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North-South Globalization and Inequality

Joël Hellier

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Joël Hellier[†]

EQUIPPE, Univ. of Lille 1, and LEMNA, Univ. of Nantes

Abstract

To analyse the globalization-inequality relationship, we extend the North-South HOS model by assuming (i) that the size of the South (emerging countries) increases over time and that the North (advanced countries) and the South never stand simultaneously inside the diversification cone, (ii) several northern and southern countries with different skill endowments, and (iii) North-South technological differences, productivity catching up and technological transfers. The model generates three phases of globalization, corresponding to different production patterns and to specific changes in inequality in the North and in the South. In the North, inequality continuously increases and unskilled workers purchasing power continuously decreases during the first phase of globalization, and inequality diverges across countries. In the South, very different profiles in terms of inequality dynamics are possible, depending on the country's skill endowment and on the its technological gap with the North. Unlike the traditional North-South HOS approach, the model predictions are consistent with observed facts.

Keywords: globalization, inequality, North-South trade, technology.

JEL Classification: D33, D63, F16, J31.

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[†]Contact details: Joël Hellier: joel.hellier@wanadoo.fr.

1. Introduction

In the last thirty years, the World has experienced a significant globalisation dynamics characterised by several major developments. Firstly, an increasing number of emerging countries (the South) have opened to world trade and the weight of the South in the world economy has critically increased. Secondly, world trade is characterised by the North (advanced countries) being specialised in skill-intensive goods and the South in unskilled intensive ones, which is in line with the relative endowments of each area in skilled/unskilled labour. In addition, the skill gap between the South and the North has always been substantial. Thirdly, the multinationalisation of firms and the liberalisation of capital flows have caused capital (both physical and financial) and technology to become highly mobile. In contrast, skilled and unskilled labours are far less mobile at the world level because of migration costs, cultural gaps and institutional rules that prevent immigration in most countries.

The globalization dynamics has coincided (i) with an increase in wage inequality in advanced countries, particularly (but not solely) between skilled and unskilled workers, and (ii) with growing divergences in within-country income inequalities across advanced economies (Chusseau et al. 2008; Van Reenen, 2011). The increase in inequality has thus been clearly uneven across northern countries. In addition, the moves in inequality have been rather diverse across emerging countries (Chusseau and Hellier, 2012), even if the general diagnosis has been made of an increase in inequality (Goldberg and Pavcnik, 2007).

Given the aforementioned characteristics, the natural approach to analyse the globalization-inequality relationship appears to be the North-South Heckscher-Ohlin-Samuelson (HOS) model. In this model, the North and the South are the two countries and skilled and unskilled labour the two factors. The North (South) being better endowed with skilled (unskilled) labour, the model predicts that North-South trade results (i) in the North (South) being specialised in the skill-intensive (unskilled-intensive) good, and (ii) in an increase in inequality (the skill premium) in the North. Both predictions are consistent with observed facts. However, most of the other observed developments that characterise the globalization process are at variance with the HOS predictions (see Hellier, 2012, for an extensive list of these contradictions). In particular: there is no factor price equalisation; the skill premium has remained significantly higher in the South compared to the North; the differences in inequality have increased across northern countries; the South has experienced an increase in inequality with very diverse profiles across countries; the South did not produce skill-intensive (tradable) goods at the first stages of globalization; the North no longer produces unskilled-intensive tradable goods.

These shortcomings of the North-South HOS model in explaining the observed developments have been interpreted in several ways. Krugman and Lawrence (1993) and Krugman (1995) have firstly pointed to the fact that the weight of the South was small. Consequently, the impact of the HOS mechanisms was negligible and the observed developments were essentially driven by other factors such as skill biased technical change and institutional changes. However, with the advent of China and India and the now crucial role of the South in both world trade and world production, such an argument is no longer valid (Krugman, 2008). The second interpretation is that the HOS framework is inadequate for modelling globalization because of its unrealistic and restrictive assumptions (Desjonqueres et al., 1999). Even if the inadequacy of certain assumption is commonly recognised, the rejection of the North-South HOS framework remains controversial because one key characteristic of globalization is that specialization in trade and production between the North and the South is driven by factoral comparative advantages in terms of skill. A third position consists in extending the traditional, factor price equalising, HOS model so as to

correct its most prominent shortcomings. In this respect, a well established condition for factor price equalisation to occur is that both countries must stand inside the diversification cone (McKenzie, 1955; Chipman, 1969). When this condition is not fulfilled, both countries do not produce simultaneously both goods. Assuming that the North and the South are not both inside the diversification cone makes the analysis more realistic in three manners. Firstly, it is in line with the substantial difference in skill endowments between the North and the South. Secondly, there is no factor price equalisation and inequality remains higher in the South than in the North. Thirdly, the North and the South do not simultaneously produce both goods.

In the North-South HOS model developed here, the hypothesis that the North and the South are not simultaneously inside the diversification cone is combined with the growing size of the South, which is another observed feature. These two assumptions define North-South globalization. We show that globalization comprises three phases that differ in the production patterns and in the variations in inequality in the North and the South. In particular, inequality increases and unskilled workers' purchasing power decreases in the North throughout the first phase of globalization. We subsequently extend the model by allowing for several countries in the North and in the South. Then, globalization makes northern countries to diverge in terms of inequality. We finally introduce an initial technological gap between the North and the South and subsequent productivity catching up and technological transfers. From these assumptions, it is shown that the inequality profiles can be very diverse across southern countries.

Section 2 exposes the North-South HOS model and determines the conditions for both countries not to be simultaneously inside the diversification cone. In Section 3, North-South globalization is introduced and the three phases of globalization are described. Section 4 extends the model by assuming several northern and several southern countries. Technological gap, productivity catching up and technological transfers are introduced in Section 5. We discuss the main findings and we conclude in Section 6.

2. The model

2.1. General Framework

We assume an HOS framework with skilled labour (H) and unskilled labour (L) being the two (homogenous) factors, goods h (H -intensive) and l (L -intensive) the two goods, and the North and the South the two countries. Southern values are depicted by an asterisk (*).

The relative endowments of the North $\lambda = L/H$ and the South $\lambda^* = L^*/H^*$ are constant, and the North is better endowed with skilled labour than the South:

$$\lambda^* > \lambda$$

The two countries share the same Cobb-Douglas production functions:

$$Y_i = A_i L_i^{\alpha_i} H_i^{1-\alpha_i}, \quad i = h, l, \quad 0 < \alpha_h < \alpha_l < 1 \quad (1)$$

The instantaneous utility functions are log linear and identical in both areas, which entails that income is spent for the consumption of good l in proportion β and for the consumption of good h in proportion $(1 - \beta)$.

