' technology spillovers brought about by FDI: local Foreign firms might 'learn' from the presence of Home multinational firms producing tasks $X1$ and $Y1$ in their home country and close the technology gap on those.

When inter-firm coordination costs $\zeta(X1)$ and $\zeta(X1)$ are zero, the offshoring Home firms would also supply $X1$ and $Y1$ to Foreign producers. This would change the pricing and employment equations to:

$$\mathbf{p}+\mathbf{S}=\mathbf{A}\mathbf{w}_\mathbf{O}, \qquad \mathbf{p}+\mathbf{S}^*=\gamma\mathbf{A}\mathbf{w}_\mathbf{O}^*; \qquad \mathbf{V}+\Delta\mathbf{V}=\mathbf{A}^\mathbf{T}\mathbf{X}_\mathbf{O}, \qquad \mathbf{V}^*+\Delta\mathbf{V}^*=\gamma\mathbf{A}^\mathbf{T}\mathbf{X}_\mathbf{O}^* \tag{19}$$

where the subscript 'O' indicate the new offshoring equilibrium (i.e. we 'reset' the notation, so the value of these endogenous variables differs from those in previous sections), and

$$\mathbf{S}=\mathbf{A}_\mathbf{1}(\mathbf{w}_\mathbf{O}-\mathbf{w}_\mathbf{O}^*), \qquad \mathbf{S}^*=(\gamma-1)\mathbf{A}_\mathbf{1}\mathbf{w}_\mathbf{O}^*; \qquad \Delta\mathbf{V}=\mathbf{A}_\mathbf{1}^\mathbf{T}\mathbf{X}_\mathbf{O}, \qquad \Delta\mathbf{V}^*=-\Delta\mathbf{V}+(\gamma-1)\mathbf{A}_\mathbf{1}^\mathbf{T}\mathbf{X}_\mathbf{O}. \tag{20}$$

Note that **S**, **S***, **ΔV** and **ΔV*** are different from the previous section (in particular, **S*** was equal to zero and **ΔV*** was equal to minus **ΔV**). Solving (19) for wages and using (6) yields:

$$\mathbf{w}_\mathbf{O}=\mathbf{w}+\mathbf{A}^{-1}(\mathbf{S}+\Delta\mathbf{p}), \qquad \mathbf{w}_\mathbf{O}^*=\mathbf{w}^*+\frac{1}{\gamma}\mathbf{A}^{-1}(\mathbf{S}^*+\Delta\mathbf{p}) \tag{21}$$

where $\Delta\mathbf{p}$ denotes $\mathbf{p}_\mathbf{O}-\mathbf{p}$ as before. Two aspects of this expression are noteworthy. First, the expression for Home factor prices is isomorphic to (18) so our analysis in the service-offshoring case in the previous section also applies in this model extension (although the exact values of $S_X$ and $S_Y$ may change since the Foreign factor prices can be different). Second, the wages of Foreign workers also benefit from the cost-savings induced by the offshoring-linked technology transfer (the exact per-sector cost saving is given by $S_X^*$ and $S_Y^*$). There is a crucial difference, though, between the factor price effects on Home versus Foreign labour. For Home labour, it is *rents* that generate the cost-savings (i.e. the fact that Foreign workers are paid less than their average products); for Foreign labour, *technology transfer* is the source of the cost-savings. Moreover, the Foreign wage changes in (21) are isomorphic to those of Home. Consequently, all the detailed analysis in the previous section

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$a_{LX1}/a_{LX}$ = $a_{LY1}/a_{LY}$. Footnote 12 in GRH (2008) 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.

relating the cost-savings to the wage effects (e.g. Proposition 4 and Figure 1) is applicable to the impact of offshoring on Foreign wages with $S_X^*$ and $S_Y^*$ substituted for $S_X$ and $S_Y$.

Solving (19) for production and using (6) yields:

$$\mathbf{\Delta X} = \left(\mathbf{A^T}\right)^{-1} \mathbf{\Delta V}, \qquad \mathbf{\Delta X^*} = \frac{1}{\gamma}\left(\mathbf{A^T}\right)^{-1} \mathbf{\Delta V^*}$$

