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THE EXPORT-MAGNIFICATION EFFECT OF OFFSHORING

by Joern Kleinert
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In 2012 all ECB publications feature a motif taken from the €50 banknote.

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Abstract

In this paper we provide a new explanation for the increase in world trade over the last two decades. We show analytically in a general equilibrium model with heterogeneous firms that a fall in variable offshoring costs boosts trade in differentiated final goods through an intra-industry reallocation of resources towards the more productive firms. That is what we call the *export-magnification effect of offshoring*. More specifically, lower barriers to offshoring reduce the average costs of inputs for offshoring firms and allow more firms to source cheap foreign intermediates, which improves firm-level price competitiveness. This, in turn, translates into higher export quantities of incumbent exporters (intensive margin) and the entry of new exporters (extensive margin). The increase in final goods trade comes on top of the boost to trade in intermediates. Hence the mechanism proposed in this paper is consistent with the fact that the share of intermediate goods in international trade has remained broadly stable over recent years.

Keywords: offshoring, international trade, multinational firms
JEL classification: F12, F15, F23

Non-technical summary

The past two decades have seen globalization proceed at an ever finer level of resolution. Production is increasingly sliced up into separate tasks that can be traded internationally. As a result, more and more firms are engaged in offshoring: they either import intermediates from offshore affiliates or purchase foreign intermediates at arm's length. This vertical fragmentation of production has been paralleled by a surge in world trade. The global trade-to-GDP ratio almost doubled between the mid-1980s and 2008. Neither income growth nor reductions in transport costs and tariffs can fully explain this phenomenon.

In this paper, we provide a new explanation for the increase in world trade, based on a general equilibrium model with heterogeneous firms and offshoring. We show analytically that a fall in offshoring costs boosts trade in differentiated final goods through an intra-industry reallocation of resources towards the more productive firms: That is what we call the *export-magnification effect of offshoring*. In a nutshell, lower barriers to offshoring allow more domestic firms to source cheap foreign intermediates and reduce the input costs of offshoring firms, which improves firm-level competitiveness. This, in turn, translates into higher export quantities of exporters (intensive margin) and the entry of new exporters (extensive margin), thereby fostering trade in final goods.

Our analysis rests on a three-sector multi-country general equilibrium model with heterogeneous firms in the vein of Melitz (2003). There are many symmetric advanced economies and one "workbench country" (think of China or the Central and Eastern European Countries). Ricardian comparative advantages determine the equilibrium trade patterns: the advanced economies import cheap intermediates from the workbench country in return for a homogeneous consumption good. At the same time, they trade differentiated products among each other to satisfy consumers' love of variety.

We study analytically the consequences of closer integration of the workbench country into the global economy - modeled as a fall in variable offshoring costs. Not surprisingly, inter-industry trade in homogeneous intermediate and final goods intensifies. More remarkably, given that trade costs in differentiated final goods between the advanced economies have remained unchanged, closer integration of intermediate goods markets also boosts exports of final goods at both the intensive and extensive margin. Access to cheaper intermediates from abroad allows highly productive firms to increase their export quantities and additional firms manage to become exporters. The ensuing reallocation of resources toward the more productive firms raises the average firm efficiency in the differentiated final good sector. This, in turn, lowers the consumption price level and raises real wages, thereby leading to a long-run welfare gain.

Of course, we claim no originality for the idea that offshoring partly accounts for the surge in world trade. That said, the mechanism proposed in this paper differs considerably from those in the existing theoretical literature, which has largely relied on models with representative firms. By their very nature, these models cannot capture the intra-industry reallocation of resources described in this paper. Moreover, our explanation is consistent with the fact that the trade share of intermediates has remained broadly stable over recent years. In essence, we show how intensified trade in intermediates boosts trade in final goods in a setup with heterogeneous firms.

1. Introduction

The past two decades have seen globalization proceed at an ever finer level of resolution. Production is increasingly sliced up into separate tasks that can be traded internationally (Grossman and Rossi-Hansberg, 2008b). As a result, more and more firms are engaged in offshoring: they either import intermediates from offshore affiliates or purchase foreign intermediates at arm's length. This is illustrated by Figure 1, which shows that the share of imported intermediates in total intermediate inputs used in the manufacturing sector increased in the vast majority of OECD countries between the mid-1990s and the mid-2000s. This "high-resolution globalisation" (Baldwin, 2006, 2008) has been paralleled by a surge in world trade. The global trade-to-GDP ratio almost doubled between the mid-1980s and 2008, from 14% to 27%. While the ratio dropped sharply amid the global downturn of 2008-09, it quickly rebounded thereafter.

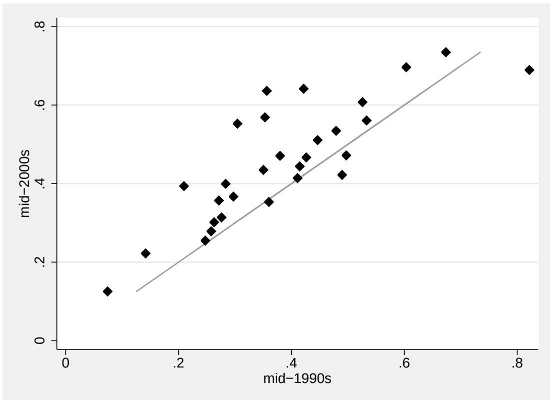

Figure 1: Share of imported intermediates in total intermediates used in the manufacturing sector for 29 OECD countries (mid-1990s vs. mid-2000s). Data not available for CH, KO, NZ and MX. The straight line shows the 45°-line. Source: OECD (STAN database).

In this paper, we propose a novel mechanism linking the rise of offshoring and the intensification of world trade, based on a general equilibrium model with heterogeneous firms. We show analytically that a fall in offshoring costs boosts trade in differentiated final goods through an intra-industry reallocation of resources towards the more productive firms: That is what we call the *export-magnification effect of offshoring*. In a nutshell, lower barriers to offshoring allow more domestic firms to source cheap foreign intermediates and reduce the input costs of offshoring firms, which improves firm-level competitiveness. This, in turn, translates into higher export quantities of exporters (intensive margin) and the entry of new exporters (extensive margin), thereby fostering trade in final goods.

Our analysis rests on a three-sector multi-country general equilibrium model with heterogeneous firms in the vein of Melitz (2003). There are many symmetric advanced economies and one "workbench country" (think of China or the Central and Eastern European Countries (CEECs)). Ricardian comparative advantages determine the equilibrium trade patterns: the advanced economies import cheap intermediates from the workbench country in return for a homogeneous consumption good. At the same time, they trade differentiated products among each other to satisfy consumers' love of variety. The export-magnification effect describes the increase in final goods trade *among the advanced economies* resulting from a drop in offshoring costs vis-à-vis the *workbench country*. Thus, neither income growth nor lower trade costs between any two advanced countries drive the rise in bilateral trade between these countries.

Crucially, each firm in the differentiated good sector is free to decide not only whether to export or not (export decision) but also whether to purchase intermediates at home or abroad (offshoring decision). Both exporting and offshoring is subject to variable and fixed costs. Therefore, only the larger, more productive firms engage in offshoring: the cost reductions generated by offshoring are proportional to the amount of intermediates used, whereas the fixed costs are identical for all firms. Likewise, only the most productive firms simultaneously engage in both offshoring and exporting. This self-selection of firms into exporting and sourcing modes is indeed broadly consistent with empirical evidence (Tomiura, 2007).

Having described the equilibrium with trade in final goods and offshoring, we study analytically the consequences of closer integration of the workbench country into the global economy - modeled as a fall in variable offshoring costs. Not surprisingly, inter-industry trade in homogeneous intermediate and final goods intensifies. More remarkably, given that trade costs in differentiated final goods between the advanced economies have remained unchanged, closer integration of intermediate goods markets also boosts exports of final goods at both the intensive and extensive margin. Access to cheaper intermediates from abroad allows highly productive firms to increase their export quantities and additional firms manage to become exporters. The ensuing reallocation of resources toward the more productive firms raises the average firm efficiency in the differentiated final good sector. This, in turn, lowers the consumption price level and raises real wages, thereby leading to a long-run welfare gain.

Of course, we claim no originality for the idea that offshoring (or the vertical fragmentation of production, for that matter) partly accounts for the surge in world trade. That said, the mechanism proposed in this paper differs considerably from those in the existing theoretical literature, which has largely relied on models with representative firms. Most prominently, Yi (2003) demonstrated in a homogeneous firms setup that multiple border crossings of intermediate goods render trade more responsive to changes in trade costs, which brings down the elasticity required to explain the actual increase in world trade. By their very nature, these representative firm models cannot capture the intra-industry reallocation of resources described in this paper, which generates an increase in final goods trade in response to lower offshoring costs, over and above the intensification in intermediates trade.

Our paper is related to an extensive offshoring literature. Our concept of offshoring is in the tradition of the theory of international fragmentation (Deardorff, 1998, 2001; Jones, 2000; Kohler, 2004). Hence, the profitability of offshoring solely depends on the interplay of comparative advantages and offshoring costs. We exclude all imperfections in contracting and matching that feature so prominently in other approaches to offshoring (Antràs, 2003; Feenstra and Hanson, 2005; Grossman and Helpman, 2005).

Our paper is also related to a few papers featuring heterogeneous firms models with trade in intermediates. Kasahara and Lapham (2008) study the decision to import and export in an extended Melitz framework. However, the paper does not analyze analytically the comparative static trade effects of a marginal drop in offshoring costs. Moreover, the model setup differs considerably from ours. Since there are $N+1$ identical countries, the model best describes trade among a group of fairly similar advanced or emerging economies respectively. Fixed import costs are firm-specific and subject to shocks. Moreover, importers use all available varieties of domestic and foreign intermediates, since there area increasing returns to variety in the production function.

