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Trading Tasks: A Dynamic Theory of Offshoring

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Abstract

This paper is a dynamic extension of the well-known theory of trade in tasks by Grossman & Rossi-Hansberg (2008). In my model, a firm's offshoring decision is governed by production cost savings, but also considers potential imitation risk. I show that such a consideration reduces the level of offshoring compared to a static optimization and that adjustment of offshoring volume with respect to changes in offshoring costs or labor endowment is characterized by overshooting and subsequent movement toward a steady state. Moreover, I find that offshoring affects wages via more channels than are apparent in static models. More precisely, I identify a short-run intertemporal profit effect and a long-run composition effect, both of which depend on the endogenous rate of product imitation. These effects can reverse well-known static wage effects from offshoring, such as the labor supply effect and productivity effect. The dynamic adjustment predicted by this model has important implications on empirical strategies to identify a meaningful correlation of offshoring and relative wages.

JEL Code: F12, F16, F43, J31, O34.
Keywords: Offshoring, trade in tasks, skill premium, imitation.

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1 Introduction

Modern offshoring theory (e.g. Grossman & Rossi-Hansberg, 2008) assumes that international wage differences determine the volume of international production sharing, because profit-maximizing producers choose the location with lowest cost of production for each task under consideration of task-specific offshoring costs. However, recent empirical evidence by Branstetter *et al.* (2011) implies that such a one-dimensional focus on short-run production costs as the sole determinant of offshoring may fail to capture important implications of globalization. The authors show that the international activity of multinational companies intensifies significantly after a patent reform in developing countries. This finding is stated to be due to the fact that a firm's offshoring decision is not driven only by production costs but also by long-run components, such as the potential risk of product imitation.

In the theoretical literature, imitation risk means that there is an endogenous probability of losing all future profit when the production is taken over by a southern firm at a lower cost.[1] Taking this view, imitation has a potentially large impact on labor demand and wages since it implies that the entire production of one good is shifted to the South, whereas offshoring usually affects only a certain share of each good. This paper fills the gap in the literature concerning the interaction of offshoring and imitation and its joint effects on relative wages.

I extend the framework of bilateral trade in tasks by explicitly introducing imitation risk into firms' optimization problem when they make their offshoring decision. Intuitively, this reduces the share of tasks sourced from abroad compared to a myopic optimization that focuses only on short-run production costs. Subsequently I analyze the dynamic adjustment processes of offshoring with respect to exogenous shocks. Important is the difference between short-run adjustments which are characterized by a constant composition of varieties and long-run adjustments where the composition of varieties has moved to its steady-state level. I show that the reaction of offshoring with respect to exogenous changes in technological offshoring

[1] Vernon's (1966) idea of the product cycle was formalized later on by Grossman & Helpman (1991a) in a variety expansion model and by Segerstrom *et al.* (1990) in a quality ladder model. Other important contributions, subsequently introducing FDI and making the imitation decision endogenous are Helpman (1993), Lai (1998), Glass & Saggi (2002), and Branstetter & Saggi (2009). The literature mostly discusses the impact of FDI and intellectual property rights on the rate of innovation.

costs or labor endowment is characterized by overshooting, so that changes in the short run are more pronounced than those in the long run. This is an implication of a reduction of the wage gap between the two countries on the transition path towards the steady-state distribution of varieties.

In a last step I consider the impact of offshoring on relative wages. I find that in addition to the productivity effect and labor supply effect of offshoring, well-known from Grossman & Rossi-Hansberg (2008), there is a short-run intertemporal profit effect to the benefit of low-skilled workers and a long-run composition effect to the benefit of high-skilled workers, always dominating the intertemporal profit effect.[2] Both of these effects are induced by endogenous changes of the imitation rate. However, whereas the intertemporal profit effect depends immediately on the imitation rate, the composition effect is induced by the subsequent adjustment of the variety composition between North and South. This pattern implies that the endogenous adjustment of the imitation rate benefits low-skilled workers in the short run, whereas it benefits high-skilled workers in the long run.

This finding has important implications for empirical research on the relationship of offshoring and wage inequality.[3] On the one hand, in this model a repeated shock to offshoring technology implies a constantly rising offshoring volume and an ambiguous reaction of the skill premium. On the other hand, after a nonrecurring shock, the offshoring volume rises in the short-run with an ambiguous reaction of the skill premium, and then is followed by a reduction in offshoring compensated for by rising imports of final goods and a rising skill premium in the dynamic adjustment toward a new steady state. This means that it can be difficult to empirically find a meaningful unambiguous correlation between offshoring volume and skill premium, given that different industries in different periods of time are characterized by different patterns of technology shocks. It may, instead be more worthwhile to identify unique shocks to offshoring technology and capture both their immediate impact on wages and the impact in subsequent

[2]My model does not feature a relative price effect since I focus on a one-sector economy for the sake of simplicity.

[3]On the industry-level, Feenstra & Hanson (1999) estimate that offshoring explains about 15% of the increasing relative wage of nonproduction workers in the US. Geishecker (2006) finds that offshoring to Central and Eastern Europe is responsible for half of the wage increase of German high-skilled workers, while Hsieh & Woo (2005) find roughly the same importance of offshoring to China for high-skilled workers' wages in Hong Kong. Yan (2006) finds a positive impact of offshoring on wages of high-skilled workers in Canada. Studies on the plant level include Verhoogen (2008) on Mexico, Amiti & Davis (2011) on Indonesia, and Hummels *et al.* (2011) on Denmark.

periods.

This paper adds to the list of theoretical articles analyzing the implications of trade on wages of different types of workers. It is well-known that the crucial role played by a country's endowments for its factor prices is reduced when countries open up to trade. Indeed, the factor price equalization theorem states that under certain conditions all countries' factor prices are determined by the world endowment. Accordingly, trade does away with premia earned by the owners of a country's scarce resources, and the factor content of trade should tell us what openness does to a country's factor prices.[4]

This logic does not hold when accounting for other aspects of international integration. A recent trend is the international fragmentation of production chains, also called offshoring.[5] Models of offshoring usually require that production be sliced into tiny components or tasks that are heterogeneous with respect to their skill intensity or offshoring costs. Theoretical studies on the effects of offshoring on factor prices differ in their results. Perhaps the most prominent example is the paper by Feenstra & Hanson (1997), in which a one-sector model with a continuum of inputs is used to show that offshoring may increase skill premia in both countries that engage in bilateral offshoring. Arndt (1997) uses a two-sector framework to demonstrate that workers may gain, even if labor-intensive activities are offshored. Trefler & Zhu (2005) point to a systematic effect towards a rising skill premium when developing countries' raise their income.[6]

The paper is structured as follows. Section 2 presents the main relationships of the model. Section 3 derives the endogenous offshoring volume. Section 4 outlines the different effects on the skill premium. Section 5 concludes.

[4]See the discussion in Deardorff (2000), Krugman (2000), Leamer (2000), and Panagariya (2000).