Qualitatively, the impact on Home production is the same as in the service-offshoring case in the previous section. The impact on Foreign production, however, is qualitatively different and the shadow migration interpretation is less clear-cut – note in particular that the signs of $\Delta L^*$ and $\Delta K^*$ are now ambiguous, though effective world endowments of $L$ and $K$ are unambiguously larger with offshoring, i.e. $\tilde{L}_O^w > \tilde{L}^w$ and $\tilde{K}_O^w > \tilde{K}^w$ (to see this, note that (19) implies $\mathbf{A^T X_O^w} = (\mathbf{V} + \mathbf{\Delta V}) + (\mathbf{V^*} + \mathbf{\Delta V^*})/\gamma \equiv \mathbf{\tilde{V}_O^w}$ and (20) implies $\mathbf{\Delta V} + \mathbf{\Delta V^*}/\gamma > \mathbf{0}$, or $\mathbf{\tilde{V}_O^w} > \mathbf{\tilde{V}^w}$). In the service-offshoring case, Home offshored technology that was used only for Home production, so the Foreign labour employed in the offshoring sector was diverted from Foreign production and this meant that the Foreign production change was proportional to the Home production effect but of the opposite sign ($\gamma\mathbf{\Delta X^*} = -\mathbf{\Delta X}$). Here the tech-transfer embodied in offshoring tends to stimulate Foreign production, so this simple proportionality breaks down. Nevertheless, the basic analysis of production effects for Foreign follows the reasoning of Proposition 3 and Figure 1 with $\mathbf{\Delta X^*}$ substituted for $\mathbf{\Delta X}$.

Since the trade effects follow from the production and factor price changes, as per the reason surrounding Propositions 5 and 6, it is clear that offshoring in the goods-case at hand will also be a source of comparative advantage and intra-industry trade. To summarise (proof in the text):

**Proposition 8** (Manufacturing task offshoring). Assume manufacturing offshoring instead of service offshoring. Then all the qualitative effects regarding trade effects as well as wage and production effects in Home remain unaltered. By contrast, Foreign production and wages are affected by offshoring in a way that is similar to Home production and wages.

## 6. Extending the basic model

In this section, we extend the basic trade-in-tasks model in two directions. First, 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). Second, we show that the basic analysis in Section 4 goes through in a simple trade model à la Helpman and Krugman (1985). This may be useful since some of the coordination-cost assumptions in our offshoring model fit more naturally in setting where firms produce differentiated product (and thus naturally have differentiated inputs).

**Intra-industry two-way offshoring** [27]

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 offshoring. Here we modify the basic model in a way that creates two-way, intra-industry offshoring in spirit akin to Davis (1995). 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'.

We assume 'mirror image' Ricardian superiority. For the purposes of this subsection, we take $N$=3, namely, there are three sets of tasks. Home has inferior technology in tasks $X$3 and $Y$3, while Foreign has inferior technology in tasks $X$1 and $Y$1. The nations have identical technology in tasks $X$2 and $Y2$. 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 $\mathbf{B} \equiv \{b_{fi}\}$ and $\mathbf{B}^* \equiv \{b^*_{fi}\}$ (with $f = L, K$ and $i = X, Y$ in the 2x2x2 case). We assume that the technological edges in tasks 1 and 3 are such that:

$$b_{fi} \equiv a_{fi1} + a_{fi2} + \gamma_3 a_{fi3}, \quad b^*_{fi} \equiv \gamma_1 a_{fi1} + a_{fi2} + a_{fi3}, \quad b_{fi} = b^*_{fi}, \quad \gamma_t > 1; \qquad f = K, L, \quad i = X, Y, \quad t = 1,3$$

so $\mathbf{B^*}$=$\mathbf{B}$. Finally, we assume nations have the same factor endowment ratios, or $\mathbf{V} = \mu\mathbf{V^*}$, some $\mu$ >0.

Given the analysis above, the outcome without offshoring (i.e. trade in tasks) is obvious. The two nations have identical wages and do not trade with each other, i.e.:

$$\mathbf{p} = \mathbf{Bw} = \mathbf{Bw}^*; \qquad \mathbf{V} = \mathbf{B^T X}, \qquad \mathbf{V}^* = \mathbf{BX}^*, \qquad \mathbf{V^w} = \mathbf{BX^w}; \qquad \mathbf{M} = \mathbf{0}. \tag{22}$$

Once we allow free offshoring – i.e. the coordination costs, the $\chi$'s and the $\zeta$'s, drop to unity – trade in tasks occurs.[28] Specifically, Home's superior technology in tasks $X$1 and $Y$1 completely displaces Foreign's technology in these tasks while Foreign's superior technology in tasks $X$3 and $Y$3 completely displaces Home's technology. In this case, offshoring (and the fact that tasks can be sold at arm's length among firms since the $\zeta$'s are unity) implies that both nations move to the technology frontier. As a result, the pricing and production equations are:

$$\mathbf{p_O} = \mathbf{Aw_O} = \mathbf{Aw^*_O}; \qquad \mathbf{V} = \mathbf{A^T X_O}, \qquad \mathbf{V^*} = \mathbf{A^T X^*_O}, \qquad \mathbf{V^w} = \mathbf{A^T X^w_O} \tag{23}$$

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

[28] Note that, since wages are equalised, this case makes sense only if we consider the case of 'manufacturing-task' offshoring.