We assume that, for the given relative endowments λ and λ^* , skilled labour is better paid than unskilled labour in both areas. Consequently, inequality can be measured by the skill premium, i.e. the ratio $w = w_H / w_L$ of the wage per unit of skilled labour on the wage per unit of unskilled labour.

Within such a framework, the equilibrium full employment skill premium of the North in autarky w_{aut} , of the South in autarky w_{aut}^* and of the World in free trade with factor price equalisation w_W are respectively (see Appendix 1):

$$w_{aut} = \frac{1-\alpha}{\alpha} \lambda \quad (2)$$

$$w_{aut}^* = \frac{1-\alpha}{\alpha} \lambda^* \quad (3)$$

$$w_W = \frac{1-\alpha}{\alpha} \frac{L+L^*}{H+H^*} = \frac{1-\alpha}{\alpha} \frac{\lambda + \sigma \lambda^*}{1+\sigma} \quad (4)$$

with $\alpha = \beta \alpha_l + (1-\beta) \alpha_h$ and $\sigma = H^*/H$.

As the relative endowments λ and λ^* are given, *the ratio $\sigma = H^*/H$ measures the relative size of the South.*

Let \underline{w} and \tilde{w} be respectively the lowest and the highest skill premium consistent with full employment in the North for the given technologies (1). The former corresponds to the North producing good l only, and the latter to the North producing good h only. Consequently:

$$\underline{w} = \frac{1-\alpha_l}{\alpha_l} \lambda \quad (5)$$

$$\tilde{w} = \frac{1-\alpha_h}{\alpha_h} \lambda \quad (5')$$

And identically for the South:

$$\underline{w}^* = \frac{1-\alpha_l}{\alpha_l} \lambda^* \quad (6)$$

$$\tilde{w}^* = \frac{1-\alpha_h}{\alpha_h} \lambda^* \quad (6')$$

By inserting inequalities $\alpha_h < \alpha < \alpha_l$ and $\lambda < \lambda^*$ into (2)-(6'), we obtain the following inequalities:

$$w_{aut} < w_W < w_{aut}^*; \quad \underline{w} < w_{aut} < \tilde{w}; \quad \underline{w}^* < w_{aut}^* < \tilde{w}^* \quad (7)$$

Note that the values $w_{aut}, w_{aut}^*, \underline{w}$ and \tilde{w}^* are fully determined by the model coefficients $(\alpha_h, \alpha_l, \beta)$ and the relative endowments λ and λ^* .

2.2. Specialisation

In a situation of free trade and full employment, both countries cannot produce simultaneously both goods if the highest full employment skill premium of the North \tilde{w} is smaller than the lowest full employment skill premium of the South \tilde{w}^* . This is because producing simultaneously both goods means the same skill premium in both countries, which is impossible for both of them being at full employment when $\tilde{w} < \tilde{w}^*$ (Figure 1). Consequently:

Lemma 1. *At full employment, the North and the South never simultaneously produce both goods if:*

$$\frac{\lambda^*}{\lambda} > \frac{\alpha_l(1-\alpha_h)}{\alpha_h(1-\alpha_l)} \quad (8)$$

Proof. $\tilde{w} < \tilde{w}^* \Leftrightarrow \frac{\lambda^*}{\lambda} > \frac{\alpha_l(1-\alpha_h)}{\alpha_h(1-\alpha_l)}$ because of (5) and (6).

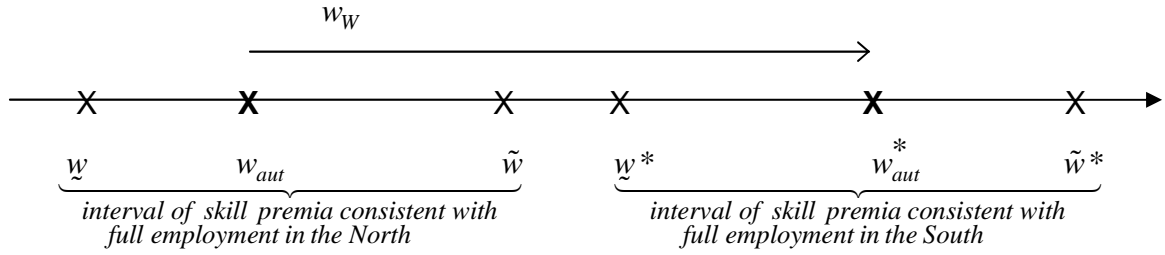


Figure 1. Both countries do not produce both goods simultaneously.

Figure 1 depicts the case in which, whatever the size of the South, both countries never simultaneously produce both goods.

Lemma 2. *The North produces h only if $\sigma > \underline{\sigma}$ and the South good l only if $\sigma < \bar{\sigma}$, with:*

$$\underline{\sigma} = \frac{(\alpha - \alpha_h)\lambda}{\alpha_h(1-\alpha)\lambda^* - \alpha(1-\alpha_h)\lambda} \quad (9)$$

$$\bar{\sigma} = \frac{\alpha(1-\alpha_l)\lambda^* - \alpha_l(1-\alpha)\lambda}{(\alpha_l - \alpha)\lambda^*} \quad (10)$$

Proof. The condition for the North to produce good h only is $\tilde{w} < w_W$, which yields because

of (4) and (5'): $\sigma > \underline{\sigma} = \frac{(\alpha - \alpha_h)\lambda}{\alpha_h(1-\alpha)\lambda^* - \alpha(1-\alpha_h)\lambda}$. The condition for the South to produce

good l only $w_W < \tilde{w}^*$, i.e. because of (4) and (6): $\sigma < \bar{\sigma} = \frac{\alpha(1-\alpha_l)\lambda^* - \alpha_l(1-\alpha)\lambda}{(\alpha_l - \alpha)\lambda^*}$.

Lemma 3. *Assume that (8) is fulfilled. Then $0 < \underline{\sigma} < \bar{\sigma}$.*

Proof. Appendix 2.

Lemma 4. *Assume that (8) is fulfilled. Then:*

1) *The case $\sigma < \underline{\sigma}$ corresponds the North producing both goods and the South good l only.*

2) *The case $\underline{\sigma} \leq \sigma \leq \bar{\sigma}$ corresponds the North producing good h only and the South good l only.*

3) *The case $\sigma > \bar{\sigma}$ corresponds to the North producing good h only and the South both goods.*

Proof. Lemma 4 directly derives from lemmas 3 and 2.