[5]Empirical evidence on the magnitude and growth of offshoring can be found in Hummels *et al.* (2001), Yeats (2001), and Yi (2003).

[6]Other theoretical contributions include Venables (1999), Egger & Falkinger (2003), Kohler (2004), Egger & Kreickemeier (2005), Antràs *et al.* (2006), and Grossman & Rossi-Hansberg (2012).

2 Model Outline

The model comprises two countries, North and South. All variables referring to the South are indicated by an asterisk. In the following, I forgo displaying separate relationships for the two countries whenever doing so is unnecessary for differentiation.

2.1 Consumer Optimization

The representative consumer in each country has an intertemporal utility function of the form

$$W = \int_0^\infty U(t)e^{-\rho t}\mathsf{d}t, \tag{1}$$

where ρ is the discount factor. Utility in each period $U(t)$ is given by

$$U(t) = \left(\int_0^{N(t)} x_j(t)^{\frac{\sigma-1}{\sigma}}\mathsf{d}j\right)^{\frac{\sigma}{\sigma-1}}, \tag{2}$$

with σ being the constant elasticity of substitution between varieties, $x_j(t)$ being consumption of variety j at time t, and $N(t)$ being the total number of varieties at time t. Since trade in final products is costless it does not matter for consumers where these varieties are produced. The demand function implied by intratemporal utility maximization is given by

$$x_j(t) = \frac{E(t)p_j(t)^{-\sigma}}{\int_0^{N(t)} p_j(t)^{1-\sigma}\mathsf{d}j}, \tag{3}$$

where $p_j(t)$ is the price of variety j at time t, and the denominator is the well-known Dixit-Stiglitz price index. The intertemporal budget constraint is given by

$$\int_0^\infty e^{-rt}E(t)\mathsf{d}t \leq \int_0^\infty e^{-rt}w(t)\mathsf{d}t + A(t), \tag{4}$$

with $E(t)$ as consumer expenditure and $A(t)$ the value of assets in period t. Maximizing Equation (1) subject to Equation (4) yields the usual Euler equation for the growth rate of consumption expenditure

$$\frac{\dot{E}}{E} = r - \rho. \tag{5}$$

I assume that wages, prices, and thus expenditure are constant over time so that utility per period rises linearly with the number of varieties available.

2.2 Research Sector

In the following I drop time- and industry-indices whenever possible. Each country is home to a fixed number of consumers L and L^*, of which a fraction, h and h^*, are highly skilled and thus a fraction, $1-h$ and $1-h^*$, are of the low-skilled type. All consumers supply one unit of their respective type of labor inelastically. High-skilled workers are employed in the research sector, whereas low-skilled workers are not qualified to conduct research. Conducted research in the North during one time period yields an expected number of successful innovations of N/a, where a is the research labor input coefficient and N is, as above, the stock of all consumed varieties at a certain point in time. The appearance of N in this term is a spillover from present knowledge in line with Grossman & Helpman (1991b), Aghion & Howitt (1992), or Romer (1990). It has the convenient feature to yield a constant growth rate of varieties when the absolute number of researchers remains constant.[7]

With a sufficiently high number of high-skilled researchers, the aggregate uncertainty in the innovation process disappears, despite the presence of idiosyncratic uncertainty. This means that a new variety can be developed at a given cost $C = sa/N$, where s is the salary of the high-skilled researcher. High-skilled researchers in the South are not able to develop new varieties, but try to copy existing northern varieties. Imitation is profitable because wages of production workers in the South are lower than those of their northern counterparts, $w/w^* > 1$.[8] This means that southern firms can produce at lower cost and drive the northern incumbent firm out of the market. Consequently, profit-maximizing imitators only target northern varieties but not southern varieties. The expected number of successful copies during one time period is given

[7] Jones (1995) argues that spillovers have the form N^{ϕ} with $0 < \phi < 1$. This "semi-endogenous growth theory" makes the growth rate depending on the population growth rate.

[8] In the absence of differences in worker productivity this assumption requires that the South is abundantly endowed with production workers.

by nI/a^*, where n is the stock of northern varieties not already disclosed to southern firms and I indicates offshoring intensity. Imitation is more likely if the number of unrevealed northern varieties is high. Moreover, imitation is more likely if the share of offshore provided tasks is high. This specification is motivated by the fact that southern researchers learn more about existing varieties when a higher share of required tasks is performed in the South. Given the absence of aggregate uncertainty, this implies costs of $C^* = s^*a^*/nI$ for a successful copy. The growth rate of varieties is defined as $g := \dot{N}/N$, which equals the growth rate of unrevealed northern varieties $\dot{n}/n$ and of southern varieties $\dot{n}^*/n^*$ on a balanced growth path. The imitation rate is $m := \dot{n}^*/n$.

The research sector is characterized by a free entry condition in both countries. I refrain from analyzing the trivial case where research is not profitable and hence the growth rate of varieties is equal to zero. Instead, I assume that the no-arbitrage condition holds with equality. This implies that profits from successful innovation π and changes in the value of a northern firm exactly compensate for interest payments foregone and the risk of loosing the entire firm value due to imitation. Analogously, profits from successful imitation π^* and changes in the value of a southern firm exactly compensate only for interest payments foregone because the imitation risk is equal to zero. These relationships can be expressed as

$$\pi + \dot{v} = rv + mv \qquad \text{and} \qquad \pi^* + \dot{v}^* = rv^*, \tag{6}$$

where v is the value of a northern firm and v^* is the value of a southern firm.

The normalizing assumption on constant expenditure over time implies that firm values decrease with the rate of innovation $\dot{v} = -gv$. The reason is that consumers spend their constant budget on an ever growing number of varieties. Using the fact that the value of a firm must equal the cost of research in equilibrium I obtain

$$\frac{sa}{N} = \frac{\pi}{r+g+m} \qquad \text{and} \qquad \frac{s^*a^*}{nI} = \frac{\pi^*}{r+g}. \tag{7}$$

2.3 Manufacturing Sector

Production of each variety is divided into a continuum of tasks defined on the unit interval $[0;1]$. To produce one unit of the final consumption good, each task must be performed exactly once each. Production tasks are exclusively performed by low-skilled workers.[9] As mentioned above, I assume that wages for low-skilled workers in the South are lower than those for low-skilled workers in the North. This implies that Northern firms can have tasks performed offshore in the South, benefiting from lower production wages. However, offshore production implies additional offshoring costs, which are heterogeneous across the unit interval of tasks. These costs, for example, represent the "non-routineness" of tasks (Levy & Murnane, 2004), the content of tacit information (Leamer & Storper, 2001), or the need for physical contact (Blinder, 2006). In the following I will call $\tau(i)$ the coordination cost schedule. As is standard in the literature, tasks are ordered from 0 to 1 with an index i such that the coordination costs rise monotonically in i, so that $\tau(i) \geq 1$ and $\tau'(i) \geq 0$. Moreover there are technological offshoring costs represented by a common multiplier $\beta \geq 1$.