where $a_{fi} \equiv a_{fi1} + a_{fi2} + a_{fi3} < b_{fi}$ and the subscript 'O' indicates two-way offshoring equilibrium variables (i.e. we have 'reset' the notation so these endogenous variables differ from those in previous sections). Since **B>A** holds by construction, it follows from (22) and (23) that wages have risen by $\mathbf{B\Delta w} = (\mathbf{B} - \mathbf{A})\mathbf{w_O} + \mathbf{\Delta p}$ (controlling for terms-of-trade effects). By the same token, world effective endowments have risen. To see this, let $\mathbf{V_O^w} \equiv \mathbf{B^T X_O^w}$ so that $\mathbf{\Delta V^w} \equiv \mathbf{V_O^w} - \mathbf{V^w} = (\mathbf{B^T} - \mathbf{A^T})\mathbf{X_O^w} > \mathbf{0}$ holds by (22) and (23); as a result, (world and domestic) production of at least one of the final goods has risen, too. As usual, by the Stolper-Samuelson and Rybczynski logics, the effect on individual wages and individual industry output are ambiguous. In symbols:

$$\mathbf{\Delta w} = [\mathbf{I} - \mathbf{B^{-1}A}]\mathbf{w_O} + \mathbf{B^{-1}\Delta p}, \qquad \mathbf{\Delta X} = [\mathbf{I} - (\mathbf{B^T})^{-1}\mathbf{A}]\mathbf{X_O}$$

where **I** is the identity matrix. The interpretation of these expressions revolves around the same considerations as in Section 5. Expressions pertaining to Foreign are isomorphic.

The production effects are simple to work out. The two-way offshoring is like 'shadow migration' *into* each country but due to the symmetry we imposed, there is no net shadow migration *between* countries. 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. Given the *ex ante* symmetry of the nations at the sector level and the *ex post* symmetry of the nations at the task level, there is no trade in final goods either before or after free offshoring. With offshoring, all trade is intra-industry trade in tasks. 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.[29]

**Offshoring in a Helpman-Krugman trade model**

A fact that has been well appreciated in the literature since Norman (1976) and Helpman and Krugman (1985) is that the basic HOV results carry through unaltered in a Dixit-Stiglitz monopolistic competition setting provided that technologies are homothetic.[30] Here we use this insight to show that the Section 4 analysis could easily be conducted in a monopolistic competition trade model setting. Such a setting has the merit of making firm-level variables better defined but the demerit of reducing comparability with the classic HOV model.

The key to the Section 4 analysis lies in the pricing and employment equations and their restatement using the shadow migration insight. As is well known, the free-entry output of a typical variety under monopolistic competition (MC) with homothetic technologies is parametrically fixed at $F(\sigma\text{-}1)$, where

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[29] 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.

[30] A 'bundle' of $i$-sector factors uses $a_{Li}$ and $a_{Ki}$ units of $L$ and $K$, respectively. The fixed cost involves $F$ bundles and the marginal cost involves 1 bundle in each sector $i = X,Y$.

$F$ is the fixed entry cost and $\sigma$ is the elasticity of substitution.[31] This implies that MC sectors display constant returns at the sector level (doubling sectoral output at equilibrium would require double the inputs). Equally well-known is Dixit-Stiglitz MC's constant mark-up pricing which makes prices proportional to marginal costs. These two facts imply that the MC pricing and employment equations differ only slightly from those of the HOV model in Section 3. Specifically, assuming Dixit-Stiglitz competition in both sectors, the Home employment and pricing conditions are:[32]

$$\mathbf{V} = \frac{\sigma}{\sigma - 1}\mathbf{A}^{\mathbf{T}}\mathbf{X}, \qquad \mathbf{p} = \frac{\sigma}{\sigma - 1}\mathbf{A}\mathbf{w}.$$

The Foreign pricing and employment conditions are isomorphic.

Since we have not specified units for the elements of **X** or **V**, we are now free to choose units such that the coefficient, $\sigma/(\sigma\text{-}1)$, is absorbed into the definitions of prices and endowments. With this, we have reduced the problem to the one solved in Sections 4 (service-task case) and so can conclude that the relevant Propositions among Propositions 1 to 8 also hold in this model.

## 7. Welfare

What are the gains from offshoring? How are the usual gains from trade in final goods affected by trade in tasks? These are the two questions this section seeks to answer. Before doing so, it is worth noting that there is no market failure in the neoclassical model of sections 3 to 5, so in general it must be the case that the world as a whole is better off as a result of trade in tasks: indeed, offshoring enables a subset of Foreign workers to replace their domestic, inferior technology with Home's, and as a result the world production possibility frontier expands.

**Gains from trade in tasks**

Consider first the gains from trading tasks, controlling for the trade in final goods (i.e. impose $\mathbf{\Delta p} = \mathbf{0}$ for the time being). First, as we noted above, world's production possibility frontier shifts out as the result of (at least some) Foreign workers conveying tasks $X1$ and $Y1$ using Home's better technology. In effect, world endowments of $L$ and $K$ increase as per (13) as a result of shadow migration. In turn, world output of either $X$ or $Y$ (or both) must increase, as per (12) and Figure 1 (left panel). A direct implication of this result is that, all else equal, real factor rewards are generally larger under offshoring than under trade in goods alone. To see this, turn first to the model of section 4 (service offshoring); as is obvious from (14) and Figure 1 (right panel), nominal wages of Home skilled or Home unskilled workers (or both) increase; given our choice of numeraire, real changes are nominal changes with $\Delta p$ =

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[31] Let $x$ denote output and $v$ denote marginal cost. Free entry requires that the price, which is $v\sigma/(\sigma\text{-}1)$, equals average cost, which equals $v(1+F/x)$; solving for $x$ yields the result in the text.