3. North-South Globalization

3.1. Definition

By selecting an HOS framework, we have already assumed free access to technologies and free trade at the level of the World. In addition to this, North-South globalization is defined by two major characteristics:

- 1) A growing size of the South compared to the size of the North, i.e., an increase in coefficient σ .
- 2) A large difference between the North and the South in terms of (relative) factor endowments, which entails that both countries never produce both goods at the same time. Consequently, inequality (8) holds and $0 < \underline{\sigma} < \bar{\sigma}$ (Lemma 3).

The growing size of the South aims at portraying the fact that an increasing number of developing countries and regions have joined and are still joining the globalized economy. As shown in Section 5, it can also portray the technological catching up of the South. It must be noted that $w_W = w_{aut}$ when the size of the South is minute compared to that of the North ($\sigma \approx 0$) whereas w_W yends towards w_{aut}^* when the South becomes huge in relation to the North ($\sigma \rightarrow \infty$). Consequently, the globalization process corresponds to w_W moving from w_{aut} towards w_{aut}^* (Figure 1).

The large difference in skill endowments between the North and the South is well documented¹. In addition, if skill endowments have increased in both developed and developing countries over the last thirty years, this increase has been greater in the former, which reinforces the difference in skill endowment.

¹ See Barro & Lee database (2010) and the UNESCO database: <http://stats.uis.unesco.org/unesco>.

3.2. The three phases of globalization

Proposition 1. *Globalization comprises three successive phases:*

- 1) *The North produces both goods and the South good l only provided that $\sigma < \underline{\sigma}$.*
- 2) *The North produces good h only and the South good l only provided that $\sigma \in [\underline{\sigma}, \bar{\sigma}]$.*
- 3) *The North produces good h only and the South both goods provided that $\sigma > \bar{\sigma}$.*

Proof. From Lemma 4. In addition, as the (relative) size of the South σ increases from zero upwards, the three phases depicted in Proposition 1 follow each other throughout the globalization process.

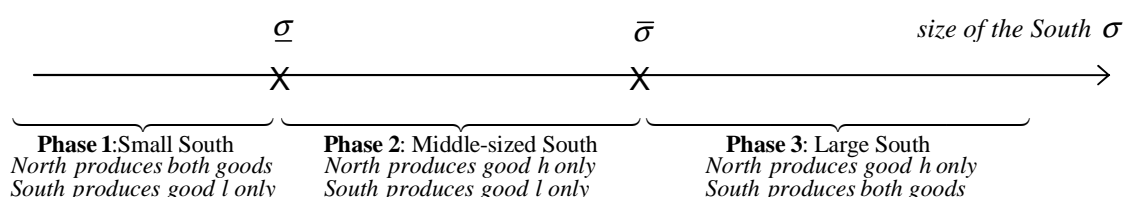


Figure 2: The three phases of globalization.

The three successive phases with their production patterns are depicted in Figure 2. The period corresponding to $\sigma < \underline{\sigma}$ is characterised by a limited size of the South and it is called Phase 1 of globalization. The situation where $\sigma \in [\underline{\sigma}, \bar{\sigma}]$ corresponds to a middle-sized South and it is called Phase 2. Finally, the situation where $\sigma > \bar{\sigma}$ is characterised by the South being large in relation to the North and it is called Phase 3 of globalization.

3.3. Globalization and inequality

Proposition 2. *During the globalization process:*

- 1) *The North skill premium increases from w_{aut} to \tilde{w} throughout Phase 1 of globalisation, and remains at the value \tilde{w} throughout phases 2 and 3.*
- 2) *The South skill premium experiences a downward jump from w_{aut}^* to \tilde{w}^* at the start of globalization and remains at this value throughout phases 1 and 2, and it continuously increases and tends towards w_{aut}^* in Phase 3.*
- 3) *The skill premium is always higher in the South.*

Proof. Appendix 3.

Proposition 3. *The purchasing power of northern unskilled workers decreases throughout Phase 1 and increases throughout phases 2 and 3 of globalization.*

Proof. Appendix 4.

It is clear that the position of unskilled workers in the North is doubly hurt during Phase 1 of globalization. As the skill premium decreases, they firstly experience an income impoverishment relative to the skilled (Proposition 2). They secondly suffer an absolute impoverishment due to their purchasing power losses (Proposition 3). Finally, once the North has reached the high inequality \tilde{w} , it remains at this level throughout phases 2 and 3.

4. Several northern and southern countries

The analysis is now extended by assuming that both the North and the South comprise several countries that differ in their factor endowments $\lambda_i = L_i / H_i$. At the beginning of the globalization process, these endowments are assumed sufficiently near inside each group of countries and sufficiently different between them (i) to ensure factor price equalisation amongst northern countries, and (ii) to place all southern countries outside the diversification cone, thereby producing good l only. As regards southern countries, we further suppose that when new countries enter the globalized economy, these newcomers do not modify the average skill (relative) endowment of the South λ^* .

We successively analyse the respective cases of several northern and of several southern countries. In each case, we consider to simplify the other group as single. The concomitance of a multiplicity of countries in both the North and the South is discussed in Section 6.

4.1. Several northern countries

There are n northern countries that are ranked in decreasing order of skill endowment: $\lambda_1 < \lambda_2 < \dots < \lambda_n$.

At the outset of globalization, the size of the South is minute and all northern countries produce both goods with the same skill premium $w_{aut} = \frac{1-\alpha}{\alpha} \lambda$, $\lambda = \sum_{j=1}^n L_j / \sum_{j=1}^n H_j$. As the size of the South increases, so does the northern skill premium. There is thus a moment when this skill premium is high enough to attain the value $\tilde{w}_1 = (1-\alpha_h)\lambda_1 / \alpha_h$ from which the northern country 1 produces good h only and remain at the skill premium value \tilde{w}_1 . With the rising size of the South, an increasing number of northern countries (successively countries 2, 3, 4 ...) pass from a position where they produced both goods to a position where they produce good h only. With this dynamics, the countries' skill premia place themselves one after the other at their highest value \tilde{w}_j , which produces a dynamics of divergent inequality across northern countries. This dynamics comes to an end when all northern countries solely produce the skill-intensive good, i.e. at the start of Phase 2. From then, the inequality divergence between northern countries stands at its highest level and each country displays the skill premium that corresponds to its factor endowment: $\tilde{w}_j = (1-\alpha_h)\lambda_j / \alpha_h$, $j = 1, \dots, n$. This divergence subsequently remains constant since all northern countries only produce good h throughout phases 2 and 3. From this discussion, we can state the following proposition:

Proposition 4. *Assume that the North comprises several countries that differ in their factor endowments λ_j . Then:*

- 1) *During Phase 1 of globalization, an increasing number of northern countries start to produce good h only and inequality diverges across northern countries.*
- 2) *In phases 2 and 3, differences in skill endowments between northern countries results in different levels of inequality, with the hierarchy in inequality replicating the hierarchy in factor endowments λ_i .*

By allowing for several countries in the North with different skill endowments, we generate inequality divergence across northern countries. Now, *Phase 1 of globalization combines an increase in inequality in all advanced countries and a divergence in inequality across them*, which are two major developments observed in the eighties and nineties.