Because expensive northern workers are replaced by cheap southern workers, offshore production implies a productivity increase. I denominate the productivity factor which depends upon the volume of tasks performed offshore and wages in the two countries as $\Theta(I, w, w^*)$, where I is the marginal tasks so that all tasks $[0; I]$ are offshored. Since production costs without offshoring are simply given by w, while production costs with a share I of offshored tasks are given by $w^*\beta \int_0^I \tau(i)\mathsf{d}i + w(1-I)$, I define

$$\Theta(I, w, w^*) := \frac{w^*}{w}\beta \int_0^I \tau(i)\mathsf{d}i + 1 - I. \tag{8}$$

As mentioned above, demand for consumption goods is characterized by monopolistic competition with an elasticity of substitution σ between varieties. Hence, firms charge a constant markup over production costs. The price charged by northern firms is given by $p = w\Theta(I, w, w^*)\sigma/(\sigma-1)$ and their profits are

$$\pi = (p - w\Theta(I, w, w^*))x = \frac{w\Theta(I, w, w^*)x}{\sigma - 1} \tag{9}$$

[9] One might argue that high-skilled workers could always pretend to be low-skilled and also perform production tasks. However, there is no incentive to do so if the parameters of the model are plausibly chosen so that $s \geq w$.

where x is still endogenous, depending on w and Θ.

For southern firms it is not profitable to use offshore production. Hence, the production cost of one unit of the southern variety is w^*. I assume that the wage difference in the two countries is sufficiently high so that southern firms can set monopoly prices for their imitated varieties according to the elasticity of substitution, the so called "wide-gap case" from Grossman & Helpman (1991a). This case is formally characterized by the condition $w^*\sigma/(\sigma-1) \leq w\Theta(I, w, w^*)$.[10] Thus, the profits of southern firms are given by

$$\pi^* = (p^* - w^*)x^* = \frac{w^* x^*}{\sigma - 1} \tag{10}$$

and relative demand for varieties from the two countries only depends on relative prices which implies that relative profits can be written as

$$\frac{\pi}{\pi^*} = \left(\frac{p}{p^*}\right)^{1-\sigma} = \left(\frac{w\Theta(I, w, w^*)}{w^*}\right)^{1-\sigma}. \tag{11}$$

Using Equation (7) I can write for output of each variety in the two economies

$$x = a\frac{s}{w}\frac{r+g+m}{n+n^*}\frac{\sigma-1}{\Theta(I, w, w^*)} \qquad \text{and} \qquad x^* = a^*\frac{s^*}{w^*}\frac{g+r}{n}\frac{\sigma-1}{I}. \tag{12}$$

Moreover, I can solve for the relative profits of northern and southern firms

$$\frac{\pi}{\pi^*} = \frac{as}{a^* s^*}\frac{r+g+m}{r+g}\frac{n}{n+n^*} I\beta\tau(I). \tag{13}$$

2.4 Labor Markets

As outlined above, I assume that high-skilled workers are only active in the research sector. Their full employment conditions are given by

$$hL = ag \qquad \text{and} \qquad h^* L^* = \frac{a^* m}{I} \tag{14}$$

[10] In the "narrow-gap case" southern firms set prices slightly below northern firms' production costs to capture the entire demand for that variety. This limit price-setting can also be interpreted as Bertrand price competition. Importantly, my results on the dynamic adjustment of offshoring and on income inequality do not depend qualitatively on the choice of price-setting.

and serve to pin down the innovation rate in the steady state and the imitation rate, once the offshoring volume is determined.[11] Northern low-skilled workers only perform a fraction $1 - I$ of tasks domestically. Their full employment condition satisfies

$$(1-h)L = nx(1-I) \tag{15}$$

and inserting from Equation (12) I obtain

$$(1-h)L = a\frac{s}{w}\frac{n}{n+n^*}\frac{1-I}{\Theta(I)}(r+g+m)(\sigma-1) \tag{16}$$

Analogously, full employment in the South is given by

$$(1-h^*)L^* = nx\beta\int_0^I \tau(i)\mathsf{d}i + n^*x^* \tag{17}$$

which can be written as

$$(1-h^*)L^* = a\frac{s}{w}\frac{n}{n+n^*}\frac{\sigma-1}{\Theta(I)}(r+g+m)\beta\int_0^I \tau(i)\mathsf{d}i + a^*\frac{s^*}{w^*}\frac{n^*}{n}\frac{\sigma-1}{I}(r+g) \tag{18}$$

where the first term on the right-hand-side represents labor used for northern offshore production while the second term is labor in southern production.

3 Offshoring Decision

In the static offshoring theory firms choose the offshoring level which minimizes per-period production costs or, equivalently, maximizes per-period profits. However, in a dynamic setup, this is a myopic decision rule that does not account for potential imitation risk. Consequently, if firms care about the future they maximize the present value of their profit streams in each period $\pi/(r+g+m)$ which is affected negatively by a higher rate of product imitation. The

[11] It can easily be seen that the innovation rate g only depends on exogenous parameters. This simplification makes the model analytically tractable and highlights the importance of imitation for the dynamic offshoring adjustment. Further research might try to incorporate endogenous adjustments of the innovation rate into the model.

first-order condition is given by

$$\frac{d\pi}{\pi} = \frac{dm}{r+g+m} \tag{19}$$

or equivalently

$$w^*\beta \int_0^I \tau(i)\mathsf{d}i + w(1-I) = \frac{r+g+m}{m} I(\sigma-1)(w-\beta\tau(I)w^*) \tag{20}$$

where the left-hand side represents the cost to produce one unit of output with offshoring level I and the last term on the right-hand side correspond to $-\partial c/\partial I > 0$, meaning that a marginal increase of I could still reduce production cost and, hence, increase per-period profits, even though it has a negative effect on the present value of profits. Note that the marginal task I does not depend only on coordination costs for this tasks $\tau(I)$ but on the entire schedule of coordination costs $\tau(i)$.

Proposition 1. *Define a marginal task of offshoring $\tilde{I}$ by maximization of per-period profits as in Grossman & Rossi-Hansberg (2008). The marginal task I is always strictly smaller than the marginal task $\tilde{I}$ in the interval $[0;1]$, $I < \tilde{I}$, whenever at least one of them is different from 0 or 1.*

Proof. The proof is in the Appendix. □

The reason is that imitation risk imposes an additional cost on offshore production. In Equation (33), I define $\nu(i)$ as the long-run offshoring cost schedule. This new cost schedule includes the coordination costs $\tau(i)$ as well as the endogenous imitation risk. It is easy to see that $\nu(i)$ lies strictly above $\tau(i)$ for all $i \in [0;1]$ and the marginal task I is defined by equating relative wages with long-run offshoring costs $w/w^* = \beta\nu(I)$. The long-run offshoring cost schedule and the coordination cost schedule are shown in Figure 1 together with the technological offshoring cost factor β.