Bas (2009) constructs a multi-sector model with heterogeneous firms and endogenous markups where the imported input intensity and import tariffs vary across industries. It is shown empirically that industries with lower import tariffs or higher import dependence generate more exporters and higher export sales than other industries. By contrast, the focus of our paper is on the within-industry trade effects of changes in offshoring costs over time. In a related paper, Kugler and Verhoogen (2008) use an extended Melitz model to study the hypothesis that input quality and plant productivity are complementary in generating output quality. In contrast to our theoretical framework, trade takes place between two symmetric countries and there can be quality differences in both intermediate and final goods.

The remainder of this paper is structured as follows. In Section 2, we present a short empirical motivation for our theoretical analysis. In Section 3, we introduce the theoretical framework. We focus on the main ideas and relegate much of the formal analysis to the appendix. In Section 4, we study the effects of lower offshoring costs on individual firms and the overall economy. This is complemented by other comparative statics, including the effects of lower export costs. Section 5 concludes.

2. The issue

International trade has increased tremendously over the last two decades. Neither income growth nor reductions in trade costs and tariffs can explain this phenomenon exhaustively. Time series regressions would usually apply a globalization time trend to account for this "unexplained" growth in trade (Murata et al., 2000; Ca'Zorzi and Schnatz, 2007). An impression of the increase in trade between 1988 and 2008 is given in Figure 2, where we present the export activities of the EU15 countries towards each other and towards non-EU15 countries in addition to EU15 imports from non EU15 countries. The cumulated increase was strongest for imports from non-EU15 countries. Trade with non-EU15 partners outperformed EU15 trade mainly because of the strong increase of imports from and exports to the new member states. The cumulated increase in trade over this period was much stronger than the increase in the GDP of the EU15, which implies an increase in the trade over GDP ratio. In standard trade models, these large increases of trade relative to GDP cannot be sufficiently explained by reductions in trade costs and tariffs alone. While trade costs and tariffs have fallen over the time period (see, for instance, Hummels (2007)), the implied elasticity of trade with respect to trade costs would be very large (Yi, 2003).

An obvious candidate to resolve this puzzle is the vertical fragmentation of production, which gained momentum in the mid-1980s, in parallel to the surge in world trade. Related explanations have so far been centered around the fact that intermediate goods often cross borders several times (with little value added

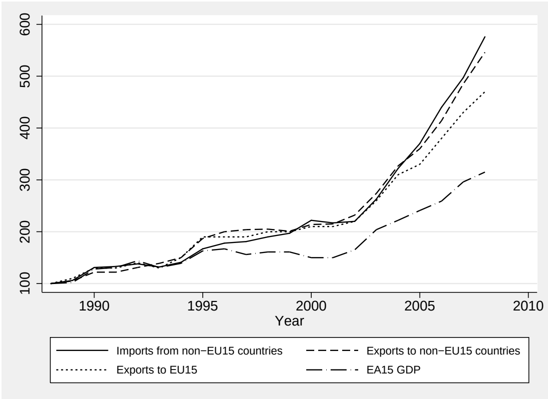

Figure 2: EU15 manufacturing export values by partner region, GDP 1988-2008 (indices, 1988=100). Source: OECD (STAN database), own composition.

at a particular production stage) before arriving at their final destination. The most basic argument highlights that, in practice, trade is measured in gross terms, whereas GDP is measured in terms of value added. This inflates the trade over GDP ratio, rendering the surge in world trade partially a statistical artifact.

However, if this were the whole story, one would expect intermediates trade to have increased significantly over time relative to trade in final goods. This is not borne out by the data: while trade in intermediates has increased at a rapid pace over the last two decades, trade in final goods has followed virtually in lockstep. As a result, the share of intermediate goods in total merchandize trade has not increased over this period (Hummels et al., 2001; Miroudot et al., 2009). This is consistent with evidence from extra-EU15 trade, where intermediate goods were less dynamic in volume terms than final goods on both the import and export side between 2000 and 2008 (using the Broad Economic Categories).

Against this backdrop, we develop a novel mechanism that (i) reserves an important role for the vertical fragmentation of production in explaining the surge in world trade and (ii) is consistent with a stable trade share of intermediates. In essence, we show analytically how intensified trade in intermediates (or offshoring, for that matter) boosts trade in final goods in a heterogeneous firms setup.

Consistent with our explanation, exports are higher in OECD countries where offshoring is more prevalent. This point is illustrated by Figure 3, which plots a country's exports (scaled by GDP) in relation to the ratio of intermediate goods in total intermediates used in the production of that particular country. The relationship is clearly positive. This positive relationship survives at the five percent level of significance if year and country fixed effects control for unobserved effects. (Country fixed effects also control for basic measures of country size.)

3. The model

In this section we develop the theoretical framework underlying our analysis. The world consists of $n + 1$ perfectly symmetric countries ("advanced

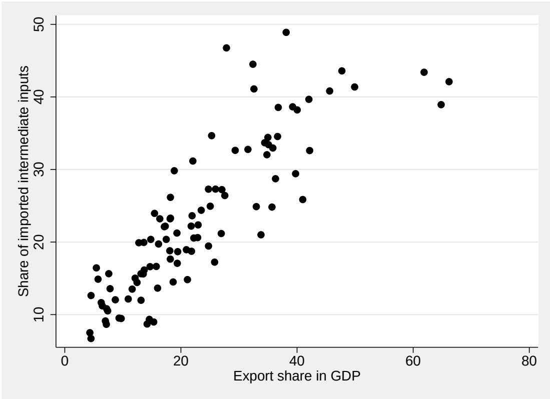

Figure 3: Manufacturing exports over GDP relative to imported intermediates share in total intermediate goods used in OECD countries (pooled data for mid-1990s, early 2000s, mid-2000s). Source: OECD (STAN database).

economies") and another country, called the "workbench country" (W). The advanced countries host three sectors. In the first sector (Y), a homogeneous final good is produced under perfect competition. This homogeneous good is consumed by households and traded without any costs between countries. Firms in the second sector (I) produce a homogeneous intermediate good under perfect competition. In the third sector (X), firms combine labor and the intermediate good to produce a differentiated consumption good. This good is traded only between advanced economies to satisfy consumers' love of variety. The sole factor of production, labor, is mobile between sectors but not between countries. Hence there is just one wage rate within each country. However, labor productivity may vary across sectors.

Country W is not directly involved in producing or trading the differentiated final good. Its main purpose is to serve as a supplier of intermediate goods to the other countries. In essence, this separation allows us to maintain the assumption that all countries trading the differentiated final good are symmetric.

Final good producers in the differentiated good sector differ in terms of productivity in the vein of Melitz (2003). Furthermore, they can purchase intermediates either from domestic or from foreign suppliers. In the latter case, we speak of *offshoring*. Crucially, the price of intermediates from country W is lower than the price requested by domestic suppliers. The lower price results from the Ricardian comparative advantage in the production of intermediates (relative to production of the homogeneous final good) that W enjoys by assumption. In addition, offshoring requires fixed costs. Think of the resources necessary to establish an office overseas for coordination purposes. The existence of fixed offshoring costs triggers self-selection of firms into the sourcing modes. Only firms with high productivity manage to take benefit of cheap foreign intermediates, because they can bear the burden of higher fixed costs.

While, in our model, trade in intermediates is at arm's length, it would be straightforward to write the model in terms of intra-firm trade (involving vertical FDI), without any change in the main findings. Regardless of the organization of the firms, the offshoring measure we look at in our static model, i.e. imported intermediate goods, fits the imported intermediate goods ratio from Figure 3.

3.1. Households

Households in all advanced economies have identical preferences. In the following, we only describe one of the $n+1$ symmetric countries, which we call the home country. If necessary, we distinguish it from the other advanced countries by the index H. Unless stated otherwise, the other countries go through analogously.

The representative household has Cobb-Douglas preferences over the homogeneous final good, Y, and the bundle of differentiated goods, X:

$$U = X^{\beta} Y^{1-\beta} \qquad (0 < \beta < 1). \tag{1}$$

The X-bundle, in turn, is a CES aggregator over the mass of available varieties, which is endogenous and denoted by Ω:

$$X = \left[\int_{\omega \in \Omega} x(\omega)^{\rho} \, \mathrm{d}\, \omega \right]^{\frac{1}{\rho}}. \tag{2}$$

Here, $x(\omega)$ is consumption of a single variety $\omega \in \Omega$. Varieties are substitutes with $\rho \equiv (\sigma - 1)/\sigma$ and σ denoting the elasticity of substitution. We assume $\sigma > 1$.

The price index of the differentiate good P_X is then given by

$$P_X = \left[\int_{\omega \in \Omega} p(\omega)^{1-\sigma} dk \right]^{1/(1-\sigma)}. \tag{3}$$

Here, $p(\omega)$ is the consumer price of variety ω.

Total expenditures, E, are made up of expenditures on good X and Y: $E = E_X + E_Y$. Cobb-Douglas preferences imply that consumers spend a constant expenditure share β on the differentiated good. Expenditure on a single variety ω is given by: $e(\omega) = (p(\omega)/P_X)^{1-\sigma} E_X$.

3.2. The homogeneous goods sectors

Each advanced economy hosts three sectors. Two of them are characterized by perfect competition between producers of homogeneous goods: the final good Y and the intermediate good I. Here, labor is the only input for production. Labor productivity, denoted by φ_Y and φ_I respectively, differs across industries, but is the same for all firms within each industry. Since labor is mobile between sectors, there is a unique wage rate w. The same is true for the other countries. Sector Y's *raison d'être* is to pin down these wage rates.

Both homogeneous goods sectors are characterized by a production technology that is linear in labor:

$$Y = \varphi_Y L_Y \tag{4}$$

$$I = \varphi_I L_I. \tag{5}$$

The workbench country also produces both types of homogeneous goods. Sector-specific labor productivity in the workbench country, denoted by φ_Y^w and φ_I^w, differs from that in the advanced economies. In the following, we assume that all countries (including the workbench country) have a positive output of both Y and I. Hence there is no complete specialization.