[32] The equilibrium output per firm in both sectors is $F(\sigma\text{-}1)$, so the per-firm demand for factor bundles (including the demand for the fixed cost) is $x = F\sigma$. Since $X$-sector output is just $nx$ where $n$ is the mass of $X$-firms, $n = X/F(\sigma\text{-}1)$, total $X$-sector labour demand is a $a_{LX}(F+x)n$, which equals $a_{LX}(\sigma/(\sigma\text{-}1))X$. Similar expressions hold for the other labour demands.

0 . In the model of section 5 (manufacturing task offshoring), Foreign workers' nominal wages increase as a result of trade in tasks if, and only if, wages of Home workers with similar skills increase, too. Thus, unless the offshoring-led factor augmenting technological progress is highly biased against one sector, workers/consumers worldwide enjoy higher real wages. Finally, none of these caveats apply to the two-way offshoring model of section 6 by virtue of the symmetry of the model, but all of them apply to the Helpman-Krugman monopolistic competition trade model.

**Immiserizing trade in tasks?**

Let us analyse now how trade in tasks affects the gains from trade in final goods. Controlling for the terms of trade effects ($\Delta\mathbf{p} = \mathbf{0}$), trading tasks does not affect the rationale of the gains from trade in final goods among nations with different factor endowments (gains from specialisation) or producing differentiated varieties in an imperfectly competitive environment (gains from increasing variety).

Offshoring does, however, alter the patterns of production and the patterns of trade in final goods. As a result, trade in tasks alters the terms of trade $p$, which benefits one country at the expense of the other, and which hurts disproportionably some factor. Thus, in theory, it is conceivable that the offshoring country might be made worse of as a result of offshoring, as pointed out by Samuelson (2004). It must be stressed that this theoretical possibility is a special, extreme case which in general is not warranted.

To summarise the findings of this section, we write:

**Proposition 9** (Welfare). Trade in tasks allows for a more efficient allocation of world resources. As a result, in all circumstances, the real wages of *some* workers in *at least one* country increase. More generally, it benefits all types of workers in all countries, unless labour cost-saving is highly biased towards some sectors and/or if it sways the terms of trade in final goods in an extreme way.

In other words, unlike trade in final goods—which has polarising effects on factor rewards (Stolper and Samuelson 1941)—trade in tasks is more like a 'tide that lifts all boats'.

## 8. Concluding remarks

Our paper presents a simple model of offshoring that allows us to derive necessary and sufficient conditions on the sign of the wage, production and trade effects of offshoring. The model's simplicity also allows us to re-formulate the four classic HOV theorems to account for trade in tasks (offshoring) as well as trade in goods. Our results can also be used to integrate the complex gallery of results derived in the extensive theoretical literature on offshoring/fragmentation. The key is that 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). The paper also shows that the basic model can easily be extended to account for two-way offshoring between similar nations. To bolster comparability between our results with offshoring and the four classic HOV theorems, we convey the bulk of our analysis in a Walrasian setting, but we show that it applies equally in a simple monopolistic competition setting – that is, to a setting where the definition of a firm squares better with the spirit of the cause of offshoring in our framework – the technology edge of Home firms. Finally, we analyse the welfare implications of offshoring and find that, in our model, trade in tasks tends to increase the real wages of workers of all skills, in sharp contrast with the well-known unequal effects of trading final goods.

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## Appendix

### A.1. Existence and uniqueness of diversified equilibrium with offshoring

We consider the case of service-task offshoring and we work with $F = I = 2$ throughout. This appendix has two aims. First, the analysis below establishes that an equilibrium in which both countries remain diversified at the offshoring equilibrium exists under some conditions; when these hold, it is also unique. Second, seeking to find general conditions under which these are true is not very rewarding since the equilibrium expressions for $\mathbf{X_0} \equiv [X_0, Y_0]'$ and $\mathbf{X_0^*} \equiv [X_0^*, Y_0^*]'$ are too unwieldy to be revealing (but see the last section of this appendix). We therefore follow a different route: we prove economically insightful conditions for some special cases to arise at equilibrium. To this aim, let

$$\kappa_{i1} \equiv \frac{a_{Ki1}}{a_{Li1}}, \qquad \phi_i \equiv \frac{a_{Li1}}{a_{Li}}, \qquad \phi_i \in [0,1) \qquad i = X, Y\,.$$

Conveniently, $\phi_i$ is an industry-specific measure of offshoring: $\phi_i$ is the fraction of (labour) tasks that can be offshored in sector *i*; without offshoring $\phi_i = 0$.