Finally note that, as long as inequality increases in one northern country, this country knows a decrease in its unskilled workers' purchasing power (the demonstration for the case of a single North provided in Appendix 4 applies here). In contrast, the unskilled workers' purchasing power increases in the countries where the skill premium remains unchanged. Consequently, during Phase 1 of globalization, the divergence in inequality is accompanied by a divergence in unskilled workers' purchasing power across northern countries. The higher the country's skill endowment, the lower the decrease in its purchasing power.

4.2. Several southern countries

Let us now suppose that there are $s > 1$ southern countries with different skill endowments λ_j^* , $j = 1, \dots, s$. Southern countries are ranked in increasing order of skill endowments ($\lambda_1^* > \lambda_2^* > \dots > \lambda_s^*$). We also assume that each southern country is sufficiently small not to modify the skill premium of the set of countries (northern and southern) that produce both goods when it enters this set. So as to centre our analysis on southern countries, we finally suppose a single North.

We now call Phase 3 of globalization the situation in which (i) the North produces good h only and (ii) all southern countries produce both goods.

Southern countries are assumed to have skill endowments such that (i) they all produce good l only at the outset of globalization, and (ii) they all belong the diversification cone for a world factor price equalization skill premium w_W that is lower than the southern autarkic factor price equalization skill premium w_{aut}^* . This last assumption indicates that all the southern countries will sooner or later produce both goods, i.e., that Phase 3 of globalization does exist.

As long as all southern countries produce l only, the differences in skill endowments make them differ in their skill premia. As $w_j^* = (1 - \alpha_l)\lambda_j^* / \alpha_l$, we have $w_1^* > w_2^* > \dots > w_s^*$.

The growing size of the South makes the skill premium of the North to increase. Consider southern country s with the lowest unskilled labour endowment λ_s^* . Two cases can be distinguished:

- 1) In the first, there is a moment when the northern skill premium becomes high enough to make country s produce both goods as the North still produces both goods. This happens when the skill premium corresponding to s producing only good l , i.e. $(1 - \alpha_l)\lambda_s^* / \alpha_l$, becomes lower than the northern skill premium before this skill premium attains the value

corresponding to the North producing h only, i.e. $(1-\alpha_h)\lambda / \alpha_h$, which yields the condition:

$$\frac{\lambda_s^*}{\lambda} < \frac{\alpha_l(1-\alpha_h)}{\alpha_h(1-\alpha_l)}. \text{ The size of the South continuing to grow, an increasing number of southern}$$

countries begin to produce both goods and a moment comes when the skill premium of the set of countries that produce both goods is high enough to make the North produce good h only. Finally, Phase 3 starts when the southern country 1 (the one with the lowest skill endowment) begins to produce both goods.

2) The southern country s (with the highest skill endowment) still produces good l only when the northern skill premium becomes sufficiently high to make the North produce good h only. This happens when the skill premium $(1-\alpha_l)\lambda_s^* / \alpha_l$ corresponding to s producing only good l is higher than the northern skill premium when the North produces h only $(1-\alpha_h)\lambda / \alpha_h$, which yields the condition: $\frac{\lambda_s^*}{\lambda} > \frac{\alpha_l(1-\alpha_h)}{\alpha_h(1-\alpha_l)}$. As in Section 3, there is then a

stage of globalization in which the North produces good h only and the whole South produces l only. However, as the skill premium continues to rise, a moment comes when country s begins to produce both goods, subsequently followed by country $s-1$, $s-2$, ... etc. Globalisation enters Phase 3 when country 1 starts to produce both goods.

From the above discussion, we can state the following proposition:

Proposition 5. *Suppose that the South comprises $s > 1$ countries ranked in increasing order of their skill endowments. Then:*

- 1) *During Phase 1 of globalization, the hierarchy of skill premia across southern countries coincides with the hierarchy of the relative endowments of unskilled labour λ_j^* .*
- 2) *If $\frac{\lambda_s^*}{\lambda} < \frac{\alpha_l(1-\alpha_h)}{\alpha_h(1-\alpha_l)}$, then Phase 2 is divided into two successive stages. During the first, the North and an increasing number of southern countries produce both goods whereas other southern countries (those with the lowest skill endowments) produce good l only. In the second stage, the North produces good h only and an increasing number of southern countries produce both goods until all of them do so. Throughout this second stage, the southern countries' skill premia converges towards $(1-\alpha_l)\lambda_1 / \alpha_l$.*
- 3) *If $\frac{\lambda_s^*}{\lambda} > \frac{\alpha_l(1-\alpha_h)}{\alpha_h(1-\alpha_l)}$, then the two stages of Phase 2 are as follows. Firstly, the North produces good h only and all the southern countries produce good l only. Subsequently, the North still produces h only but an increasing number of southern countries produce both goods with the southern skill premia converging to $(1-\alpha_l)\lambda_1 / \alpha_l$.*
- 4) *Phase 3 is characterised by the North producing h only and all the southern countries producing both goods with the same skill premium that tends towards w_{aut}^* .*

Proposition 5 shows that Phase 1 of globalization is characterised by significant differences in inequality between southern countries and that these differences tend to decrease and vanish during Phase 2.

5. Technological catching-up and transfer

Following the usual HOS hypotheses, we have assumed identical technologies in both the North and the South. However, even if multinationals can export northern technologies to the South, differences in infrastructures, difficulties in the implementation of the imported technologies, inefficiencies in firms' organisation and management etc. cause the total factor productivity (TFP) to be lower in the South than in the North. With time, this productivity gap tends to decrease because of learning-by-doing, improvements in infrastructures, adoption of new methods of management etc. This produces productivity catching-up.