We choose good Y as the numeraire and set $p_Y = 1$. Perfect competition implies $p_Y = 1 = w/\varphi_Y$ and $p_Y^w = w^w/\varphi_Y^w$. Notice that superscript w stands for the workbench country W. Since good Y is traded without costs between countries, prices are equalized: $p_Y = p_Y^w = 1$. This pins down the wage rates: $w = \varphi_Y$ and $w^w = \varphi_Y^w$. As the intermediate good sector is also perfectly competitive, factory prices are determined as

$$p_I^d = \frac{w}{\varphi_I} = \frac{\varphi_Y}{\varphi_I}, \qquad p_I^w = \frac{w^w}{\varphi_I^w} = \frac{\varphi_Y^w}{\varphi_I^w}, \tag{6}$$

where the superscript d indicates the intermediate goods produced by *domestic* firms in the advanced countries. Trade in intermediates involves variable trade costs τ_I (with $\tau_I > 1$). Assuming iceberg costs, the c.i.f. price of the foreign intermediate good is $p_I^{off} = \tau_I p_I^w$. If the c.i.f. price of foreign intermediates were higher than the price of domestic intermediates, no domestic firm would find it profitable to source intermediates from abroad. Therefore, the following assumption is critical:

Assumption A.1. *Foreign's comparative advantage in the production of good I (relative to production of good Y) is large enough to make up for the trade costs τ_I. In other words, the c.i.f. price of foreign intermediates, p_I^{off}, is lower than the price of domestic intermediates, p_I^d:*

$$\frac{\varphi_Y/\varphi_Y^w}{\varphi_I/\varphi_I^w} > \tau_I > 1 \qquad \Leftrightarrow \qquad \frac{p_I^{off}}{p_I^d} < 1.$$

This assumption on comparative advantages determines the equilibrium pattern of trade between any advanced economy and the workbench country. It requires trade costs τ_I to be not too large. Under this assumption, the advanced economies import intermediate goods from the workbench country and export the homogeneous final good Y in exchange. Furthermore, the advanced economies trade the differentiated final goods with each other. Although they do not trade good Y among each other, they share the same price $p_Y = 1$ as they all trade Y freely with W.

3.3. Differentiated good producers

In the X sector heterogeneous firms produce a differentiated final good under Dixit-Stiglitz-type monopolistic competition. Production requires domestic labor and the intermediate good. The production technology is of Cobb-Douglas type, with α representing the importance of the intermediate input ($0 < \alpha < 1$).

Crucially, as in Melitz (2003) firms differ in their productivity φ which is drawn at entry from a common distribution $g(\varphi)$.[1] Furthermore, firms are free to source their intermediates either from domestic or foreign suppliers. Hence the second key element determining a firm's production costs (next to its productivity draw) is the price p_I^k that the firm pays for intermediate inputs (with $k = (d, off)$):

$$p_I^k = \begin{cases} p_I^d & \text{if the firm sources domestic intermediates} \\ p_I^{off} & \text{if the firm sources foreign intermediates.} \end{cases} \tag{7}$$

[1] We assume that the $(\sigma - 1)$th uncentered moment of $g(\varphi)$ is finite. This will ensure that the productivity of the average firm is finite.

For convenience, we define a summary measure - called *firm efficiency* - that combines a firm's productivity level φ and its unit cost of intermediate inputs: $\phi^k = \varphi/(p_I^k)^\alpha$. As will become obvious, the optimal sourcing decision and therefore the firm-specific sourcing cost of intermediates depend on firm productivity: $p_I^k = p_I^k(\varphi)$. More specifically, more productive firms will opt for foreign intermediates, whereas less productive firms will have to content themselves with domestic ones. (Below, we will describe the conditions under which this partitioning of firms holds.) This implies that firm efficiency is itself a function of the firm's productivity level. For the sake of simplicity, firms will be indexed by ϕ^k, bearing in mind that the firm efficiency is ultimately determined by firm-specific productivity. Note that offshoring reduces the marginal costs of a manufacturing firm similarly to an increase in productivity. Feenstra and Hanson (1999) argue that for that reason it is hard to distinguish between trade and productivity effects on wages or unemployment.

Since the production technology is of Cobb-Douglas type, variable costs are given by $c(\phi^k) = w^{1-\alpha}/\phi^k$. In this monopolistic competitive setting, every firm sets its price $p(\phi^k)$ optimally by multiplying its marginal costs with a fixed mark-up factor of $1/\rho$. Hence revenues from domestic sales are given by

$$r_H(\phi^k) = \left[\frac{w^{1-\alpha}}{\rho\phi^k}\right]^{1-\sigma} \frac{E_X}{P_X^{1-\sigma}}. \tag{8}$$

Production of the final good requires fixed overhead costs f_p in terms of labor. Hence, if a firm sources its intermediates domestically ($k = d$), its profits from sales at home are given by

$$\pi_H(\phi^d) = \frac{r_H(\phi^d)}{\sigma} - f_p w. \tag{9}$$

If a firm purchases foreign intermediates ($k = off$), it faces additional fixed costs of offshoring, f_I. Its profits can then be written as

$$\pi_H(\phi^{off}) = \frac{r_H(\phi^{off})}{\sigma} - (f_p + f_I)w. \tag{10}$$

In both cases, profits rise with firm efficiency ϕ^k and aggregate demand, whereas they depend negatively on the domestic wage rate and fixed costs.

Firms whose productivity is too low to recoup the fixed costs f_p have to leave the market immediately after drawing their productivity. Let the minimum productivity a firm must have drawn to survive be denoted by $\widehat{\varphi}_{min}$. Firms with productivity $\varphi = \widehat{\varphi}_{min}$ will make zero profits, which yields:

$$\widehat{\varphi}_{min} = \frac{w^{1-\alpha}\left(p_I^d\right)^\alpha}{\rho P_X}\left(\frac{\sigma f_p w}{E_X}\right)^{\frac{1}{\sigma-1}}. \tag{11}$$

Notice that $r_H(\phi^d(\widehat{\varphi}_{min})) = \sigma f_p w$. For the time being, we take as given that the marginal firm entering the market neither exports nor engages in offshoring. Hence it is possible to derive the minimum efficiency: $\widehat{\phi}_{min} = \widehat{\varphi}_{min}/(p_I^d)^\alpha$.

Every firm is free to source its intermediates from abroad. By assumption A.1, the price of foreign intermediates is lower than that of domestic ones. Nevertheless, the least productive firms cannot afford to engage in offshoring.

Since they sell less than their competitors, the lower variable cost associated with offshoring cannot make up for the fixed cost f_I. Therefore, offshoring is only profitable for firms passing a certain threshold productivity. Let this productivity level for which a firm is indifferent between domestic sourcing and offshoring be denoted by $\widehat{\varphi}_{off}$. Then:

$$\begin{aligned}\widehat{\varphi}_{off} &= \left[\left(\frac{p_I^{off}}{p_I^d}\right)^{\alpha(1-\sigma)} - 1\right]^{\frac{1}{1-\sigma}} \frac{w^{1-\alpha}(p_I^d)^{\alpha}}{\rho P_X}\left(\frac{\sigma f_I w}{E_X}\right)^{\frac{1}{\sigma-1}} \\ &= \widehat{\varphi}_{min}\left(\frac{f_I}{f_p}\right)^{\frac{1}{\sigma-1}}\left[\left(\frac{p_I^{off}}{p_I^d}\right)^{\alpha(1-\sigma)} - 1\right]^{\frac{1}{1-\sigma}}.\end{aligned} \tag{12}$$

Again, deriving the corresponding firm efficiency is straightforward: $\widehat{\phi}_{off} = \widehat{\varphi}_{off}/(p_I^{off})^{\alpha}$.

As already indicated, we assume that only the most productive firms find it profitable to export. In addition to f_p and f_I, they have to bear the fixed cost of exporting, f_{ex}. At the same time, however, these firms are able to lift their sales by serving foreign consumers. Recall that country H trades the differentiated good only with the n symmetric advanced economies. Owing to the symmetry assumption, a firm will either serve all n export markets or none at all. Total profits are therefore given by:

$$\begin{aligned}\pi(\phi^{off}) &= \pi_H(\phi^{off}) + n\pi_F(\phi^{off}) \\ &= \left(1 + n\tau^{1-\sigma}\right) r_H(\phi^{off})/\sigma - (f_p + f_I + nf_{ex})\, w.\end{aligned} \tag{13}$$

Here, τ denotes iceberg trade costs associated with the final good ($\tau > 1$).

The cutoff productivity level $\widehat{\varphi}_{ex,off}$ for which an offshoring firm is indifferent between exporting and non-exporting is defined by:

$$\begin{aligned}\widehat{\varphi}_{ex,off} &= \tau\frac{w^{1-\alpha}(p_I^{off})^{\alpha}}{\rho P_X}\left(\frac{\sigma f_{ex} w}{E_X}\right)^{\frac{1}{\sigma-1}} \\ &= \widehat{\varphi}_{min}\,\tau\left(\frac{f_{ex}}{f_p}\right)^{\frac{1}{\sigma-1}}\left(\frac{p_I^{off}}{p_I^d}\right)^{\alpha}.\end{aligned} \tag{14}$$

Notice that $\widehat{\phi}_{ex,off} = \widehat{\varphi}_{ex,off}/(p_I^{off})^{\alpha}$.

As indicated above, we have taken as given that $\widehat{\varphi}_{min} < \widehat{\varphi}_{off} < \widehat{\varphi}_{ex,off}$. The following assumptions, together with assumption A.1, ensure that this partitioning of firms indeed holds true (see also Appendix A).