Lemma 1. *The marginal task I depends positively on the northern wage rate w, whereas it depends negatively on the southern wage rate w^* and the technological offshoring costs β, given that southern researchers are not overly productive. This implies that there exists a unique optimal offshoring volume in the range $[0;1]$.*

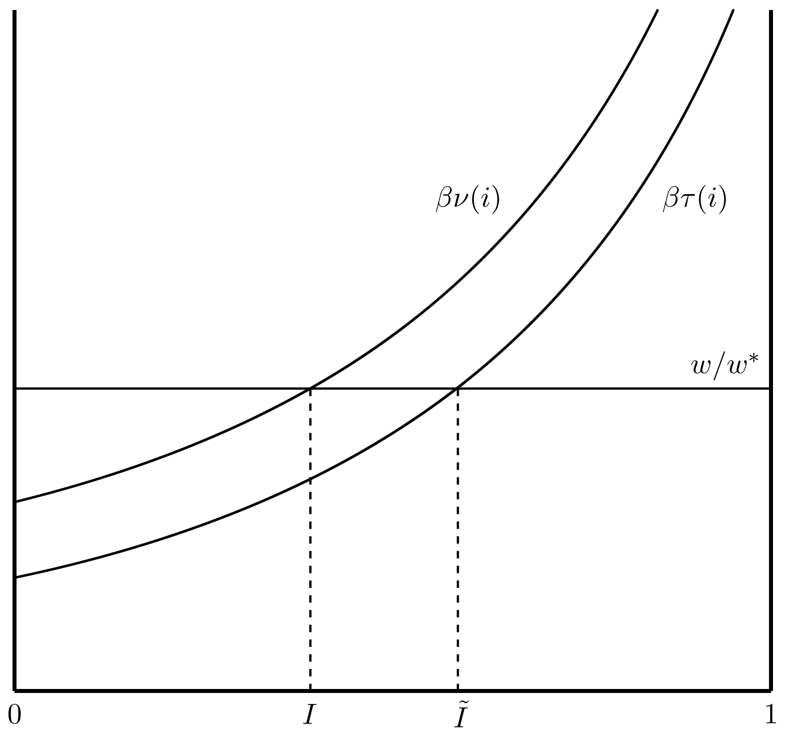

Figure 1. Long-run offshoring cost schedule

Proof. The proof is in the Appendix. □

It is now possible to eliminate relative wages from the offshoring savings factor and write

$$\Theta(I) = \frac{\left(\tau(I)(1-I) + \int_0^I \tau(i)\mathsf{d}i\right) \frac{r+g+m}{m} I(\sigma-1)}{\int_0^I \tau(i)\mathsf{d}i + \tau(I)\frac{r+g+m}{m} I(\sigma-1)}. \tag{21}$$

Lemma 2. *The offshoring savings factor $\Theta(I)$ is always smaller than 1 and falls with a rising offshoring volume $\frac{\partial\Theta(I)}{\partial I} < 0$, given that southern researchers are not overly productive.*

Proof. The proof is in the Appendix. □

All endogenous variables in the model react to changes in the endogenous offshoring volume. Hence, it is crucial to characterize the endogenous adjustment of the offshoring volume before analyzing the reaction of other endogenous variables. I denote with bold-face variables the ratio of a northern variable to the respective southern variable $\boldsymbol{z} := z/z^*$ and employ hat notation to refer to relative changes in variables so that $\hat{\boldsymbol{z}} := \hat{z} - \hat{z}^*$. Lemma 1 states that I increases in the relative wage $\boldsymbol{w} := w/w^*$ and falls in the technological offshoring costs β so that I can write

$$\hat{\boldsymbol{w}} - \hat{\beta} = \xi \hat{I}, \tag{22}$$

where $\xi := \frac{\hat{w} - \hat{w^*} - \hat{\beta}}{\hat{I}}$ is the elasticity of $\boldsymbol{w}$ with respect to I as determined in Equation (34).[12] Moreover, from Equations (9) and (10), I derive

$$\hat{\boldsymbol{\pi}} = \hat{\boldsymbol{w}} + \hat{\boldsymbol{x}} + \hat{\Theta}(I), \tag{23}$$

while Equation (11) yields

$$\hat{\boldsymbol{\pi}} = (1 - \sigma) \left(\hat{\boldsymbol{w}} + \hat{\Theta}(I) \right). \tag{24}$$

Finally, I use Equations (15) and (17) to obtain

$$\frac{\hat{\boldsymbol{n}} + \hat{\boldsymbol{x}}}{\boldsymbol{n}\boldsymbol{x}} = \beta \int_0^I \tau(i) \mathsf{d}i \hat{\beta} + I \beta \tau(I) \hat{I} + (1 - I) \frac{\widehat{(\boldsymbol{1} - \boldsymbol{h})} + \hat{\boldsymbol{L}}}{(\boldsymbol{1} - \boldsymbol{h})\boldsymbol{L}} + \frac{I \hat{I}}{(\boldsymbol{1} - \boldsymbol{h})\boldsymbol{L}}. \tag{25}$$

I define the short run as the time during which the relative distribution of varieties remains fixed, $\hat{\boldsymbol{n}} = 0$, after disproportional changes in the innovation rate g or the imitation rate m. This interval is infinitesimal small in my model with continuous time. However, the short run may be quite long in a world where imitation takes its time. In the long run, however, the number of varieties is governed by g and m. The steady-state is defined as the distribution of varieties which remains constant as long as g and m remain constant. It must satisfy $\boldsymbol{n} = g/m$ and I use Equation (14) to write[13]

$$\hat{\boldsymbol{n}} = \hat{\boldsymbol{h}} + \hat{\boldsymbol{L}} - \hat{I} \tag{26}$$

which indicates the relative change in the ratio of product varieties to reach the new steady-state equilibrium. Below, I follow Grossman & Rossi-Hansberg (2008) in considering only equilibria where the initial share of tasks performed in the South is not zero, $I > 0$.

Assumption 1. *The demand for northern labor relative to southern labor falls with rising offshoring volume. This means that the decrease of relative labor demand at the extensive margin*

[12]In the case of a myopic offshoring decision characterized by $w = \beta \tau(\tilde{I}) w^*$ holds $\xi = \frac{\tau'(\tilde{I})\tilde{I}}{\tau(\tilde{I})}$.

[13]By definition, in the steady state all variables grow at the same rate. Inserting the definitions of $g := \dot{n}/n$ and $m := \dot{n}^*/n$ into $\dot{n}/n = \dot{n}^*/n^*$ yields $g = mn/n^*$ or $g/m = n/n^*$.

of offshoring, that is, jobs that are incorporated in tasks that were previously performed in the North but are now performed offshore, is larger than the potential increase at the intensive margin of offshoring, that is, changes in labor demand due to changes in the relative output of firms $\boldsymbol{x}$ *that are induced by the endogenous reaction of* $\hat{\boldsymbol{w}}$ *and* $\Theta(I)$.