Formally, let $\theta = (L, L^*, k, k^*, \kappa_X, \kappa_Y, a_{LX}, a_{LY}, \phi_X, \phi_Y, \kappa_{X1}, \kappa_{Y1}, \alpha) \in \Theta \equiv \mathbb{R}_+^{13}$ define the 13-dimensional vector of parameters of the 2x2x2x2 model. Assumptions in the text about the relative factor intensities of industries and the relative factor abundances of countries restricts the set of value θ might take to a subset of Θ, defined as $\Theta_0$, with $\Theta_0 \subset \Theta$.

In the 2x2x2 model without offshoring, for instance, the (convex) subset of parameters defined as $\Theta_0^{\text{No Offshoring}} \equiv \left\{\theta \in \Theta, i \in \{X, Y\} : \kappa_X < k^* < k < \kappa_Y, \kappa_{i1} = 0, \phi_i = 0\right\}$ ensures that the diversified equilibrium described in the text exists and is unique (it is the unique solution to a system of linear independent equations). Let $\Theta_1 \subset \Theta_0$ be any subset of parameters of the model such that both countries are diversified at the equilibrium both with offshoring and without. Let $\bigcup \Theta_1$ be the union of all possible $\Theta_1$, so $\bigcup \Theta_1 \subset \Theta$.[33] Characterizing $\bigcup \Theta_1$ is neither insightful nor easy a task; however, we might characterize some of its elements. Specifically, we shall choose some (economically-meaningful) *values* for some elements of the vector $\theta_1$ and then impose conditions on other elements of $\theta_1$ (*inequalities*) that ensure that the diversified equilibrium exists. By continuity, we know that these inequalities ensure that such an equilibrium also exists in the neighbourhood of the initial values we have imposed; that is, for any $\theta \in \operatorname{int} \bigcup \Theta_1$ (i.e. for any $\theta$ in $\bigcup \Theta_1$ bar its boundaries), there exists a

[33] Hence $\Theta_0^{\text{No Offshoring}} \in \bigcup \Theta_1$.

$\bar{\varepsilon} \in \mathbb{R}^{13}_{+}$ such that $\theta + \varepsilon \in \bigcup \Theta_1$ for all $\varepsilon < \bar{\varepsilon}$. Also, by the convexity of $\Theta_1$, it is readily verified that, for any δ in the unit interval and for some $\tilde{\Theta}_1 \in \bigcup \Theta_1$, we have $\theta, \theta' \in \tilde{\Theta}_1 \Rightarrow \delta\theta + (1-\delta)\theta' \in \bigcup \Theta_1$. Thus, the general results we derive in the text are truly general indeed. For instance, the normalisations and parameter restrictions of the central case studied by Grossman and Rossi-Hansberg (2008) has $\kappa_{i1} = 0$ and $\phi_i = \phi \in (0,1)$, $i = X, Y$ and the parameter restrictions in their section 4 implies $\kappa_{i1} = \kappa_i > 0$ and $\phi_i = \phi \in (0,1)$, $i = X, Y$. We characterise $\Theta_1$ in such cases as well as in more general ones.

## A.2. Conditions for $\mathbf{X_0}, \mathbf{X_0^*} > 0$ when $\kappa_{i1} \in \{0, \kappa_i\}$ and $\phi_i = \phi \in (0,1)$, $i = X, Y$

In this section we look at necessary and sufficient conditions that ensure that both countries remain fully diversified when an identical fraction of unskilled labour tasks can be offshored in both industries ($0 < \phi_i = \phi < 1$). In this case, Home output is equal to:

$$X_0\big|_{\lambda_i=\lambda} = \frac{L}{a_{LX}(1-\phi)} \frac{\kappa_Y - k - \phi(\kappa_{Y1} - k)}{\kappa_Y - \kappa_X - \phi(\kappa_{Y1} - \kappa_{X1})}, \qquad Y_0\big|_{\lambda_i=\lambda} = \frac{L}{a_{LY}(1-\phi)} \cdot \frac{k - \kappa_X - \phi(k - \kappa_{X1})}{\kappa_Y - \kappa_X - \phi(\kappa_{Y1} - \kappa_{X1})} \tag{24}$$