Assumption A.2. *The comparative advantage of the workbench country in producing the intermediate good, adjusted for distance costs, i.e.* $\tau_I\varphi_Y^w\varphi_I/\varphi_I^w\varphi_Y = p_I^{off}/p_I^d$, *is in the interval* $(\min\{\tilde{p}_1, \tilde{p}_2\}, \max\{\tilde{p}_1, \tilde{p}_2\})$, *where*

$$\tilde{p}_1 \equiv \left(\frac{f_p}{f_p + f_I}\right)^{\frac{1}{\alpha(\sigma-1)}}, \qquad \tilde{p}_2 \equiv \left(1 - \frac{f_I}{f_{ex}\tau^{\sigma-1}}\right)^{\frac{1}{\alpha(\sigma-1)}}.$$

To ensure that the minimum productivity $\widehat{\varphi}_{ex,off}$ is larger than the minimum productivity $\widehat{\varphi}_{off}$, as assumed above, we further need the following assumption, which has a similar counterpart in Melitz (2003):

Assumption A.3. *The threshold levels are ordered such that:* $\tilde{p}_2 > \tilde{p}_1$. *That requires* $f_p + f_I < f_{ex}\tau^{\sigma-1}$.

In essence, the competitive edge of foreign suppliers of intermediates must be large enough to make offshoring profitable for some domestic firms. At the same time, it cannot be too large, because otherwise all firms would engage in offshoring. Higher variable trade costs τ enlarge the interval of admissible relative prices p_I^{off}/p_I^d. The same is true for higher fixed costs f_p and higher fixed export costs f_{ex}, whereas the interval shrinks with higher fixed offshoring costs f_I. If f_I were zero, no level of variable offshoring costs τ_I would be large enough to restore the assumed ordering of firms, since all firms would self-select into the same sourcing mode.

Violation of assumptions A.1 through A.3 would give rise to a different partitioning of firms in equilibrium. We would see either no offshoring (violation of A.1) or all firms offshoring (violation of A.2). We might also see only exporting firms offshoring (violation of A.3).

The partitioning of firms assumed above ($\widehat{\varphi}_{min} < \widehat{\varphi}_{off} < \widehat{\varphi}_{ex,off}$) is entirely motivated by empirical evidence. The first inequality should be uncontroversial in the light of overwhelming evidence that firms involved in international trade tend to be more productive than "non-traders". It is also a well-established fact that firms involved in both importing and exporting are generally more productive than firms that only import or only export.[2] This justifies our assumption that the most productive firms choose to import and export.

It is less obvious which of the two "incomplete" internationalization strategies - i.e. only exporting or only offshoring - requires higher productivity. (In the model, the two strategies cannot occur simultaneously in equilibrium. If offshoring is less demanding in terms of firm productivity, for instance, the export-only strategy will always be dominated.) Looking at data on Japanese manufacturing firms, Tomiura (2007) finds that firms engaged in international outsourcing are less productive than firms that only export (and both have higher productivity than non-traders), although the productivity differential between outsourcers and exporters is relatively small. This is consistent with our assumptions on the ordering of cut-off productivities.

While there is also a growing literature comparing the characteristics of importing and exporting firms, it is of limited use for our purpose. The main reason is that most of the studies do not differentiate between imports of intermediates and final goods (including capital and consumption goods). For instance, Castellani et al. (2010) find that Italian firms engaged only in importing generally have higher productivity than firms involved in exporting only. This is consistent with evidence for Belgium (Muuls and Pisu, 2009) and Hungary (Altomonte and Békés, 2010). Castellani et al. (2010) caution, however, that their findings may partly reflect imports of capital goods and sectoral composition effects, since the incidence of firms only involved in importing is higher for capital intensive industries. Moreover, the evidence from this literature on the pecking order of importing and exporting firms is far from clear-cut. In contrast to the studies previously mentioned, McCann (2009) finds that in Ireland exporters-

[2] For a survey of the related empirical literature, see Wagner (2007, 2011); Bernard et al. (2011). See also Bernard et al. (2009).

only are significantly more productive than importers-only. For China, Manova and Zhang (2009) show that there are more small firms (which tend to be less productive) among importers than among exporters. Andersson et al. (2008) show for Sweden that the "productivity premium" is of similar magnitude for exports and imports. Due to data constraints, all these studies cannot capture the import content of domestic intermediates used by domestic firms.

Against this backdrop, we stick to the assumption that offshoring is less demanding in terms of productivity ($\widehat{\varphi}_{off} < \widehat{\varphi}_{ex,off}$). However, we will discuss below how a different ordering of cut-off productivities would affect the main results.

3.4. Aggregation

In this model, all aggregate variables can be expressed in terms of appropriate industry-level averages. It is convenient to use weights reflecting the relative output shares of individual firms. Recall that differences in the relative output shares of two individual firms will be driven by differences in firm efficiency: $x(\phi')/x(\phi'') = (\phi''/\phi')^{\sigma}$. Therefore, cross-firm averages based on output shares must take into account different input costs (as long as the firms do not share the same sourcing mode). Against this backdrop, let $\widetilde{\phi}$ denote the average efficiency of all domestic firms and $\widetilde{\phi}_t$ the average efficiency of all firms active in country H (including foreign exporters):

$$\begin{aligned}\widetilde{\phi} &= \left[\int_0^{\infty} \left(\phi^k(\varphi)\right)^{\sigma-1} \mu(\varphi)\,\mathrm{d}\,\varphi\right]^{\frac{1}{\sigma-1}} \\ &= \left\{\frac{1}{M}\left[M_d\widetilde{\phi}_d^{\sigma-1} + M_{off}\widetilde{\phi}_{off}^{\sigma-1} + M_{ex,off}\widetilde{\phi}_{ex,off}^{\sigma-1}\right]\right\}^{\frac{1}{\sigma-1}} \qquad (15)\\ \widetilde{\phi}_t &= \left\{\frac{1}{M_t}\left[M\widetilde{\phi}^{\sigma-1} + nM_{ex,off}\left(\tau^{-1}\widetilde{\phi}_{ex,off}\right)^{\sigma-1}\right]\right\}^{\frac{1}{\sigma-1}}. \qquad (16)\end{aligned}$$

Here, $\mu(\varphi) = g(\varphi)/[1 - G(\widehat{\varphi}_{min})]$ is the equilibrium productivity distribution. Furthermore, $\widetilde{\phi}_d$, $\widetilde{\phi}_{off}$ and $\widetilde{\phi}_{ex,off}$ represent the average efficiency of the three groups of domestic firms in equilibrium (see Appendix B). The mass of firms in each group is M_d, M_{off} and $M_{ex,off}$. Similarly, M denotes the total mass of domestic firms and M_t the mass of all firms active in country H. By symmetry, $\widetilde{\phi}_t$ is also the average efficiency of all domestic firms, taking into account the foreign sales of domestic exporters and controlling for transport costs τ.

It is now straightforward to express all aggregate variables as functions of the average efficiency $\widetilde{\phi}_t$:

$$\begin{aligned}P_X &= M_t^{\frac{1}{1-\sigma}} p(\widetilde{\phi}_t) \\ R_X &= M_t r_H(\widetilde{\phi}_t) = Mr(\widetilde{\phi}),\end{aligned}$$

Furthermore, welfare per worker, W, is captured by the real wage rate:

$$W = \frac{w}{P} = w\hat{\beta}\left[M_t^{\frac{1}{1-\sigma}} p(\widetilde{\phi}_t)\right]^{-\beta} = \widehat{\varphi}_{min}^{\beta} w\hat{\beta}\left[\frac{\rho}{w^{1-\alpha}(p_I^d)^{\alpha}}\right]^{\beta}\left(\frac{\beta L}{\sigma f_p}\right)^{\frac{\beta}{\sigma-1}}. \qquad (17)$$

Notice that $P = P_X^{\beta} p_Y^{1-\beta}/\hat{\beta} = P_X^{\beta}/\hat{\beta}$, where $\hat{\beta} = [\beta^{\beta}(1-\beta)^{1-\beta}]$.

It is important to realize that domestic welfare rises with the minimum productivity $\widehat{\varphi}_{min}$. Analogous reasoning applies to the other advanced economies. However, welfare in country W is fixed at φ_Y^w, as households in W consume only the numeraire good Y. Since the nominal wage rate in terms of the numeraire is fixed, so is welfare in country W.

3.5. Open Economy Equilibrium

3.5.1. Differentiated good sector

There is market entry in off-equilibrium situations with new firms competing profits away. Market entry in the differentiated good sector is subject to fixed costs f_e in terms of labor. Failure must be taken into account, as paying the fixed costs of entry does not guarantee that the entrant's productivity draw exceeds $\widehat{\varphi}_{min}$. Therefore, expected profits are given by $\nu_{in}\bar{\pi}$, where $\nu_{in} = 1 - G(\widehat{\varphi}_{min})$ is the ex-ante probability of successful entry and $\bar{\pi} = \pi(\tilde{\phi})$ is the average profit of all surviving domestic firms in the X sector. Firms enter as long as expected profits exceed fixed market entry costs $f_e w$. This yields the free entry (FE) condition:

$$\bar{\pi} = \frac{f_e w}{\nu_{in}}. \tag{18}$$

Furthermore, average profits of domestic firms earned at home and abroad, $\bar{\pi}$, can be written as:

$$\bar{\pi} = \nu_d \pi(\widetilde{\phi}_d) + \nu_{off} \pi(\widetilde{\phi}_{off}) + \nu_{ex,off} \pi(\widetilde{\phi}_{ex,off}). \tag{19}$$

Notice that ν_d, ν_{off} and $\nu_{ex,off}$ stand for the probabilities of belonging to one of the three equilibrium groups of firms, conditional on successful entry: $\nu_d = [G(\widehat{\varphi}_{off}) - G(\widehat{\varphi}_{min})]/[1 - G(\widehat{\varphi}_{min})]$, $\nu_{off} = [G(\widehat{\varphi}_{ex,off}) - G(\widehat{\varphi}_{off})]/[1 - G(\widehat{\varphi}_{min})]$ and $\nu_{ex,off} = [1 - G(\widehat{\varphi}_{ex,off})]/[1 - G(\widehat{\varphi}_{min})]$. Also, recall that average profits are functions of the minimum productivity level $\widehat{\varphi}_{min}$. Following Melitz (2003), we call equation (19) the zero cutoff profit condition (ZCP). The ZCP and FE conditions together identify a unique equilibrium (see Appendix C).