In addition, it is reasonable to assume that the southern technologies were less skill intensive in the South than in the North before openness and globalization. This can particularly derive from factor cost driven technological change as modelled by Acemoglu (1998). In this case, the transfer to the South of northern technologies results in a rise in the demand for skilled labour that can counteract the decrease due to the specialisation of the South in unskilled intensive goods.

5.1. Productivity catching-up

We assume that the TFPs, i.e. the values A_i , $i = h, l$ in the production functions (1), are smaller in the South than in the North at the outset of globalization. This can be modelled by assuming production functions $Y_i = A_i L_i^{\alpha_i} H_i^{1-\alpha_i}$ in the North and $Y_i^* = A_i^* (L_i^*)^{\alpha_i} (H_i^*)^{1-\alpha_i}$ in the South, with $A_i^* = \eta A_i$, $0 < \eta < 1$. Consequently, the productivity gap is initially the same in both sectors.

As the production functions are homogeneous of degree 1, assuming that the southern TFPs are lower than the northern TFPs in the proportion η is equivalent to assuming that one southern worker accounts for η northern worker whatever her/his skill. Consequently, this corresponds to multiplying the population of the South by η inside the HOS model.

We now suppose that the South catches up the North in terms of TFP. Compared to the analysis developed in Section 3, this is equivalent to (i) reducing the size of the South at the beginning of the globalization process, and (ii) accelerating the rhythm of growth of the South population since this must now combine the increase in the size of the population itself and the increase in labour productivity due to the catching up dynamics. This typically bears two consequences:

1) The impact of North-South openness and trade on the North is lessened in the first stages of globalization because the size of the South must be cut by the labour productivity gap. This could explain why North-South trade has remained limited until the early nineties, postponing thereby the influence of the Heckscher-Ohlinian mechanisms on the demands for skilled and unskilled workers.

2) The increase in the size of the South (in terms of North-equivalent labour) goes faster, which accelerates the rise of the skill premium during the globalization process.

5.2. Technological transfer

We now suppose that, in addition to the TFP gap, northern technologies are more skill intensive than traditional southern technologies. This is modelled by assuming production functions $Y_i = A_i L_i^{\alpha_i} H_i^{1-\alpha_i}$ in the North and $Y_i^* = A_i^* (L_i^*)^{\alpha_i^*} (H_i^*)^{1-\alpha_i^*}$ in the South, with

$A_i^* < A_i$ and $\alpha_i^* > \alpha_i$, $i = h, l$. We further assume that, in all cases, the factor endowments are such that the South only produces good l at the start of North-South openness. We finally limit our analysis to the first two phases of globalization, i.e., when the South only produces good l . This is explained by the fact that, if one can reasonably assume that a number of unskilled-intensive goods (clothing, textile, leather goods, toys, furniture etc.) were produced using traditional technologies in the South before openness, such a situation becomes unlikely for skill-intensive high-tech goods. As the difference in technologies between the North and the South is motivated by the search of a more realistic framework, it is rather logic to suppose that the technology for skill-intensive goods is imported from the North after openness. For unskilled intensive goods in contrast, firms in the South have the choice between maintaining the traditional southern technology or adopting the more skill-intensive northern technology.

Proposition 6. *During the first two phases of globalization, the South adopts the northern technology if:*

$$\lambda^* < \left(\frac{A_l \alpha_l}{A_l^* \alpha_l^*} \right)^{\frac{1}{\alpha_l^* - \alpha_l}} \quad (11)$$

Proof. Appendix 5.

During the first two phases, the South only produces good l . To explain condition (11), let us rewrite it: $\frac{A_l}{A_l^*} > \frac{\alpha_l^*}{\alpha_l} (\lambda^*)^{\alpha_l^* - \alpha_l}$. The right hand side of this inequality depicts the multiplying coefficient in the production cost of l due to the fact that the northern technology is more skill intensive than the southern technology ($\alpha_l^* > \alpha_l$), coefficient that is all the higher as the relative endowment in unskilled labour λ^* is elevated. This is because a higher λ^* entails a higher skill premium, which increases the cost of using the northern technology that is more skill intensive. The left hand side is the reduction coefficient in cost due to the fact that the northern technology has a total factor productivity that is higher than the southern technology ($A_l > A_l^*$). For the northern technology to be adopted, this reduction in cost must be higher than the increase in cost due to higher skill intensity, i.e. condition (11).

Finally, condition (11) shows that southern firms may decide not to adopt the northern technology when the South displays a sufficiently high endowment in unskilled labour, which is logic since the northern technology is more skill-intensive.

Proposition 7. *Assume that the South adopts the northern technology (Condition 11 holds). Then the skill premium increases (decreases) in the South at the start of Phase 1 if:*

$$\frac{1 - \alpha^*}{\alpha^*} < (>) \frac{1 - \alpha_l}{\alpha_l} \quad (12)$$

with $\alpha^* = \beta \alpha_l^* + (1 - \beta) \alpha_h^*$.

Proof. With the traditional southern technology, the before globalization southern skill premium is $w_{aut}^* = (1 - \alpha^*) \lambda^* / \alpha^*$, with $\alpha^* = \beta \alpha_l^* + (1 - \beta) \alpha_h^*$. The skill premium of the

South in Phase 1 if this area adopts the northern technology is $\tilde{w}^* = (1 - \alpha_l)\lambda^*/\alpha_l$. Hence:

$$w_{aut}^* \begin{matrix} > \\ < \end{matrix} \tilde{w}^* \Leftrightarrow \frac{1 - \alpha^*}{\alpha^*} \begin{matrix} > \\ < \end{matrix} \frac{1 - \alpha_l}{\alpha_l}.$$

Proposition 7 indicates that, when technologies are different in the North and the South before globalization and if the South adopts the northern technology that is more skill intensive, then globalization can come with both lower or higher inequality (skill premium) in the South, depending on whether $w_{aut}^* = (1 - \alpha^*)\lambda^*/\alpha^*$ is higher or lower than $\tilde{w}^* = (1 - \alpha_l)\lambda^*/\alpha_l$.

Finally Propositions 6 and 7 have been exposed by assuming one single South. When considering a multi-country South, these propositions still hold for each of them. In this case, A_l^* and α_l^* are replaced by A_{lj}^* and α_{lj}^* in Condition (11), and α^* by $\alpha_j^* = \beta\alpha_{lj}^* + (1 - \beta)\alpha_{hj}^*$ in condition (12), where j indicates southern country j .