This assumption guarantees that the resulting equilibrium is unique and stable. If the assumption is violated, a small positive deviation from the equilibrium offshoring level drives up demand for northern labor, raising relative wages of northern production workers and magnifying the initial shock to offshoring volume according to firms' profit maximization. The opposite reasoning holds for a negative shock to the equilibrium offshoring level. Hence, the equilibrium is knife-edged in nature.

In Grossman & Rossi-Hansberg (2008) this problem does not arise. At the extensive margin, offshoring shifts tasks from the North to the South, decreasing relative demand for northern labor. At the intensive margin, wages of northern workers relative to those of southern workers increase more than the offshoring productivity factor $\Theta(I)$, so that output of northern firms falls relative to output of southern firms. Thus, higher levels of offshoring always drive up relative demand for southern labor. In my model, the offshoring productivity factor $\Theta(I)$ can decrease faster than relative wages increase. This drives up output of northern firms relative to southern firms and contributes to a rising demand for northern labor relative to southern labor.

Proposition 2. *Given an exogenous reduction of technological offshoring costs* β*, the increase in the offshoring level* I *is larger in the short run than in the long run.*

Proof. The proof is in the Appendix. □

This adjustment process is shown in Figure 2, where the initial exogenous shift is a improvement in the offshoring technology, reducing β to β'. In line with Assumption 1 this drives down the relative wage of northern production workers to $(w/w^*)^s$ and the new offshoring volume is $I^s > I$ because potential savings on production costs become larger so that producers are willing to accept a higher imitation risk. The adjustment of the wage rate occurs immediately to eliminate any excess supply or demand for labor in any of the two countries.

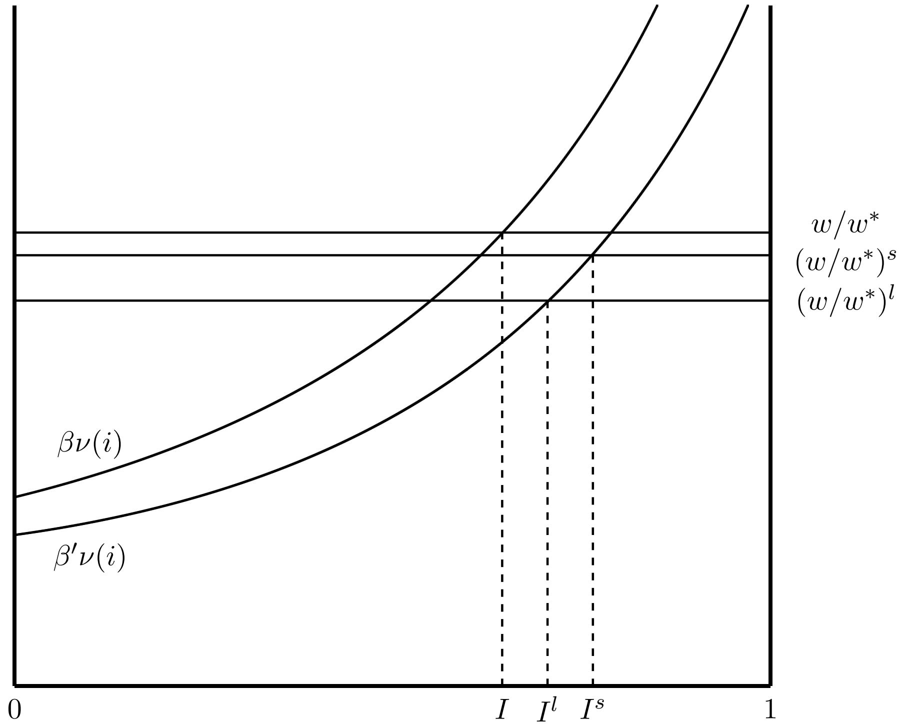

Figure 2. Offshoring adjustment

The rising offshoring level induces an increase of the imitation rate from m to m^s and as outlined above the composition of varieties in the steady state before the shock was characterized by $n/n^* = g/m$. This means that the equilibrium characterized by $(w/w^*)^s$, I^s, m^s, and n/n^* cannot be a steady state because the composition of varieties has not yet adjusted. With this distribution, the number of imitated varieties $\dot{n}^*$ is too high and the net growth of northern varieties $\dot{n}$ is too small to maintain the composition of varieties constant. Hence, the subsequent time periods are characterized by a convergence of the relative composition of varieties to the new steady state $(n/n^*)^l = g/m^l$ with $g/m^s < g/m^l < g/m$, which will only be reached asymptotically. The slowly growing share of southern varieties drives up demand for southern production workers and therefore drives up their wage, so that each period is characterized by a slight decrease of the offshoring volume, which compensates for a part of the initial increase. In the new steady state when relative wages have slowly moved to $(w/w^*)^l$ the offshoring volume will be I^l.[14] The imitation rate is then m^l.

[14] This overshooting and subsequent reduction in offshoring level may be related to the recent appearance of the terms "backshoring" or "reshoring" in the media and business literature, meaning that firms reduce their oversea capacities and increasingly turn to domestic production. See e.g. Maher & Tita (2010) and Simchi-Levi *et al.* (2011).

Proposition 3. *Given an exogenous increase in the relative proportion of high-skilled researchers* $\boldsymbol{h}$*, the offshoring level* I *increases in both the short run and in the long run.*

Proof. The proof is in the Appendix. □

In the short run, a higher share of high-skilled researchers in the North, but keeping the total size of the workforce constant, drives up offshoring volume. This occurs because reduction in the number of northern production workers drives up their wages and drives down output of each variety. This reduces demand for southern production workers when a share of tasks is already offshored. Since the number of southern production workers remains constant, the share of offshored tasks must rise. This effect is larger, the smaller the initial offshoring volume because the channel from endowment changes to output changes is de-leveraged by offshore production.

To determine the long-run effect on offshoring two additional effects have to be considered. First, the cost of imitation is reduced for southern researchers, leading to a higher rate of imitation. Second, the higher share of researchers in the North results in an increased rate of innovation. The relative strength of these two effects is ambiguous, implying that it is unclear whether the share of northern varieties increases or decreases. Hence, it is impossible to determine whether the long-run effect on offshoring volume is smaller or larger than the short-run effect, but both effects are strictly positive.

Proposition 4. *Given an exogenous increase in the relative size of the labor force* $\boldsymbol{L}$*, the reduction of offshoring volume in the short run is larger than in the long run.*

Proof. The proof is in the Appendix. □

A higher number of workers in the North drives down their wages and makes domestic production more attractive relative to offshoring for northern firms. In the long run, however, the higher number of researchers and the reduced imitation rate drive up the share of northern varieties. Demand for northern workers increases again and raises their wages. This means that the long-run reduction in offshoring volume is smaller than the short-run reduction.