3.5.2. Market clearing

The world market for good X clears if

$$(n+1)E_X = (n+1)\beta w L = (n+1)R_X. \tag{20}$$

Hence aggregate revenues in the X sector are exogenously fixed: $R_X = \beta w L$. This implies that, if P_X falls, aggregate output in the differentiated good sector will increase.

For the world Y market to clear, total demand must equal supply. Owing to Cobb-Douglas preferences, consumers will always spend a fraction $(1 - \beta)$ of their total expenditure on good Y. Also, consumers in country W spend their entire income on the homogeneous final good. Thus:

$$(n+1)E_Y + E_Y^w = (n+1)(1-\beta)wL + w^w L^w = (n+1)Y + Y^w. \tag{21}$$

Since world demand for good Y is fixed, changes in Y and Y^w need to cancel out. Hence an increase in the supply of good Y in the advanced economies, say, must be compensated by a decrease in the supply originating in country

W. Then labor market clearing in W requires that labor shifts to sector I: $L^w = L_Y^w + L_I^w$. Consequently, W's output of intermediates will increase.

The domestic labor market is in equilibrium if $L = L_Y + L_I + L_X + L_e$. Here, L_e denotes labor used for entry in the manufacturing sector: $L_e = M f_e$ where M is the mass of firms in equilibrium. This mass is determined by the free-entry condition $f_e = [1 - G(\widehat{\varphi}_{min})]\bar{\pi}/w$. Combining the preceding equations yields: $L_e = M\bar{\pi}/w$. Hence profits in the X sector are fully paid out to the investment workers facilitating entry, ensuring that total household income equals the wage bill.

The world market for intermediate goods is in equilibrium if the advanced economies' demand for intermediates equals the world supply of intermediates. Furthermore, trade between the advanced economies is always balanced, by the symmetry assumption. Finally, recall that country W imports good Y and exports its entire output of intermediates, $p_I^w I^w$. Hence W's trade with the group of advanced economies (expressed in terms of f.o.b. prices) is balanced if $p_I^w I^w = E_Y^w - Y^w$.

4. The impacts of economic integration

The model presented in the previous section allows us to study the impacts of economic integration on individual firms, international trade and aggregate welfare in a comparative static analysis. In a first step, we explore the consequences of lower variable offshoring costs, showing that a decline in these costs stimulates trade in differentiated final goods. In a second step, we briefly look at the impacts of changes in other model parameters. We relegate the formal analysis to Appendix D and focus on the main ideas.

4.1. Competition intensifies

Over the last two decades, the "glue" holding together individual production stages in close geographical proximity has gradually melted (Baldwin, 2006). For instance, new forms of telecommunication - such as the internet - have facilitated the monitoring and coordination of remote links of the supply chain. At the same time, political liberalization has reduced artificial barriers to trade in intermediates. In particular, a number of countries - including China and the CEECs - that lend themselves to produce intermediates for the advanced economies have been gradually integrated into the world economy. In the model, we capture these developments with a drop in variable offshoring costs τ_I. All other exogenous parameters, including the variable costs of exporting final goods, remain unchanged. Note that we think that τ_I and τ not only differ because they are related to different goods (intermediate versus final goods) but also because they apply to different country pairs. Trade costs of final goods τ concern trade among the advanced countries, while trade costs τ_I relate to trade between the workbench country and the advanced countries.

What are the impacts of a marginal drop in offshoring costs? The new equilibrium is determined by the zero-cutoff profit condition (ZCP) and the free entry condition (FE). While the FE condition in equation (18) remains unaffected by the change in τ_I, the ZCP condition in (19) shifts to the right. As a result, the cutoff productivity level in the new equilibrium, $\widehat{\varphi}'_{min}$, is higher than the one in the previous equilibrium. (Notice that variables with a prime correspond to the new equilibrium with lower offshoring costs.) With slight abuse of terminology, we summarize this finding as follows:[3]

Result R.1. ***Competition intensifies.*** *A marginal drop in variable offshoring costs (τ_I) forces the least productive firms to quit the domestic market.*

This may come as a surprise, because the least productive firms do not engage in offshoring (due to the fixed offshoring costs) and, therefore, are not directly affected by changes in τ_I. However, they are harmed by an indirect effect stemming from increased competition in the domestic market. Several mechanisms are at play. To start with, all firms that already sourced their intermediates from abroad before the drop in τ_I see their marginal cost fall, because the c.i.f. price of foreign intermediates decreases. Moreover, lower offshoring costs render foreign sourcing profitable for more domestic firms, i.e. the cutoff productivity $\widehat{\varphi}_{off}$ falls. (We call firms that are engaged in offshoring or exporting at the higher level of offshoring costs τ_I incumbent offshoring or exporting firms, respectively. Firms in the productivity range that allows for offshoring or exporting only for the new level of τ_I are called new offshoring firms or new exporters, respectively.) The decrease in input costs of incumbent and new offshoring firms translates into lower prices of their varieties. This downward pressure on the aggregate price level P_X stiffens competition in the domestic market. In addition, new foreign exporters enter the domestic market, intensifying competition further. All these mechanisms contribute to the extinction of the least productive firms.

4.2. Trade effects

We now move on to show that the drop in variable offshoring costs stimulates not only intermediates trade but also trade in differentiated final goods. More specifically, we will demonstrate that lower offshoring costs allow incumbent exporters to increase their export quantities (intensive margin) and enable new domestic firms to become exporters (extensive margin).

Turning to the extensive margin first, notice that, for a marginal fall in variable offshoring costs from τ_I to τ_I', we have:

$$\frac{\widehat{\varphi}'_{ex,off}}{\widehat{\varphi}_{ex,off}} = \left(\frac{\tau_I'}{\tau_I}\right)^{\alpha} \left(\frac{\widehat{\varphi}'_{min}}{\widehat{\varphi}_{min}}\right) < 1. \tag{22}$$

The first term on the right-hand side of the equality captures the direct effect of lower variable offshoring costs on incumbent offshoring firms. A drop in τ_I leads to lower marginal costs and, ceteris paribus, higher profits from foreign sales. This direct effect makes exporting profitable for some firms that were previously unable to sell to foreign markets. However, there is also an indirect effect - captured by the second term on the right-hand side - stemming from the increase in competition. This countervailing effect diminishes the profitability of exporting, because stiffened competition weighs on market shares. At first sight, it appears that the overall effect is ambiguous. Yet, one can show analytically that the direct effect will always outweigh the indirect effect so that the

[3]Of course, the overall degree of competition in the differentiated good sector is indexed by σ. When we speak of an intensification of competition, we refer to the deterioration in the relative prices of low-productivity firms.

overall effect is positive (see Appendix D, equation (D.1)). Thus, lower variable offshoring costs always lead to a decrease in the export cutoff productivity, allowing additional domestic firms to enter the export markets.[4]

A reduction in offshoring costs also boosts exports of differentiated final goods through the intensive margin, i.e. incumbent exporters increase their export quantities. This reflects a cross-country reallocation of market shares from low-productivity to high-productivity firms. More specifically, incumbent exporters from country H experience a drop in input costs, which allows them to sell their variety at a lower price. This, in turn, gives them a competitive edge in foreign markets over local competitors whose productivity is too low to render offshoring profitable. Notably, price competitiveness vis-à-vis competing exporters from third countries does *not* improve. Since the advanced economies are assumed to be perfectly symmetric, foreign exporters experience the same drop in input costs as the domestic exporters. Thus, the mirror image of higher domestic exports are diminishing sales of foreign low-productivity firms that neither export nor offshore.

To derive the effect on the intensive margin analytically, notice that, in nominal terms, the intensive margin of trade corresponds to the revenues from foreign sales. Export revenues must rise in response to lower offshoring costs, since

$$\frac{r'_F(\phi^{off})}{r_F(\phi^{off})} = \left[\left(\frac{\tau'_I}{\tau_I} \right)^{\alpha} \left(\frac{\widehat{\varphi}'_{min}}{\widehat{\varphi}_{min}} \right) \right]^{1-\sigma} > 1. \tag{23}$$

Here, we have made use of equation (22). A similar expression holds for real exports. We summarize our key finding as follows:

Result R.2. ***The export-magnification effect of offshoring.*** *A marginal drop in variable offshoring costs (τ_I) fosters intra-industry trade in differentiated final goods among the advanced economies through both the intensive and extensive margin of trade.*

Note that we cannot pinpoint the magnitude of the contributions of the intensive margin and the extensive margin to the overall change in exports without further assumptions on the productivity distribution $g(\varphi)$. The reason is that the mass of exporters entering the foreign market has to be set against the mass of incumbent exporters ramping up their foreign sales. That said, the importance of adjustments through the intensive margin will increase with the elasticity of substitution σ, which governs consumers' response to changes in relative goods prices.

The expansion of trade between the advanced economies is non-trivial. In the model, the advanced economies trade only differentiated final goods with each other and the distance costs τ associated with this type of international trade have remained unchanged. Thus, the intensification of trade in differentiated final goods stems entirely from the resource reallocation between heterogeneous firms.

[4] It should be noted that we cannot pin down the overall *mass* of new exporters without restrictions on the shape of the productivity distribution function. For the sake of simplicity, we refer to the change in the cutoff export productivity as the change in the extensive margin of exports.