These values are positive if the relative factor abundance remains in the *effective* cone of diversification (i.e. adjusted for offshoring). Mathematically, this will be the case if the numerator and the denominator for both $X_0$ and $Y_0$ have the same sign. When $X$ remains L-intensive with offshoring, this is the case if $(1-\phi)\kappa_X + \phi(\kappa_X - \kappa_{X1}) < (1-\phi)k < (1-\phi)\kappa_Y + \phi(\kappa_Y - \kappa_{Y1})$.[34] This condition is satisfied under the more general assumption A3 below. Further, using (24), assume first $\kappa_i = 0$, which (together with $\phi_i = \phi$) implies $X_0 = [a_{LX}(1-\phi)(\kappa_Y - \kappa_X)]^{-1} L[\kappa_Y - (1-\phi)k] > X/(1-\phi)$, which is necessarily positive by Assumption 2, and $Y_0 = [a_{LY}(1-\phi)(\kappa_Y - \kappa_X)]^{-1} L[(1-\phi)k - \kappa_X] < Y/(1-\phi)$, which is positive only if the share of offshoreable tasks $\phi$ is small enough; the inequalities follow from the closed-form solutions to (6).[35] Note that when unskilled labour services may be offshored then the output of the unskilled-labour intensive sector $X$ rises by more than the output of the skilled-labour-intensive sector $Y$ (a Rybczynski effect that results from the 'shadow migration' effect of offshoring). Assuming instead that offshored services have the same factor intensities as non-offshored ones, i.e. $\kappa_{i1} = \kappa_i > 0$, then the expressions in (24) simplify to $(1-\phi)^{-1}X$ and $(1-\phi)^{-1}Y$, respectively: intuitively, offshoring allows Home factors to be employed on a subset $1-\phi$ of tasks, hence Home output is $1-\phi$ larger than it would be otherwise – hence offshoring is identical to Hicks-neutral technical progress in this case.

[34] Both numerators and both numerators are negative if these inequalities are reversed, in which case the production of good $Y$ becomes L-intensive.

[35] Alternatively, to get the closed form solutions to $X$ and $Y$, set $\phi = 0$ in the expressions for $X_0$ and $Y_0$ in the text.

The values for Foreign output are too unwieldy to provide any insight, even in the relatively special case $0<\phi_i=\phi<1$. Hence we further assume that no skilled labour task is offshoreable ($\kappa_{i1}=0$). For Foreign output, we obtain:

$$X_0^*\big|_{\lambda_i=\lambda,\kappa_{i1}=0}=\frac{L^*}{\gamma a_{LX}(\kappa_Y-\kappa_X)}\left[\kappa_Y-k^*-\frac{L}{L^*}\frac{\phi}{1-\phi}\kappa_Y\right]<X^*,$$
$$Y_0^*\big|_{\lambda_i=\lambda,\kappa_{i1}=0}=\frac{L^*}{\gamma a_{LY}(\kappa_Y-\kappa_X)}\left[k^*-\kappa_X+\frac{L}{L^*}\frac{\phi}{1-\phi}\kappa_X\right]>Y^*.$$

Observe that the output of the unskilled-labour-intensive sector contracts, i.e. $X_0$* is lower with offshoring ($\phi$>0) that without ($\phi$=0), whereas $Y_0$* is *larger* than *Y**; this, again, is due to the Rybczynski effect that is a consequence of the shadow (outward) migration brought about by offshoring.

Foreign X-output remains positive if Foreign's labour force is large enough so that production of both offshoring services *and* production of *Y** do not fully absorb the labour force; a sufficient and necessary condition is:

**Assumption A0.** $\frac{L^*}{L}>\frac{\phi}{1-\phi}\frac{\kappa_Y}{\kappa_Y-k^*}$.

Now, assume instead $\kappa_{i1}=\kappa_i$. For Foreign output, we obtain:

$$X_0^*\big|_{\lambda_i=\lambda,\kappa_{i1}=\kappa_i}=\frac{L^*}{\gamma a_{LX}(\kappa_Y-\kappa_X)}\left[\kappa_Y-k^*-\frac{L}{L^*}\frac{\phi}{1-\phi}(\kappa_Y-k)\right]<X^*$$
$$Y_0^*\big|_{\lambda_i=\lambda,\kappa_{i1}=\kappa_i}=\frac{L^*}{\gamma a_{LY}(\kappa_Y-\kappa_X)}\left[k^*-\kappa_X+\frac{L}{L^*}\frac{\phi}{1-\phi}(k-\kappa_X)\right]>Y^*.$$

Foreign X-output remains positive if Foreign's labour force is large enough; a sufficient and necessary condition is $L^*/L>[(1-\phi)(\kappa_Y-k^*)]^{-1}\phi(\kappa_Y-k)$, which is necessarily fulfilled if Assumption A0 holds.