4 Wage Inequality

Having analyzed how the offshoring level is affected by changes in exogenous variables, I now investigate how the skill premium reacts to changes in offshoring intensity. From Equation (16) I can solve for the northern skill premium, ω, defined as

$$\omega := \frac{s}{w} = \frac{1-h}{h} \frac{\Theta(I)}{1-I} \cdot \frac{n+n^*}{n} \cdot \frac{g}{r+g+m} \cdot \frac{1}{\sigma - 1} \tag{27}$$

which consists of four components: (1) efficiency units of low-skilled workers in domestic production relative to high-skilled workers; (2) the inverted share of northern varieties; (3) the growth rate of varieties relative to the discount rate of firm profits in the North; and (4) firm profits relative to production costs. The first three terms depend on various exogenous variables and the endogenous share of offshored tasks, while the fourth term depends only on the elasticity of substitution between varieties. Note that g depends on L and h, while m depends on L^*, h^*, and I. Moreover, the steady-state distribution of varieties is $(n + n^*)/n^* = (g + m)/m$.

To analyze changes in the skill premium with respect to changes in exogenous variables, I need to account for the relationships between offshoring volume and the respective exogenous variables derived above. However, how the skill premium changes with I is interesting in and off itself. The differentiated impact of offshoring on the skill premium via three effects is stressed in the seminal contribution by Grossman & Rossi-Hansberg (2008). This is a justifiable emphasis because it can be observed that the volume of offshoring rises much faster than gross output, which implies a rising share of offshore production, illustrated by a rising I. This rapid growth of offshoring is caused by improvements in the offshoring technology, such as information, communication, and transport, illustrated by a falling β. In my model, as in most other relevant literature, β has no direct effect on the skill premium in the North. Therefore, I can analyze exogenous changes in β simply by recognizing that a falling β implies a rising I, which in turn implies a rising productivity in northern production, characterized by a falling $\Theta(I)$.[15]

Differentiating Equation (27) with respect to I yields three components. The first and second

[15] Exogenous changes in endowments do not only affect the skill premium via I, but also via h or g.

correspond to the well-known productivity effect and labor supply effect, respectively.[16] Note that the productivity effect is negative since it works in favor of low-skilled workers, while the labor supply effect works in favor of high-skilled researchers and, hence, is positive. The analysis by Grossman & Rossi-Hansberg (2008) concerning the relative strength of the productivity effect and labor supply effect applies here as well. The first bit of offshoring does not increase productivity and, hence, works in favor of high-skilled researchers. However, the productivity effect may dominate the labor supply effect when the offshoring volume is large and the offshoring cost schedule $\tau(i)$ rises steeply.

Moreover, there are two other effects that are innate to dynamic analysis and both are induced by an increase in the imitation rate. First, the intertemporal profit effect implies a reduction of the skill premium, due to a higher discount rate of future profit streams, which harms high-skilled researchers. However, it is dominated by the composition effect. The declining share of northern varieties reduces demand for production labor and thus induces an increase of the skill premium. Again, I use a hat on a variable to refer to relative changes and thus write the above outlined relationship as

$$\hat{\omega} = \hat{\Theta}(I) + \frac{\mathrm{d}I}{1-I} + \mu \hat{m}(I), \tag{28}$$

where $\hat{\Theta}(I)$ and $\hat{m}(I)$ represent the elasticities of Θ and m with respect to I and

$$\mu := \frac{n^*}{n+n^*}\hat{n}^*(m) - \frac{m}{r+g+m} \tag{29}$$

where $\hat{n}^*(m)$ is the elasticity of n^* with respect to m.

Considering the timing of events more explicitly, it is important to remember that the short run is defined by a constant composition of varieties. This implies $\hat{n}^*(m) = 0$. Productivity effect, labor supply effect, and intertemporal profit effect do not rely on changes in the variety composition and set in instantaneously. The long-run, however, is defined by complete adjustment so that the variety composition has reached the new steady state. From Equation (26) it

[16] My analysis differs from Grossman & Rossi-Hansberg (2008) by having high-skilled researchers as fixed cost of production, a non-homothetic technology as coined by Horn (1983), whereas in Grossman & Rossi-Hansberg (2008) low-skilled and high-skilled labor are variable inputs into production of two types of goods. Hence, they do not focus on skill premia, but analyze changes in the wages of the high-skilled and low-skilled separately.

is known that this implies $\hat{n}^*(m) = 1$ and the composition of varieties in the new steady state implies that the first term in Equation (29) can be written as $m/(g+m)$. The composition effect kicks in after the first period of higher imitation and increases further until the economy has reached a new steady state. The implications for the pattern of wage changes are summarized in the following proposition.

Proposition 5. *Offshoring has a strictly positive short-run effect on the skill premium if and only if the labor supply effect dominates the productivity effect and the intertemporal profit effect. This condition is characterized by*

$$\frac{\mathrm{d}I}{1-I} > \frac{m}{r+g+m}\hat{m}(I) - \hat{\Theta}(I). \tag{30}$$

Moreover, offshoring has a strictly positive long-run effect on the skill premium if and only if the labor supply effect and the composition effect jointly dominate the productivity effect and the intertemporal profit effect. This condition is characterized by

$$\frac{\mathrm{d}I}{1-I} + \frac{m}{g+m}\hat{m}(I) > \frac{m}{r+g+m}\hat{m}(I) - \hat{\Theta}(I). \tag{31}$$

It is easy to see that equation (30) represents a stronger condition than equation (31). This implies that a positive short-run effect on the skill premium is a sufficient prerequisite for a positive long-run effect. Expressed differently, a positive long-run effect is a necessary implication of a positive short-run effect.

Proof. Proposition 5 results from Equations (28) and (29) and the fact that $\frac{\mathrm{d}I}{1-I}$, $\frac{m}{r+g+m}\hat{m}(I)$, and $\frac{m}{g+m}\hat{m}(I)$ are all positive for $\mathrm{d}I > 0$ while $\hat{\Theta}(I)$ is negative for $\mathrm{d}I > 0$ under consideration that $\hat{n}^*(m) = 0$ in the short run and $\hat{n}^*(m) = 1$ in the long run. □

When tracing these effects back to changes in technological offshoring costs it is important to remember that an exogenous reduction of β leads to a strong increase of I in the short run, whereas I falls again in subsequent periods, compensating for part of the initial increase. However, this reaction of I with respect to changes in β only affects the strength of the aggregate effect in the long run and in the short run. The sign of the long-run and short-run effect is entirely determined by the relative strength of the productivity effect, labor supply effect, intertemporal profit effect, and composition effect.

Nevertheless, it is crucial to note that different shocks of β yield a different correlation of offshoring and relative wage movements. For example, continued improvement of offshoring technology implies a constantly rising offshoring volume and an ambiguous reaction of the skill premium. The initial shock that drives up offshoring volume from zero to a positive value does not feature a productivity effect and is very likely to be to the favor of high-skilled researchers, giving a positively correlated movement of offshoring and the skill premium. Subsequent shocks to offshoring technology, however, may benefit low-skilled workers if the productivity effect becomes large.