At the same time, the drop in τ_I also boosts trade in intermediates between the advanced economies and the workbench country. For one thing, more domestic firms find it profitable to import foreign intermediates ($\widehat{\varphi}_{off}$ falls); for another thing, the more productive firms in the differentiated goods sector, which increase their foreign sales, demand additional imported intermediates. Both effects contribute to an increase in imports of intermediates by the advanced economies. Since trade must be balanced, higher imports of intermediates require an expansion of Home's output and exports in its comparative advantage sector Y. Labor is reallocated from the domestic intermediate good sector to the homogeneous final good sector Y. The additional output units of Y are traded for intermediates from country W. This effect comes on top of the export-magnification effect of offshoring. In other words:

Result R.3. ***Inter-industry trade intensifies.*** *A marginal drop in variable offshoring costs (τ_I) also intensifies inter-industry trade between the advanced economies and the workbench country. This implies that trade in intermediates increases in parallel to trade in final goods.*

The overall trade expansion matches the exports over GDP ratio we have used in Figure 2, since in our static model aggregate income is constant in nominal terms. Any increase in trade increases trade relative to income. This increase in trade is positively related to the share of intermediate inputs used in production, as shown in Figure 3. Hence, the export-magnification effect developed in this paper provides a novel explanation for the growth in world trade over the last two decades. The gradual decline in offshoring costs over this period triggered a "Darwinian evolution" that gave rise to a reallocation of market shares from low-productivity firms to high-productivity exporters. This process stimulated not only trade in intermediates but also trade in differentiated final goods among the advanced economies.

This basic mechanism remains intact if assumption A.3 is violated, i.e. when offshoring-only requires higher productivity than exporting-only. (We stress again that such a partitioning of firms would not be in line with empirical evidence, as presented by Tomiura (2007).) In this case, a drop in variable offshoring costs τ_I still triggers an intra-industry reallocation of resources towards the more productive firms, which increase their exports. Interestingly, though, a lower τ_I (and, similarly, a lower f_I) is now associated with an increase in the export cut-off. This is because the least productive exporters are not engaged in offshoring and therefore cannot benefit from lower input costs, while being hurt by the indirect effect of increased competition. However, this is counterbalanced by the increase in exports of the more productive exporters. In addition, inter-industry trade is boosted by increased demand for intermediates. In the following, we concentrate again on the case in which assumption A.3 holds.

4.3. Impacts on revenues, profits and aggregate welfare

Lower variable offshoring costs also have repercussions on the revenues and profits of individual firms and aggregate welfare. In brief, we find:

Result R.4. ***The intra-industry reallocation raises aggregate welfare.*** *A marginal drop in variable offshoring costs (τ_I) leads to an intra-industry reallocation of market share and resources towards the more productive firms. The* *associated increase in average firm efficiency raises real wages and, thereby, aggregate welfare.*

To see this, note that all incumbent offshoring firms - i.e. firms with relatively high productivity - see their domestic revenues rise:

$$\frac{r'_H(\phi^{off})}{r_H(\phi^{off})} = \frac{r'_F(\phi^{off})}{r_F(\phi^{off})} > 1. \tag{24}$$

At the same time, they benefit from higher export sales. For new exporters this is trivial, for seasoned exporters it follows from equation (23). Of course, variable profits increase in tandem, as they are proportional to revenues. Hence, all incumbent offshoring firms unequivocally benefit from lower offshoring costs.

By contrast, it is unclear whether the firms switching from domestic to foreign sourcing see their profits rise or fall. On the one hand, their domestic revenues rise. On the other hand, they now have to bear the fixed costs of offshoring. However, each of these new offshoring firms realizes higher profits compared to a hypothetical case in which they refrain from offshoring.

Low-productivity firms who continue to purchase domestic intermediates have to digest a fall in revenues and profits. Increased competition squeezes their market share, whereas their input costs remain unchanged. Therefore, the least productive of these firms have to leave the market.

Overall, the marginal fall in offshoring costs leads to an intra-industry reallocation of market share and resources towards the more productive firms. As a result, the average firm efficiency is higher in the new equilibrium. The consumer price index falls, resulting in higher real wages. Thus, welfare unequivocally rises in all advanced economies. While it is not clear whether the product variety available increases (because the number of additional foreign exporters could be smaller than the number of domestic firms leaving the market), this variety-effect is always dominated by the effect of lower average prices (see equation 17). However, the associated adjustments involve a significant reallocation of labor both between and within sectors. Such an adjustment process is likely to be painful in the presence of frictions in labor and goods markets which we have assumed away.

As already indicated, welfare in the workbench country W is tied to labor productivity in the Y sector and therefore not affected by the change in offshoring costs.

4.4. Other comparative statics

One might expect that the impacts of a change in *fixed* offshoring costs (f_I) are very similar to those for variable offshoring costs. However, a drop in fixed offshoring costs actually raises the minimum productivity cut-off level necessary to become a successful exporter ($\widehat{\varphi}_{ex,off}$) (see Appendix D). Hence, some incumbent exporters are forced to stop selling their goods abroad. The reason is that, on the one hand, competition abroad intensifies, as some foreign firms engage in offshoring for the first time and thereby improve their competitiveness. On the other hand, the marginal domestic firm that is indifferent between exporting and staying at home is assumed to be already engaged in offshoring. Hence, a decline in fixed offshoring costs has no impact on the marginal costs of this firm. As a result, exporting becomes unprofitable for the marginal exporter.

(By contrast, variable offshoring costs enter the marginal costs and therefore affect foreign sales prospects.) In addition, surviving exporters see their export revenues fall. Hence the drop in f_I also has a negative effect on trade in differentiated final goods at the intensive margin. At the same time, however, there is a positive effect on inter-industry trade. Lower fixed costs of offshoring f_I prompt more firms to import foreign intermediates from the workbench country (i.e. $\widehat{\varphi}_{off}$ falls). In return, exports of the homogeneous good Y also rise. Hence the effect of a drop in f_I on total trade is generally ambiguous. Nevertheless, welfare in the advanced economies unequivocally increases.

It is also tempting to ask for the overall trade effect in the case of a simultaneous drop in both f_I and τ_I. Over the last two decades, both variable and fixed offshoring costs have arguably fallen. Taken at face value, the model results would point towards an important role for reductions in τ_I, because they unequivocally stimulate trade in differentiated final goods between advanced economies and trade in intermediates with "workbench countries". Such an outcome would be consistent with the stylized facts outlined in Chapter 2. A more elaborate analysis (going beyond infinitesimally small changes in trade costs) would require a quantitative assessment of the relative importance of historical reductions in variable and fixed offshoring costs, respectively. Since this is clearly beyond the scope of this paper, we leave this interesting topic for future empirical research.

The results so far have shown that changes in variable offshoring costs have important consequences for the firms' export decision. However, the converse is also true, i.e. changes in parameters related to final goods' trade among the advanced economies also affect the firms' offshoring decision. In fact, both a decrease in the variable cost of trading final goods (τ) and a drop in the corresponding fixed costs (f_{ex}) raise the cutoff productivity for offshoring firms, $\widehat{\varphi}_{off}$ (see Appendix D). The weakest firms that previously engaged in offshoring are hurt by the deflection of demand toward foreign exporters and have to switch to domestic sourcing. Interestingly, the intensification of competition stems entirely from the entry of new foreign exporters. In contrast, changes in offshoring costs also stiffen competition through a second channel, namely the boost in competitiveness of all domestic firms who are able to offshore. This channel is absent in the case of a reduction in τ, since lower trade costs among the advanced countries do not affect the marginal cost of producing for the home market. It is also worth noting that our results are fully consistent with Melitz (2003). Hence, qualitatively, changes in the parameters related to trade in final goods (τ, f_{ex} and n) have the same consequences on the minimum cutoff productivity and the exporting threshold as in the Melitz model.

5. Conclusions

World trade drastically increased in the two decades preceding the global downturn of 2008-09. Based on a general equilibrium model with heterogeneous firms, we argue that the *export-magnification effect of offshoring* contributes to an explanation of the surge in world trade. Trade between two advanced countries increases because firms in the advanced countries offshore a part of their production to a workbench country and import some of their intermediate goods from there. As barriers to offshoring decreased over time, more and more firms were able to cut production costs by relocating some production stages to low-wage countries and the input costs of offshoring firms decreased. This improvement in price competitiveness allowed them to ramp up their exports (intensive margin) or to become exporters for the first time (extensive margin). As a result, international trade in differentiated final goods among the advanced economies intensified. Crucially, the export-magnification effect reflects a reallocation of market shares towards the high-productivity firms, since only these firms are able to bear the fixed costs associated with offshoring and exporting. Of course, this explanation of the expansion of world trade over the last two decades should be seen as complementary to other approaches, particularly the one by Yi (2003).

We see several promising avenues for future research in this field. First, it would be interesting to build a similar model featuring offshoring between advanced economies. Empirically, similar countries tend to trade intermediates heavily among each other (Grossman and Rossi-Hansberg, 2008a). Second, the model could be extended to allow for asymmetries across the advanced economies, particularly as regards the productivity distributions in the differentiated good sector. This would open up the possibility that domestic exporters improve their competitiveness vis-à-vis foreign exporters, too, rather than only vis-à-vis foreign non-offshoring, non-exporting firms.

Appendix A. Ranking of cutoff productivity levels

We have assumed the following ranking of productivity cutoff levels: $\widehat{\varphi}_{min} < \widehat{\varphi}_{off} < \widehat{\varphi}_{ex,off}$. This appendix demonstrates that assumptions A.1 - A.3 indeed ensure that this ranking holds.