6. Discussion and conclusion

The model main findings are firstly recalled and their accuracy to portray observed developments is underlined. The results from combining the multiple-country approach and the model with technological differences, catching up and transfer are subsequently discussed. Further extensions are finally tackled.

6.1. Main findings

We have developed a North-South HOS model by assuming that both areas never simultaneously produce both goods and that the size of the South increases over time. We have subsequently extended the model (i) by assuming several northern and several southern countries with different skill endowments, and (ii) by introducing technological differences, productivity catching up and technological transfers between the North and the South.

The two-country model determines three phases of globalization. In the first, inequality continuously increases in the North and there is a downward jump in inequality in the South. Phase 1 also experiences a decrease in the purchasing power of unskilled workers in the North. Phase 2 corresponds to constant skill premia in both the South and the North and Phase 3 to an increase in inequality in the South. Finally inequality is always higher in the South than in the North.

By assuming several northern countries with different skill endowments we have shown that Phase 1 of globalization is characterised by both growing inequality in all northern countries and growing divergence in inequality across them. One after the other, northern countries move from a two-good production pattern to the production of good h only. The moments when they operate this move as well as the skill premium they reach replicate their differences in skill endowment. The countries that are better endowed with skill are the first to move and they display the lowest inequality. In these countries, the decrease in unskilled workers' purchasing power is also lower and short-lived. Note that the loss of purchasing power can be erased if productivity increases in the North.

Assuming several southern countries with different skill endowments, this yields different skill premia across them throughout the first phase of globalization. The resulting hierarchy of inequality reproduces the hierarchy of relative endowments of unskilled labour. The second

phase of globalization is characterised by a distribution of southern countries between the decreasing number of those who remain specialised in the sole production of l (the less skill-endowed) and the increasing number of those who produce both goods (the most skill-endowed). The latter display lower inequality in Phase 1, and experience an increase in inequality in Phase 2. Finally, Phase 3 is characterised by all southern countries producing both goods and having the same increasing skill premium.

From the assumptions of initial TFP gap and technological differences between the North and the South, we have analysed the effects of TFP catching up and technological transfers. TFP gap acts as a reduction in the size of the South and TFP catching up as a rise in the growth rate of this size. This (i) lessens the impacts of the South on the North production and inequality at the beginning of globalization, and (ii) accelerates the rise of these impacts throughout the globalization process. Moreover, transfers of more skill-intensive technologies from the North to the South can reverse the initial decrease in inequality in the South. This is in line with the result from Pissarides (1997) except that our model does not generate an additional transitory inequality in the South due to technological adjustment. Finally, introducing openness-driven technological catching up and transfer into the analysis generates a large range of possible situations depending (i) on the South skill endowment, and (ii) on the technological differences between the North and the South.

In contrast with the traditional North-South HOS approach, the model is consistent with a number of observed developments:

1. During the first phase of globalization, the North does not only know an increase in inequality and a decrease in its unskilled workers' purchasing power, but it also witnesses a divergence in inequality across northern countries.
2. There is no factor price and skill premium equalization and the South displays a skill premium which is always higher than that of the North.
3. The model can generate very different and opposite developments in the South.
4. Even when the size (population) of the South is no longer negligible, its influence can remain secondary due to the TFP gap. This can explain Krugman's analysis in the nineties.

6.2. Combining country multiplicity and technological differences

In the theoretical analyses carried out in sections 4 and 5, we have successively investigated (i) the case of several northern countries with a single South, (ii) the case of several southern countries with a single North, and (iii) productivity catching up and technological transfers within a two-country model. So as to achieve simple analytical results, we have not put together several northern and southern countries with technological differences, catching up and transfers. It is clear that combining these extensions generates a multiplicity of very different situations. We now describe certain aspects of such a combination and put forward (i) the developments that are common to all the cases and can thereby be diagnosed as invariant results of the analysis, and (ii) the possible coincidence of very diverse profiles across countries that may provide an explanation to certain observed facts.

Inequality and specialisation in the North

Both results that inequality increases in the North during the first stage of globalization and that this increase differs in intensity across countries are verified in all cases. In terms of specialisation in production, northern countries move one after the other from a configuration in which they produced both goods to a situation in which they only produce good h . The least skill-endowed countries are the most inegalitarian and the last to move to the production of the sole good h . Finally, unskilled workers suffer purchasing power losses in the North during the first phase of globalization.

In addition, as usual in HOS-type models, it can be straightforwardly shown that the setting of a minimum wage (or a skill premium lower than its equilibrium level because of labour market rigidities) results in unemployment of the unskilled in the countries that implement such policy. However, contrary to Davis (1998) and in line with Oslington (2002), the growing size of the South does not systematically and overwhelmingly hurt the northern country that has set a minimum wage and this wage does not preserve other northern countries from the South's competition. At any moment of the globalization process, the northern countries that only produce good h are ipso facto insulated from the influence of the South. In contrast, the rising size of the South directly affects those northern countries that produce both goods by increasing inequality, and/or unemployment in the case of labour market rigidities. Then, Davis' results only concern the northern countries that produce both goods.

Several southern countries with technological differences, catching up and transfers

When the South is composed of several countries whose technologies differ not only from these of the North but also between them, there is room for a large range of different profiles amongst southern countries. Firstly, the least skill-endowed countries do not adopt the northern technology because they do not fulfil Condition (11). However, with TFP catching up, they can later turn out to fulfil this condition and select the northern technology. When this technology is adopted, the country experiences an increase in inequality because producing l with the northern technology is more skill demanding than with the traditional southern technology. Several different profiles are thus achievable depending on the country's position in terms of conditions (11) and (12):

1. When condition (11) is not initially fulfilled, inequality firstly decreases as the country specialises itself in the sole production of l . Once TFP catching has made the northern technology profitable, inequality goes up. If condition (12) is fulfilled (not fulfilled), then inequality goes beyond (remains beneath) its level before openness and globalization.

2. If condition (11) is fulfilled, the country knows either an increase in inequality, or a decrease, depending on whether condition (12) is fulfilled or not.

3. From the moment when the country begins to produce both goods, inequality begins to lastingly increase.

Finally, these different profiles typically coexist when the southern countries are initially sufficiently different in their technologies and/or enter the globalized economy at different moments of time. Reviewing the empirical literature on the subject, Anderson (2005) notes that cross country empirical estimates find little impact of openness upon inequality in developing countries. Our model results in consistent with such finding.