On the other hand, after a nonrecurring shock to offshoring technology, offshoring volume rises in the short-run with an ambiguous reaction of the skill premium depending on the initial level of offshoring. If offshoring technology then remains constant in subsequent periods, the initial shock is followed by a reduction of the offshoring volume compensated for by rising imports of final goods and a rising skill premium in the dynamic adjustment toward a new steady state. This implies a negative correlation of offshoring and the skill premium.

5 Conclusion

In this paper I extend the seminal contribution on task trade by Grossman & Rossi-Hansberg (2008) with a dynamic dimension borrowed from classic product-cycle models. I show that when explicitly considering the risk of product imitation, firms generally choose a lower level of offshoring than when maximizing per-period profits. Considering the dynamic adjustment process explicitly, I find that the reaction of offshoring volume to exogenous changes in technological offshoring costs and aggregate labor endowment is characterized by overshooting as long as the composition of varieties remains constant and subsequent partial dissipation of the overreaction when the composition of varieties endogenously adjusts toward a new steady state.

Knowing the adjustment pattern of offshoring allows me to derive short-run and long-run comparative statics for the effects on wages of high-skilled researchers relative to those of low-skilled workers. In addition to the well-known productivity effect and labor supply effect, I identify a short-run intertemporal profit effect and a long-run composition effect. Given an increase in offshoring volume, the rising discount rate of future profit streams harms high-skilled researchers in the short run. In the long run, the endogenous adjustment of northern and southern varieties towards the new steady state more than compensates the high-skilled for the loss from a higher discount rate. However, these effects are not large enough to do away with the ambiguity of the aggregate wage effect derived by Grossman & Rossi-Hansberg (2008).

An important implication is that the correlation of offshoring and relative wages strongly depends on the underlying shocks to offshoring technology. This suggests that empirical studies trying to identify a stable relationship of changes in offshoring on relative wages might be misguided. It may be more promising and fruitful to instead focus on identifying the short-run and long-run impact on relative wages of a nonrecurring shock to offshoring technology.

Appendix

Proof of proposition 1. Firstly, the first order condition for the maximization of per-period profits is given by

$$\frac{\partial \pi}{\partial \tilde{I}} = (\sigma - 1)(w - \beta\tau(\tilde{I})w^*) = 0, \tag{32}$$

which implies that the cost-minimizing offshoring level is characterized by the fact that offshoring costs for the marginal tasks exactly make up for the wage differential between the two countries. Secondly, equation (20) can be reformulated to

$$w = w^*\beta \frac{\frac{r+g+m}{m} I(\sigma-1)\tau(I) + \int_0^I \tau(i)\mathrm{d}i}{\frac{r+g+m}{m} I(\sigma-1) - (1-I)} = w^*\beta\nu(I) > w^*\beta\tau(I), \tag{33}$$

which shows that the offshoring costs of the marginal task I do not compensate for the wage differential between the two countries. From $\tau(I) < \tau(\tilde{I})$ and the assumption of $\tau'(i) > 0$ follows directly $I < \tilde{I}$. □

Proof of lemma 1. Totally differentiating equation (33) and considering that $\frac{\partial m}{\partial I} = \frac{m}{I} = \frac{h^* L^*}{a^*}$ yields

$$\begin{aligned}\frac{\hat{w} - \hat{w^*} - \hat{\beta}}{\hat{I}} &= I \frac{\frac{r+g+m}{h^*L^*} a^*(\sigma-1)\left(\left(\frac{r+g+m}{h^*L^*} a^*(\sigma-1) - (1-I)\right)\tau'(I) + \sigma\tau(I)\right) - \sigma\tau(I)(1-I) - \sigma}{\left(\frac{r+g+m}{h^*L^*} a^*(\sigma-1)\tau(I) + \int_0^I \tau(i)\mathsf{d}i\right)\left(\frac{r+g+m}{h^*L^*} a^*(\sigma-1) - (1-I)\right)} \\ &> I \frac{\tau'(I)\left(\frac{r+g+m}{h^*L^*} a^*(\sigma-1)\right)^2 + \sigma\tau(I)\frac{r+g+m}{h^*L^*} a^*(\sigma-1) - \sigma(\tau(I)+1)}{\left(\frac{r+g+m}{h^*L^*} a^*(\sigma-1)\tau(I) + \int_0^I \tau(i)\mathsf{d}i\right)\left(\frac{r+g+m}{h^*L^*} a^*(\sigma-1) - (1-I)\right)},\end{aligned} \tag{34}$$

which is clearly positive if

$$\frac{a^*}{h^*L^*}(r+g+m)(\sigma-1) \geq 1 + \frac{1}{\tau(I)} \tag{35}$$

so that southern researchers have to be sufficiently but not infinitely unproductive. □

Proof of lemma 2. The first part follows directly from plugging $w > w^*\beta\tau(I)$ from equation (33) into equation (8) while the second part follows from differentiating equation (21) with respect to I and considering that $\frac{\partial m}{\partial I} = \frac{m}{I} = \frac{h^*L^*}{a^*}$ which yields

$$\begin{aligned}\frac{\partial\Theta(I)}{\partial I} &= \frac{\tau'(I)(1-I)\frac{r+g+m}{h^*L^*} a^*(\sigma-1) + \left(\tau(I)(1-I) + \int_0^I \tau(i)\mathsf{d}i\right)(\sigma-1)}{\int_0^I \tau(i)\mathsf{d}i + \tau(I)\frac{r+g+m}{h^*L^*} a^*(\sigma-1)} \\ &- \frac{\left(\sigma\tau(I) + \tau'(I)\frac{r+g+m}{h^*L^*} a^*(\sigma-1)\right)\left(\tau(I)(1-I) + \int_0^I \tau(i)\mathsf{d}i\right)\frac{r+g+m}{h^*L^*} a^*(\sigma-1)}{\left(\int_0^I \tau(i)\mathsf{d}i + \tau(I)\frac{r+g+m}{h^*L^*} a^*(\sigma-1)\right)^2}.\end{aligned} \tag{36}$$

The sign of $\frac{\partial\Theta(I)}{\partial I}$ is identical to the sign of

$$\begin{aligned}&\tau'(I)(1-I)\frac{r+g+m}{h^*L^*} a^*(\sigma-1)\int_0^I \tau(i)\mathsf{d}i + \tau(I)\tau'(I)(1-I)\left(\frac{r+g+m}{h^*L^*} a^*(\sigma-1)\right)^2 \\ &+ \left(\tau(I)(1-I) + \int_0^I \tau(i)\mathsf{d}i\right)(\sigma-1)\int_0^I \tau(i)\mathsf{d}i + \left(\tau(I)(1-I) + \int_0^I \tau(i)\mathsf{d}i\right)\frac{r+g+m}{h^*L^*} a^*\tau(I)(\sigma-1)^2 \\ &- \left(\tau(I)(1-I) + \int_0^I \tau(i)\mathsf{d}i\right)\frac{r+g+m}{h^*L^*} a^*\tau(I)\sigma(\sigma-1) \\ &- \tau(I)\tau'(I)(1-I)\left(\frac{r+g+m}{h^*L^*} a^*(\sigma-1)\right)^2 - \tau'(I)\left(\frac{r+g+m}{h^*L^*} a^*(\sigma-1)\right)^2\int_0^I \tau(i)\mathsf{d}i \\ &= \left(1 - I - \frac{r+g+m}{m} I(\sigma-1)\right)\tau'(I)\frac{r+g+m}{h^*L^*} a^*(\sigma-1)\int_0^I \tau(i)\mathsf{d}i \\ &+ \left(\int_0^I \tau(i)\mathsf{d}i - \frac{r+g+m}{h^*L^*} a^*\tau(I)\right)\left(\tau(I)(1-I) + \int_0^I \tau(i)\mathsf{d}i\right)(\sigma-1),\end{aligned} \tag{37}$$

which is negative whenever

$$\frac{a^*}{h^*L^*}(r+g+m)(\sigma-1) \geq 1 - I \tag{38}$$

so that southern researchers have to be sufficiently but not infinitely unproductive. Note that this condition is weaker than the condition required for lemma 1. □