To start with, notice that

$$\begin{aligned}
\widehat{\varphi}_{min} < \widehat{\varphi}_{off} \quad &\Leftrightarrow \quad \frac{p_I^{off}}{p_I^d} > \left(\frac{f_p}{f_I + f_p}\right)^{\frac{1}{\alpha(\sigma-1)}} \equiv \tilde{p}_1 \\
\widehat{\varphi}_{off} < \widehat{\varphi}_{ex,off} \quad &\Leftrightarrow \quad \frac{p_I^{off}}{p_I^d} < \left(1 - \frac{f_I}{f_{ex}\tau^{\sigma-1}}\right)^{\frac{1}{\alpha(\sigma-1)}} \equiv \tilde{p}_2.
\end{aligned}$$

Assumption A.3 ensures that $\tilde{p}_1 < \tilde{p}_2 < 1$. Thus, the ordering $\widehat{\varphi}_{min} < \widehat{\varphi}_{off} < \widehat{\varphi}_{ex,off}$ holds if

$$\tilde{p}_1 < \frac{p_I^{off}}{p_I^d} < \tilde{p}_2 < 1. \tag{A.1}$$

This ranking holds true under assumptions A.1 - A.3. In words, if the relative price of intermediates is neither too large nor too small, then the cutoff productivity levels will be ordered as described in the main text.

In principle, firms could also opt for a fourth strategy, i.e. exporting without offshoring. However, under assumptions A.1-A.3, this strategy is always dominated by another strategy. The derivation of this result is relatively straightforward and therefore omitted.

Appendix B. Aggregation

In equilibrium, the X sector hosts three kinds of firms. Let M denote the equilibrium mass of incumbent firms in this sector. Then the mass of all domestic firms that neither export nor offshore is given by $M_d = \nu_d M$. Furthermore, the mass of incumbent offshoring firms is $M_{off} = \nu_{off} M$ and the mass of domestic exporters $M_{ex,off} = \nu_{ex,off} M$. Finally, the mass of all firms serving the domestic market, including foreign exporters, is $M_t = M + nM_{ex,off}$.

Let $\widetilde{\phi}_d$ be the average efficiency of all domestic firms that neither export nor engage in offshoring. Analogously, $\widetilde{\phi}_{off}$ stands for the average efficiency of all domestic firms that purchase foreign intermediates without exporting and $\widetilde{\phi}_{ex,off}$ for the average efficiency of all domestic exporters who also engage in offshoring. More specifically:

$$\begin{aligned}
\widetilde{\phi}_d &= \left\{ \frac{1}{G(\widehat{\varphi}_{off}) - G(\widehat{\varphi}_{min})} \int_{\widehat{\varphi}_{min}}^{\widehat{\varphi}_{off}} \left[\frac{\varphi}{(p_I^d)^\alpha} \right]^{\sigma-1} g(\varphi)\, \mathrm{d}\,\varphi \right\}^{\frac{1}{\sigma-1}} \\
\widetilde{\phi}_{off} &= \left\{ \frac{1}{G(\widehat{\varphi}_{ex,off}) - G(\widehat{\varphi}_{off})} \int_{\widehat{\varphi}_{off}}^{\widehat{\varphi}_{ex,off}} \left[\frac{\varphi}{\left(p_I^{off}\right)^\alpha} \right]^{\sigma-1} g(\varphi)\, \mathrm{d}\,\varphi \right\}^{\frac{1}{\sigma-1}} \\
\widetilde{\phi}_{ex,off} &= \left\{ \frac{1}{1 - G(\widehat{\varphi}_{ex,off})} \int_{\widehat{\varphi}_{ex,off}}^{\infty} \left[\frac{\varphi}{\left(p_I^{off}\right)^\alpha} \right]^{\sigma-1} g(\varphi)\, \mathrm{d}\,\varphi \right\}^{\frac{1}{\sigma-1}} .
\end{aligned}$$

Notice that all averages of firm efficiency depend on the productivity cutoff levels. Since these cutoffs are functions of $\widehat{\varphi}_{min}$, the same is true for the averages. In particular:

$$\tilde{\phi}_t \;=\; \widehat{\phi}_{min}\left[\frac{r_H(\tilde{\phi}_t)}{r_H(\widehat{\phi}_{min})}\right]^{\frac{1}{\sigma-1}} = \frac{\widehat{\varphi}_{min}}{(p_I^d)^{\alpha}}\left(\frac{\beta L}{M_t\sigma f_p}\right)^{\frac{1}{\sigma-1}}.$$

Appendix C. Open economy equilibrium

This appendix proves that the zero cutoff profit (ZCP) condition and the free entry (FE) condition together identify a unique cutoff level $\widehat{\varphi}_{min}$, as in Melitz (2003).

To start with, recall that the ZCP and FE conditions together imply:

$$\begin{aligned} f_e w =&[G(\widehat{\varphi}_{off}) - G(\widehat{\varphi}_{min})]\pi(\widetilde{\phi}_d) + [G(\widehat{\varphi}_{ex,off}) - G(\widehat{\varphi}_{off})]\pi(\widetilde{\phi}_{off}) \\ &+ [1 - G(\widehat{\varphi}_{ex,off})]\pi(\widetilde{\phi}_{ex,off}). \end{aligned} \tag{C.1}$$

Average profits of the three groups of firms occurring in equilibrium are given by:

$$\begin{aligned} \pi(\widetilde{\phi}_d) &= \left[\left(\frac{\widetilde{\phi}_d}{\widehat{\phi}_{min}}\right)^{\sigma-1} - 1\right] f_p w \\ \pi(\widetilde{\phi}_{off}) &= \left[\left(\frac{\widetilde{\phi}_{off}}{\widehat{\phi}_{min}}\right)^{\sigma-1} - 1\right] f_p w + \left[\left(\frac{\widetilde{\phi}_{off}}{\widehat{\phi}_{off}}\right)^{\sigma-1} - 1\right] f_I w \\ \pi(\widetilde{\phi}_{ex,off}) &= \left[\left(\frac{\widetilde{\phi}_{ex,off}}{\widehat{\phi}_{min}}\right)^{\sigma-1} - 1\right] f_p w + \left[\left(\frac{\widetilde{\phi}_{ex,off}}{\widehat{\phi}_{off}}\right)^{\sigma-1} - 1\right] f_I w \\ &\quad + \left[\left(\frac{\widetilde{\phi}_{ex,off}}{\widehat{\phi}_{ex,off}}\right)^{\sigma-1} - 1\right] n f_{ex} w \end{aligned}$$

To condensate equation (C.1), we define two auxiliary functions:

$$U(\varphi',\varphi'') = \int_{\varphi'}^{\varphi''}\left(\frac{\zeta}{(p_I(\zeta)^{\alpha}}\right)^{\sigma-1} g(\zeta)\,\mathrm{d}\,\zeta$$
$$V(\varphi',\varphi'') = G(\varphi'') - G(\varphi').$$

Now, noting that $V(\varphi',\varphi'')+V(\varphi'',\varphi''') = V(\varphi',\varphi''')$ and $U(\varphi',\varphi'')+U(\varphi'',\varphi''') = U(\varphi',\varphi''')$, we recast equation (C.1):

$$\begin{aligned} f_e = &\left[(\widehat{\phi}_{min})^{\sigma-1}U(\widehat{\varphi}_{min},\infty) - V(\widehat{\varphi}_{min},\infty)\right] f_p + \left[(\widehat{\phi}_{off})^{1-\sigma}U(\widehat{\varphi}_{off},\infty) - V(\widehat{\varphi}_{off},\infty)\right] f_I \\ &+ \left[(\widehat{\phi}_{ex,off})^{1-\sigma}U(\widehat{\varphi}_{ex,off},\infty) - V(\widehat{\varphi}_{ex,off},\infty)\right] n f_{ex}. \end{aligned} \tag{C.2}$$

To boil down the preceding equation even further, we define:

$$\begin{aligned} j(\varphi) &= \phi(\varphi)^{1-\sigma}U(\varphi,\infty) - V(\varphi,\infty) \\ &= [1 - G(\varphi)]\left[\left(\frac{\widetilde{\phi}(\varphi)}{\phi(\varphi)}\right)^{\sigma-1} - 1\right] = [1 - G(\varphi)]k(\varphi). \end{aligned}$$

Here,

$$\widetilde{\phi}(\varphi)^{\sigma-1} = \frac{1}{1-G(\varphi)}\int_{\varphi}^{\infty}\left(\frac{\zeta}{(p_I(\zeta)^{\alpha}}\right)^{\sigma-1} g(\zeta)\,\mathrm{d}\,\zeta$$
$$k(\varphi) = \phi(\varphi)^{1-\sigma}\widetilde{\phi}(\varphi)^{\sigma-1} - 1.$$

Equation (C.2) can be rewritten as follows:

$$f_p j(\widehat{\varphi}_{min}) + f_I j(\widehat{\varphi}_{off}) + n f_{ex} j(\widehat{\varphi}_{ex,off}) = f_e. \tag{C.3}$$

Recall that $\widehat{\varphi}_{off}$ and $\widehat{\varphi}_{ex,off}$ are implicitly defined as functions of $\widehat{\varphi}_{min}$ by equations (12) and (14).

It is now straightforward to show that equation (C.3) identifies a unique cutoff level $\widehat{\varphi}_{min}$ and that the ZCP curve cuts the FE curve from above in (φ, π) space. In fact, the proof is analogous to Melitz (2003) and therefore omitted. One should keep in mind, however, that the ZCP curve has a discontinuity at $\varphi = \widehat{\varphi}_{off}$. At this point, $\phi(\varphi)$ switches from $\varphi/(p_I^d)^{\alpha}$ to $\varphi/(p_I^{off})^{\alpha}$. That said, our assumptions ensure that the equilibrium $\widehat{\varphi}_{min}$, i.e. the intersection of the ZCP and FE curves, is strictly to the left of this discontinuity, in the range $(0, \widehat{\varphi}_{off})$. In this subset, $j(\varphi)$ and therefore the ZCP curve are continuous.

Having identified $\widehat{\varphi}_{min}$, equations (12) and (14) determine the remaining cutoff levels $\widehat{\varphi}_{off}$ and $\widehat{\varphi}_{ex,off}$. All other endogenous variables can be expressed as functions of these three cutoff levels.

Appendix D. Comparative statics

In this appendix, we derive analytically the comparative statics described in Section 4.