Intermediate countries

Until now, we have assumed that northern and southern countries were sufficiently different so that the North and the South never simultaneously produce both goods. This broadly corresponds to the observed specialisation in terms of tradable goods and such a hypothesis is thus justified within a North-South two-country model. However, a more precise examination shows that certain southern countries have begun to produce skill intensive goods in the nineties (Korea, Taiwan)² whereas certain northern countries were still producing unskilled-intensive goods (Portugal, Spain, the Italian Mezzogiorno etc.).

We assume now several southern and northern countries. We still suppose that, at the outset of globalization, all northern countries produce both goods and all southern countries produce good l only. We call *intermediate countries* the countries that produce both goods

² Given their skill endowments, Korea and Taiwan can no longer be considered as southern countries in the 2000s.

whereas there are northern countries producing good h only and southern countries producing l only. Consequently, the list and the number of intermediate countries vary throughout the globalization process. The set of intermediate countries starts to exist as and when the most skill-endowed northern country begins to produce good h only, and it vanishes once all southern countries produce both goods. As the size of the South increases, more and more northern countries begin to produce h only and more and more southern countries begin to produce both goods. The most interesting situation is that in which the set of intermediate countries comprises countries from both the North and the South. These countries have a key importance because they are the only ones that are affected by the growing size of the South. Indeed, in the countries producing one good only, the skill premium is constant and fully determined by their skill endowments and the good they produce. In contrast, the countries producing both goods suffer a continuous increase in inequality. This typically shows that, during a long period of time, certain northern and southern countries know simultaneously an increase in inequality (those who produce both goods) whereas others experience unchanged inequality (those who produce one good only) and certain southern countries even demonstrating decreasing inequality (those who enter the globalized economy).

6.3. Further extensions

We discuss three simplifying assumptions of HOS-type models that impact on inequality profiles and could be removed, namely, constant skill endowments, given existing technologies and the two-good assumption.

It is clear that, over the last thirty years, there has been a critical increase in the skill level of the working population in both developed and developing countries. However, at least in the eighties and nineties, this increase has been higher in the former than in the latter. Consequently, the assumption of significant differences in skill endowments between the North and the South still holds. Nevertheless, the general increase in skill supply should typically lessen the skill premium and inequality. This has albeit been counteracted by the fact that technological change has been skill biased in northern countries and by the adoption in developing countries of more skill-intensive northern technologies (as modelled in Section 5).

An additional characteristic of the developments observed over the last thirty years is the substantial technological change that originated in the North. The spreading of ICTs can be seen as the advent of a general purpose technology that has been to a large extent skill-biased. The impact of skill biased technological change (SBTC) upon the demand for skill and inequality has been particularly significant in the United States (Bound and Johnson, 1992; Berman et al., 1994; Harrigan, 2000, Allen, 2001). As the model developed here assumes given technologies (even when these initially differs across countries), SBTC is thereby ignored in the North. A simple way to model the impact of SBTC is to assume that the coefficients α_i , $i = h, l$, have decreased in addition to the growing size of the South. However, the ICT story does not equally apply to all northern countries. In fact, the technologically most advanced country(ies) create(s) new skill intensive goods for the production of which it (they) have a temporary monopolistic position. These goods and technology subsequently spread out to other northern countries as the most advanced country(ies) invent newer goods with more skill-intensive technologies. The spreading out of new goods can also come with a decrease in their skill intensity as their production expands. The technology creator position has typically been that of the United States. To model this dynamics, two additional modifications should be added to our two-good approach. The first is to concentrate SBTC in sector h that becomes a high-tech skill-intensive sector. The second is to assume different technologies with different skill intensities (coefficient α_h) across northern countries. Such modifications allow modelling the case of the US that is at variance

with the approach developed here. In fact, this approach predicts that inequality amongst northern country is inversely proportional to the country's skill endowment. This is in line with the European experience (southern Europe is the least egalitarian, followed by continental Europe and Scandinavian countries). But it also signifies that the US should display the lowest inequality (this country has the highest skill endowment), whereas the contrary is observed. When assuming that the US is the technology creator, this makes its coefficient α_h to decrease more than in other advanced countries, heightening thereby the demand for skill and inequality in this country. To be robust, such a scenario should obviously be clearly micro-founded and modelled. It nevertheless makes it possible to explain the now well documented evidence that SBTC has been the main explanation for growing inequality in the US (Morrison Paul and Siegel, 2001; Haskel and Slaughter, 2002; Autor et al, 2003).

Finally, by assuming a two-good model, we have made the North to jump from a two-good (in Phase 1) to a single good (in Phase 2) specialisation, and the South to jump from a two-good (before openness) to a single good (after openness), and back to a two-good (in Phase 3) production framework. Another possible extension would consist in assuming a continuum of goods so as to avoid such jumps and smooth the changes in both production and inequality. Hellier and Chusseau (2010) developed a North-South HOS model of this type with several northern countries. They showed that the growing size of the South increases inequality (or/and unemployment) in the North, this increase being larger in the unskilled labour intensive than in the skill intensive countries. This approach could be extended by inserting the technological differences and dynamics assumed before. Such a model would however be too complex to provide clear analytical results and its possible outcomes could only be determined by simulations.

Appendix 1

To simplify, the subscript indicating the country is omitted.

The total demand for l (Y_l^d) and h (Y_h^d) are $p_l Y_l^d = \beta I$ and $p_h Y_h^d = (1 - \beta) I$, with $I = w_L L + w_H H$ being the country's total income. Equalising supply (Y_l^s and Y_h^s) and demand on both markets yields:

$$p_l Y_l^s = \beta (w_L L + w_H H) \quad (\text{A1})$$

$$p_h Y_h^s = (1 - \beta) (w_L L + w_H H) \quad (\text{A2})$$

Because of the production functions, the demands for unskilled labour in each sector at the firm optimum are $L_l = \alpha_l p_l Y_l^s / w_L$ and $L_h = \alpha_h p_h Y_h^s / w_L$, and thereby at the country level:

$$L^d = L_l + L_h = \alpha_l p_l Y_l^s / w_L + \alpha_h p_h Y_h^s / w_L \quad (\text{A3})$$

Inserting (A1) and (A2) into (A3) and equalizing supply and demand on the markets for skilled and unskilled labour yields $L = (\beta \alpha_l + (1 - \beta) \alpha_h) w_L^{-1} (w_L L + w_H H)$. Hence, the full employment skill premium $w = w_H / w_L$ is:

$$w = \frac{1 - \alpha}{\alpha} \lambda \quad (\text{A4})$$

with $\lambda = L / H$ and $\alpha \equiv \beta \alpha_l - (1 - \beta) \alpha_h$.