Proof of proposition 2. Inserting equations (22), (23), and (24) into equation (25) and holding $\boldsymbol{L}$, $\boldsymbol{h}$ and $\boldsymbol{n}$ constant, I can write for the relative change in the short run

$$\frac{\hat{I}^s}{\hat{\beta}} = -\frac{\beta \int_0^I \tau(i)\mathrm{d}i + \frac{\sigma}{\boldsymbol{nx}}}{I\left(\beta\tau(I) + \frac{1}{(\boldsymbol{1}-\boldsymbol{h})\boldsymbol{L}}\right) + \frac{\sigma}{\boldsymbol{nx}}\frac{\hat{\Psi}}{\hat{I}}} < 0, \tag{39}$$

where $\hat{\Psi}/\hat{I} := \xi + \hat{\Theta}/\hat{I}$ is the effect on labor demand at the intensive margin of offshoring. It is positive if relative wages of northern workers rise faster than the offshoring productivity factor $\Theta(I)$ and negative else. However, the fact that the denominator is positive is guaranteed by assumption 1. The relative change in the long run can be identified by additionally considering that changes in $\boldsymbol{n}$ are governed by equation (26) as

$$\frac{\hat{I}^l}{\hat{\beta}} = -\frac{\beta \int_0^I \tau(i)\mathrm{d}i + \frac{\sigma}{\boldsymbol{nx}}}{I\left(\beta\tau(I) + \frac{1}{(\boldsymbol{1}-\boldsymbol{h})\boldsymbol{L}}\right) + \frac{\sigma}{\boldsymbol{nx}}\frac{\hat{\Psi}}{\hat{I}} + \frac{1}{\boldsymbol{nx}}} < 0, \tag{40}$$

which can be obtained simply by adding $1/\boldsymbol{nx}$ to the denominator of the short-run effect. It is easy to see that $\frac{\partial I^s}{\partial \beta} < \frac{\partial I^l}{\partial \beta} < 0$. □

Proof of proposition 3. Inserting Equations (22), (23), and (24) into Equation (25) and holding β, $\boldsymbol{L}$, and $\boldsymbol{n}$ constant yields for the short run

$$\frac{\hat{I}^s}{\hat{\boldsymbol{h}}} = -\frac{\frac{1-I}{(\boldsymbol{1}-\boldsymbol{h})\boldsymbol{L}}}{I\left(\beta\tau(I) + \frac{1}{(\boldsymbol{1}-\boldsymbol{h})\boldsymbol{L}}\right) + \frac{\sigma}{\boldsymbol{nx}}\frac{\hat{\Psi}}{\hat{I}}}\frac{\widehat{\boldsymbol{1}-\boldsymbol{h}}}{\hat{\boldsymbol{h}}} > 0, \tag{41}$$

while the long run effect is given under consideration of Equation (26) by

$$\frac{\hat{I}^l}{\hat{\boldsymbol{h}}} = \frac{\left(\frac{1}{\boldsymbol{nx}} - \frac{1-I}{(\boldsymbol{1}-\boldsymbol{h})\boldsymbol{L}}\frac{\widehat{\boldsymbol{1}-\boldsymbol{h}}}{\hat{\boldsymbol{h}}}\right)}{I\left(\beta\tau(I) + \frac{1}{(\boldsymbol{1}-\boldsymbol{h})\boldsymbol{L}}\right) + \frac{\sigma}{\boldsymbol{nx}}\frac{\hat{\Psi}}{\hat{I}} + \frac{1}{\boldsymbol{nx}}} > 0. \tag{42}$$

In the long run the cost of imitation is reduced for southern researchers, leading to a higher rate of imitation, showing up as an additional $1/\boldsymbol{nx}$ in the denominator. Moreover, the higher share of researchers in the North allows to increase the rate of innovation, showing up as an additional $1/\boldsymbol{nx}$ in the numerator. The relative strength of these two effects is ambiguous, implying it is unclear whether the share of northern varieties rises or falls. Hence, it is unclear whether the long-run effect is smaller or larger than the short-run effect. However, both effects are clearly positive. □

Proof of proposition 4. Inserting Equations (22), (23), and (24) into Equation (25) and holding β, $\boldsymbol{h}$, and $\boldsymbol{n}$ constant, the short-run effect on the offshoring volume is given by

$$\frac{\hat{I}^s}{\hat{\boldsymbol{L}}} = -\frac{\frac{1-I}{(\boldsymbol{1-h})\boldsymbol{L}}}{I\left(\beta\tau(I) + \frac{1}{(\boldsymbol{1-h})\boldsymbol{L}}\right) + \frac{\sigma}{\boldsymbol{nx}}\frac{\hat{\Psi}}{\hat{I}}} < 0 \tag{43}$$

while taking into account Equation (26) yields for the long-run effect

$$\begin{aligned}\frac{\hat{I}^l}{\hat{\boldsymbol{L}}} &= \frac{\frac{1}{\boldsymbol{nx}} - \frac{1-I}{(\boldsymbol{1-h})\boldsymbol{L}}}{I\left(\beta\tau(I) + \frac{1}{(\boldsymbol{1-h})\boldsymbol{L}}\right) + \frac{\sigma}{\boldsymbol{nx}}\frac{\hat{\Psi}}{\hat{I}} + \frac{1}{\boldsymbol{nx}}} \\ &= -\frac{\beta\int_0^I \tau(i)\mathrm{d}i}{I\left(\beta\tau(I) + \frac{1}{(\boldsymbol{1-h})\boldsymbol{L}}\right) + \frac{\sigma}{\boldsymbol{nx}}\frac{\hat{\Psi}}{\hat{I}} + \frac{1}{\boldsymbol{nx}}} < 0\end{aligned} \tag{44}$$

It is easy to see that $\frac{\hat{I}^s}{\hat{\boldsymbol{L}}} < \frac{\hat{I}^l}{\hat{\boldsymbol{L}}}$ since the numerator of Equation (43) is larger in absolute terms than the one of Equation (44) while the denominator is smaller. □

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