Lower τ_I

Differentiating equation (C.3) with respect to τ_I yields:

$$\frac{\mathrm{d}\,\widehat{\varphi}_{min}}{\mathrm{d}\,\tau_I} = -\frac{\alpha\widehat{\varphi}_{min}}{\tau_I\hat{p}}\frac{f_I j'(\widehat{\varphi}_{off})\widehat{\varphi}_{off} + n f_{ex} j'(\widehat{\varphi}_{ex,off})\widehat{\varphi}_{ex,off}\hat{p}}{f_I j'(\widehat{\varphi}_{off})\widehat{\varphi}_{off} + f_p j'(\widehat{\varphi}_{min})\widehat{\varphi}_{min} + n f_{ex} j'(\widehat{\varphi}_{ex,off})\widehat{\varphi}_{ex,off}} < 0$$

Here, $\hat{p} \equiv 1 - (p_I^{off}/p_I^d)^{\alpha(\sigma-1)} < 1$.

Since $\mathrm{d}\,\widehat{\varphi}_{min}/\,\mathrm{d}\,\tau_I > -\alpha\widehat{\varphi}_{min}/(\tau_I\hat{p})$, we have:

$$\frac{\mathrm{d}\,\widehat{\varphi}_{off}}{\mathrm{d}\,\tau_I} = \frac{\alpha\widehat{\varphi}_{off}}{\tau_I\hat{p}} + \frac{\widehat{\varphi}_{off}}{\widehat{\varphi}_{min}}\frac{\partial\widehat{\varphi}_{min}}{\partial\tau_I} > 0.$$

Hence the direct effect of a decrease in τ_I on $\widehat{\varphi}_{off}$ dominates the indirect effect operating through $\widehat{\varphi}_{min}$. Similarly, since $\mathrm{d}\,\widehat{\varphi}_{min}/\,\mathrm{d}\,\tau_I > -\alpha\widehat{\varphi}_{min}/\tau_I$:

$$\frac{\partial\widehat{\varphi}_{ex,off}}{\partial\tau_I} = \frac{\alpha\widehat{\varphi}_{ex,off}}{\tau_I} + \frac{\widehat{\varphi}_{ex,off}}{\widehat{\varphi}_{min}}\frac{\partial\widehat{\varphi}_{min}}{\partial\tau_I} > 0. \tag{D.1}$$

To verify this, notice that $\mathrm{d}\,\widehat{\varphi}_{min}/\,\mathrm{d}\,\tau_I > -\alpha\widehat{\varphi}_{min}/\tau_I$ can be rewritten as follows:

$$\begin{aligned}\hat{p}^{-1} - 1 &< \frac{f_p j'(\widehat{\varphi}_{min})\widehat{\varphi}_{min}}{f_I j'(\widehat{\varphi}_{off})\widehat{\varphi}_{off}} \\ &< \frac{f_p}{f_I}\frac{\int_{\widehat{\varphi}_{min}}^{\infty}\left(\frac{\zeta}{p_I(\zeta)^{\alpha}}\right)^{\sigma-1} g(\zeta)\,\mathrm{d}\,\zeta}{\int_{\widehat{\varphi}_{off}}^{\infty}\left(\frac{\zeta}{p_I(\zeta)^{\alpha}}\right)^{\sigma-1} g(\zeta)\,\mathrm{d}\,\zeta}\left(\frac{\phi(\widehat{\varphi}_{off})}{\phi(\widehat{\varphi}_{min})}\right)^{\sigma-1}.\end{aligned}$$

Using equation (12) and the definition of $\hat{p}$ above, we arrive at:

$$\frac{p_I^{off}}{p_I^d} < \left[\frac{\int_{\widehat{\varphi}_{min}}^{\infty}\left(\frac{\zeta}{p_I(\zeta)^\alpha}\right)^{\sigma-1} g(\zeta)\,\mathrm{d}\,\zeta}{\int_{\widehat{\varphi}_{off}}^{\infty}\left(\frac{\zeta}{p_I(\zeta)^\alpha}\right)^{\sigma-1} g(\zeta)\,\mathrm{d}\,\zeta}\right]^{\frac{1}{\alpha(\sigma-1)}}.$$

Under assumption A.1, this condition always holds, since the right-hand side is greater than one.

Lower f_I

$$\frac{\mathrm{d}\,\widehat{\varphi}_{min}}{\mathrm{d}\,f_I} = \frac{\widehat{\varphi}_{min}\left[1 - G(\widehat{\varphi}_{off})\right]}{f_p j'(\widehat{\varphi}_{min})\widehat{\varphi}_{min} + f_I j'(\widehat{\varphi}_{off})\widehat{\varphi}_{off} + n f_{ex} j'(\widehat{\varphi}_{ex,off})\widehat{\varphi}_{ex,off}} < 0$$

Since $\mathrm{d}\,\widehat{\varphi}_{min}/\,\mathrm{d}\,f_I > -\widehat{\varphi}_{min}/[(\sigma-1)f_I]$:

$$\frac{\mathrm{d}\,\widehat{\varphi}_{off}}{\mathrm{d}\,f_I} = \frac{\widehat{\varphi}_{off}}{(\sigma-1)f_I} + \frac{\widehat{\varphi}_{off}}{\widehat{\varphi}_{min}}\frac{\mathrm{d}\,\widehat{\varphi}_{min}}{\mathrm{d}\,f_I} > 0$$

$$\frac{\mathrm{d}\,\widehat{\varphi}_{ex,off}}{\mathrm{d}\,f_I} = \frac{\widehat{\varphi}_{ex,off}}{\widehat{\varphi}_{min}}\frac{\mathrm{d}\,\widehat{\varphi}_{min}}{\mathrm{d}\,f_I} < 0$$

Lower τ

$$\frac{\mathrm{d}\,\widehat{\varphi}_{min}}{\mathrm{d}\,\tau} = -\frac{\widehat{\varphi}_{min}}{\tau}\frac{n f_{ex} j'(\widehat{\varphi}_{ex,off})\widehat{\varphi}_{ex,off}}{f_p j'(\widehat{\varphi}_{min})\widehat{\varphi}_{min} + f_I j'(\widehat{\varphi}_{off})\widehat{\varphi}_{off} + n f_{ex} j'(\widehat{\varphi}_{ex,off})\widehat{\varphi}_{ex,off}} < 0$$

$$\frac{\mathrm{d}\,\widehat{\varphi}_{off}}{\mathrm{d}\,\tau} = \frac{\widehat{\varphi}_{off}}{\widehat{\varphi}_{min}}\frac{\mathrm{d}\,\widehat{\varphi}_{min}}{\mathrm{d}\,\tau} < 0$$

Since $\mathrm{d}\,\widehat{\varphi}_{min}/\,\mathrm{d}\,\tau > -\widehat{\varphi}_{min}/\tau$:

$$\frac{\mathrm{d}\,\widehat{\varphi}_{ex,off}}{\mathrm{d}\,\tau} = \frac{\widehat{\varphi}_{ex,off}}{\tau} + \frac{\widehat{\varphi}_{ex,off}}{\widehat{\varphi}_{min}}\frac{\mathrm{d}\,\widehat{\varphi}_{min}}{\mathrm{d}\,\tau} > 0$$

Lower f_{ex}

$$\frac{\mathrm{d}\,\widehat{\varphi}_{min}}{\mathrm{d}\,f_{ex}} = \frac{\widehat{\varphi}_{min} n\left[1 - G(\widehat{\varphi}_{ex,off})\right]}{f_p j'(\widehat{\varphi}_{min})\widehat{\varphi}_{min} + f_I j'(\widehat{\varphi}_{off})\widehat{\varphi}_{off} + n f_{ex} j'(\widehat{\varphi}_{ex,off})\widehat{\varphi}_{ex,off}} < 0$$

$$\frac{\mathrm{d}\,\widehat{\varphi}_{off}}{\mathrm{d}\,f_{ex}} = \frac{\widehat{\varphi}_{off}}{\widehat{\varphi}_{min}}\frac{\mathrm{d}\,\widehat{\varphi}_{min}}{\mathrm{d}\,f_{ex}} < 0$$

Since $\mathrm{d}\,\widehat{\varphi}_{min}/\,\mathrm{d}\,f_{ex} > -\widehat{\varphi}_{min}/[(\sigma-1)f_{ex}]$:

$$\frac{\mathrm{d}\,\widehat{\varphi}_{ex,off}}{\mathrm{d}\,f_{ex}} = \frac{\widehat{\varphi}_{ex,off}}{(\sigma-1)f_{ex}} + \frac{\widehat{\varphi}_{ex,off}}{\widehat{\varphi}_{min}}\frac{\mathrm{d}\,\widehat{\varphi}_{min}}{\mathrm{d}\,f_{ex}} > 0$$

Higher n

$$\frac{\mathrm{d}\,\widehat{\varphi}_{min}}{\mathrm{d}\,n} = -\frac{f_{ex} j(\widehat{\varphi}_{ex,off})\widehat{\varphi}_{min}}{f_p j'(\widehat{\varphi}_{min})\widehat{\varphi}_{min} + f_I j'(\widehat{\varphi}_{off})\widehat{\varphi}_{off} + n f_{ex} j'(\widehat{\varphi}_{ex,off})\widehat{\varphi}_{ex,off}} > 0$$

$$\frac{\mathrm{d}\,\widehat{\varphi}_{off}}{\mathrm{d}\,n} = \frac{\widehat{\varphi}_{off}}{\widehat{\varphi}_{min}}\frac{\mathrm{d}\,\widehat{\varphi}_{min}}{\mathrm{d}\,n} > 0$$

$$\frac{\mathrm{d}\,\widehat{\varphi}_{ex,off}}{\mathrm{d}\,n} = \frac{\widehat{\varphi}_{ex,off}}{\widehat{\varphi}_{min}}\frac{\mathrm{d}\,\widehat{\varphi}_{min}}{\mathrm{d}\,n} > 0$$

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