### A.3. Conditions for $\mathbf{X_0},\mathbf{X_0^*}>0$ when $\kappa_{i1}=\kappa_i$

In this section we relax the assumption $\phi_i=\phi$ and we derive necessary and sufficient conditions so that both countries produce both final goods at the offshoring equilibrium under the special case $\kappa_{i1}=\kappa_i$, $i=X,Y$. Let

$$X_0\equiv\frac{num_X}{den_X},\qquad Y_0\equiv\frac{num_Y}{den_Y},\qquad X_0^*\equiv\frac{num_{X^*}}{den_{X^*}},\qquad Y_0^*\equiv\frac{num_{Y^*}}{den_{Y^*}}\tag{25}$$

Under the assumption $\kappa_{i1}=\kappa_i$, Home output in both industries is positive without requiring further assumptions; indeed:

$$X_0\big|_{\kappa_{i1}=\kappa_i} = \frac{L}{a_{LX}(1-\phi_X)}\frac{\kappa_Y - k}{\kappa_Y-\kappa_X} > 0, \qquad Y_0\big|_{\kappa_{i1}=\kappa_i} = \frac{L}{a_{LY}(1-\phi_Y)}\frac{k-\kappa_X}{\kappa_Y-\kappa_X} > 0\,,$$

where the inequality follows from our ranking of sectoral factor intensities. Turn now to Foreign output. In this case, using the definitions in (25) we obtain:

$$den_{X^*}\big|_{\kappa_{i1}=\kappa_i} = \gamma a_{LX}(\kappa_Y-\kappa_X)(1-\phi_X) > 0\,,$$

where the inequality follows from our ranking of sectoral factor intensities, and

$$num_{X^*}\big|_{\kappa_{i1}=\kappa_i} = (\kappa_Y - k^*)(1-\lambda_X)L^* - \phi_X(\kappa_Y-k)L\,.$$

Output must be positive, so a necessary and sufficient condition for $X_0$*>0 to hold is:

**Assumption A1.** $\dfrac{L^*}{L} > \dfrac{\phi_X}{1-\phi_X}\dfrac{\kappa_Y-k}{\kappa_Y-k^*}$.

In words, this says that the Foreign labour force has to be large enough not to be fully employed in producing offshoring tasks for Home firms. An analogous condition holds for $K^*/K$ if and only if assumption A1 holds. By the same token, using the definitions in (25), we get:

$$den_{Y^*}\big|_{\kappa_{i1}=\kappa_i} = \gamma a_{LY}(\kappa_Y-\kappa_X)(1-\phi_Y) > 0\,,$$

where the inequality follows from our ranking of sectoral factor intensities, and

$$num_{Y^*}\big|_{\kappa_{i1}=\kappa_i} = (k^*-\kappa_X)(1-\phi_Y)L^* - \phi_Y(k-\kappa_X)L\,.$$

Output must be positive, so a necessary condition for $Y_0$*>0 to hold is:

**Assumption A2.** $\dfrac{L^*}{L} > \dfrac{\phi_Y}{1-\phi_Y}\dfrac{k-\kappa_X}{k^*-\kappa_X}$.

Note that assumptions A1 and A2 are trivially satisfied for $\phi_i = 0$.

### A.4. Sufficient conditions for $\mathbf{X_0 > 0}$

In this section, we provide sufficient and necessary conditions so that Home output is positive in both industries at the offshoring equilibrium *in general*. Let us start with $X_0$. Using the definitions in (25):

$$\begin{aligned}\frac{num_X}{L} &= (\kappa_Y - \phi_Y\kappa_{Y1}) - (1-\phi_Y)k = \kappa_Y - k - \phi_Y(\kappa_{Y1}-k),\\ \frac{den_X}{a_{LX}} &= (1-\phi_X)(\kappa_Y-\phi_Y\kappa_{Y1}) - (1-\phi_Y)(\kappa_X - \phi_X\kappa_{X1}).\end{aligned} \tag{26}$$

Note that both expressions are trivially positive without offshoring. Similarly,

$$\frac{num_Y}{L} = (1-\phi_X)k - (\kappa_X - \phi_X \kappa_{X1}) = k - \kappa_X - \phi_X (k - \kappa_{X1}),$$
$$\frac{den_Y}{a_{LY}} = (1-\phi_X)(\kappa_Y - \phi_Y \kappa_{Y1}) - (1-\phi_Y)(\kappa_X - \phi_X \kappa_{X1}) = \frac{den_X}{a_{LX}}. \tag{27}$$

Both $num_X$ and $num_Y$ are positive if, and only if, the following holds:

**Assumption A3.** $\kappa_X + \frac{\phi_X}{1-\phi_X}(\kappa_X - \kappa_{X1}) < k < \kappa_Y + \frac{\phi_Y}{1-\phi_Y}(\kappa_Y - \kappa_{Y1})$.

That is, Home's relative endowment must belong to the cone of diversification, adjusted for offshoring (obviously $\phi_i = 0$, all *i*, implies $\kappa_X < k < \kappa_Y$).

Let $\kappa_{X1}^{\min} \equiv \max\{0, [\kappa_X - k(1-\phi_X)]/\phi_X\}$ and $\kappa_{Y1}^{\max} \equiv [\kappa_Y - k(1-\phi_Y)]/\phi_Y$ so assumption A3 may be rewritten as:

**Assumption A3'.** $\kappa_{X1} \geq \max\left\{0, k - \frac{k-\kappa_X}{\phi_X}\right\} \equiv \kappa_{X1}^{\min}, \quad \kappa_{Y1} \leq k + \frac{\kappa_Y - k}{\phi_Y} \equiv \kappa_{Y1}^{\max}$.

If A3 holds, then, $\forall i$ :

$$\begin{aligned}\frac{den_i}{a_{Li}} &= (1-\phi_X)(\kappa_Y - \phi_Y \kappa_{Y1}) - (1-\phi_Y)(\kappa_X - \phi_X \kappa_{X1}) \\ &> (1-\phi_X)(1-\phi_Y)k - (1-\phi_Y)(\kappa_X - \phi_X \kappa_{X1}) \\ &> (1-\phi_Y)(\kappa_X - \phi_X \kappa_{X1}) - (1-\phi_Y)(\kappa_X - \phi_X \kappa_{X1}) \\ &= 0,\end{aligned}$$

where the first inequality follows from $num_Y > 0$ and the second follows from $num_X > 0$.[36] Thus, assumption A3 is sufficient to ensure that $den_i > 0$, $i = X, Y$ holds, too.

## A.5. Sufficient conditions for $\mathbf{X}_0^* > 0$

The first result that is useful to us is $den_{i*} = \gamma(\kappa_Y - \kappa_X)den_i$, which ensures that $den_{X*}, den_{Y*} > 0$ if and only if $den_X, den_Y > 0$, which holds by assumption A3. Therefore, we may no longer worry about the sign and the zeroes of the denominators. A second useful set of results is that the relationship between output and the relative factor intensities of offshoreable tasks is monotonic:

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[36] A more direct but slightly more cryptic proof would make use of the following identity, which follows from (26) and (27): $den_i / a_{Li} = \sum_i (1-\phi_i) num_i / L$. Then $num_i$ >0 (all *i*) immediately implies $den_i$ >0.

$$\frac{\partial X_0^*}{\partial \kappa_{X1}} = B^2 \frac{L\lambda_X}{\gamma a_{LX}}(1-\phi_Y)\left[\kappa_Y - \phi_Y \kappa_{Y1} - (1-\phi_Y)k\right] > 0,$$
$$\frac{\partial X_0^*}{\partial \kappa_{Y1}} = -B^2 \frac{L\lambda_Y}{\gamma a_{LX}}(1-\phi_Y)\left[\kappa_X - \phi_X \kappa_{X1} - (1-\phi_Y)k\right] > 0,$$
$$\frac{\partial Y_0^*}{\partial \kappa_{Y1}} = B^2 \frac{L\lambda_Y}{\gamma a_{LY}}(1-\phi_X)\left[\kappa_X - \phi_X \kappa_{X1} - (1-\phi_Y)k\right] < 0,$$
$$\frac{\partial Y_0^*}{\partial \kappa_{X1}} = -B^2 \frac{L\lambda_X}{\gamma a_{LY}}(1-\phi_X)\left[\kappa_Y - \phi_Y \kappa_{Y1} - (1-\phi_Y)k\right] < 0,$$

where $1/B \equiv -(1-\phi_X)(\kappa_Y - \phi_Y \kappa_{Y1}) + (1-\phi_Y)(\kappa_X - \phi_X \kappa_{X1})$ the inequalities follow from assumption A3; note that $1/B \neq 0$ also holds by assumption A3. Therefore, in general there exist bounds for the parameters $\kappa_{i1}$, ($i$ = $X$,$Y$) which we may express as functions of the remaining parameters of the model such that $X_0^*, Y_0^* > 0$ holds. We have characterised such restrictions in the previous sections of this Appendix.

# Figure

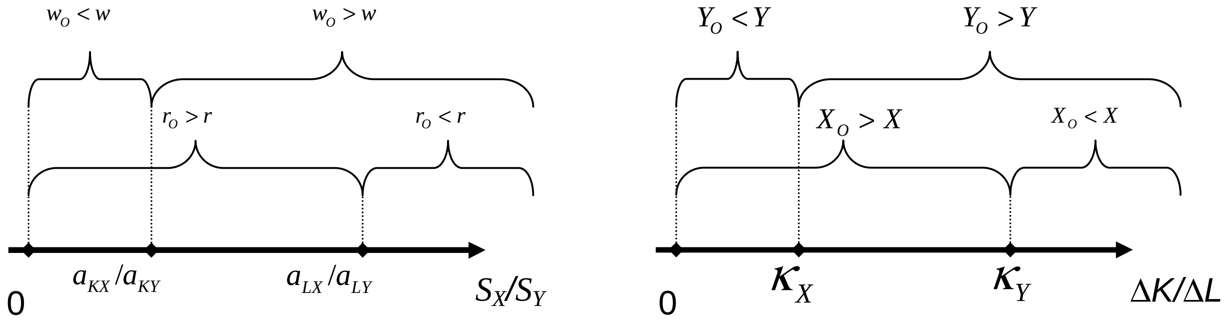


**Figure 1. Shadow-migration, cost-savings, and offshoring's production and wage effects**