Relation (A4) applies for each country being in autarky as well as at the world level when both the North and the South are inside the diversification cone. This determines relations (2)-(4) in the text.

Appendix 2

It is shown: 1) that (8) $\Rightarrow \underline{\sigma} > 0$, and 2) that $\underline{\sigma} < \bar{\sigma} \Leftrightarrow (8)$.

1) (8) $\Rightarrow \underline{\sigma} > 0$.

As $\underline{\sigma} = \frac{(\alpha - \alpha_h)\lambda}{\alpha_h(1-\alpha)\lambda^* - \alpha(1-\alpha_h)\lambda}$ and $\alpha > \alpha_h$, then $\underline{\sigma} > 0 \Leftrightarrow \frac{\lambda^*}{\lambda} > \frac{\alpha(1-\alpha_h)}{\alpha_h(1-\alpha)}$

Condition (8) is: $\frac{\lambda^*}{\lambda} \geq \frac{\alpha_l(1-\alpha_h)}{\alpha_h(1-\alpha_l)}$. (8) $\Rightarrow \frac{\lambda^*}{\lambda} > \frac{\alpha(1-\alpha_h)}{\alpha_h(1-\alpha)}$ because $\alpha_l > \alpha \Rightarrow \underline{\sigma} > 0$.

2) $\underline{\sigma} < \bar{\sigma} \Leftrightarrow (8)$

Inserting (9) and (10) into $\underline{\sigma} < \bar{\sigma}$ yields $\frac{(\alpha - \alpha_h)\bar{\lambda}}{\alpha_h(1-\alpha)\bar{\lambda}^* - \alpha(1-\alpha_h)\bar{\lambda}} < \frac{\alpha(1-\alpha_l)\bar{\lambda}^* - \alpha_l(1-\alpha)\bar{\lambda}}{(\alpha_l - \alpha)\bar{\lambda}^*}$,

which gives after rearranging (see technical note): $\frac{\lambda^*}{\lambda} > \frac{\alpha_l(1-\alpha_h)}{\alpha_h(1-\alpha_l)}$, i.e. (8).

Appendix 3

1) *The North*. During Phase 1, the North produces both goods. As the size of the South increases, the production of l by the South increases more than the world demand for l (since the income generated by the production of l in the South goes to the purchase of both h and l) and consequently the share of h in the North production increases, inducing an increase in the northern skill premium (a formal demonstration is available upon request). At the outset of Phase 1, the size of the South is minute and the northern skill premium is thus equal to the northern autarkic skill premium w_{aut} . At the end of Phase 1, the North produces good h only and its skill premium is thus equal to \tilde{w} . In phases 2 and 3, the North still produces h only and its skill premium remains at this value \tilde{w} .

2) *The South*. At the start of globalization, the South passes from a situation where it produced both goods in autarky with a skill premium w_{aut}^* to the situation in which it produces l only, which makes its skill premium become $\tilde{w}^* < w_{aut}^*$. This value is maintained throughout phases 1 and 2 since the South only produces good l during both these phases. In Phase 3, the South produces both goods with an increasing share of h in its production (since the production of h by the North increases less than the world production and income), which causes a permanent increase in the southern skill premium. As the size of the South continues to grow, the relative size of the North becomes increasingly small and the southern skill premium thus tends towards its autarkic value w_{aut}^* .

3) Finally, the skill premium is always higher in the South than in the North in the three phases because $\tilde{w} < \tilde{w}^*$.

Appendix 4

The purchasing power of a northern unskilled worker is $\omega_L = \frac{w_L}{p_l^\beta p_h^{1-\beta}}$.

1) In Phase 1, the North produces both goods. $p_h = \frac{w_L w^{1-\alpha_h}}{A_h (1-\alpha_h)^{1-\alpha_h} \alpha_h^{\alpha_h}}$ and

$p_l = \frac{w_L w^{1-\alpha_l}}{A_l (1-\alpha_l)^{1-\alpha_l} \alpha_l^{\alpha_l}}$ because of the Cobb-Douglas technology. Hence,

$\omega_L = \frac{\left(A_l (1-\alpha_l)^{1-\alpha_l} \alpha_l^{\alpha_l}\right)^\beta \left(A_h (1-\alpha_h)^{1-\alpha_h} \alpha_h^{\alpha_h}\right)^{1-\beta}}{w^{1-(\beta\alpha_l+(1-\beta)\alpha_h)}}$, and thus: $\partial\omega_L / \partial w < 0$. As Phase 1 is

characterised by an increase in w , then ω_L decreases.

2) Phase 2: Let us firstly show that p_h / p_l increases during Phase 2. As l is totally produced by the South and h is totally produced by the North, we have because of the demand functions: $\frac{p_h Y}{p_l Y^*} = \frac{1-\beta}{\beta} \Rightarrow \frac{p_h}{p_l} = \frac{1-\beta}{\beta} \frac{Y^*}{Y}$. As the size of the South increases more than that of the North, then the ratio Y^*/Y increases, which induces a rise in p_h / p_l .

As The North produces h only and from the Cobb-Douglas technology, we have $\frac{w_L}{p_h} = \frac{A_h \alpha_h}{\lambda^{1-\alpha_h}}$.

We can thus write: $\omega_L = \frac{w_L}{p_l^\beta p_h^{1-\beta}} = \frac{w_L}{p_h} (p_h / p_l)^\beta = \frac{A_h \alpha_h}{\lambda^{1-\alpha_h}} (p_h / p_l)^\beta$. As p_h / p_l increases during Phase 2, hence ω_L increases as well.

3) In Phase 3, both goods are produced by the South, the North produces h only and the skill premium increases in the South. As the North produce h only, we have (see above):

$\omega_L = \frac{A_h \alpha_h}{\lambda^{1-\alpha_h}} (p_h / p_l)^\beta$. As both goods are produced by the South, the Cobb-Douglas

technology entails: $\frac{p_h}{p_l} = \frac{A_l (1-\alpha_l)^{1-\alpha_l} \alpha_l^{\alpha_l}}{A_h (1-\alpha_h)^{1-\alpha_h} \alpha_h^{\alpha_h}} (w^*)^{\alpha_l - \alpha_h}$, which shows that $\frac{\partial(p_h / p_l)}{\partial w^*} > 0$. As

w^* increases in Phase 3, then p_h / p_l increases as well as ω_L .

Appendix 5

In sector i , the firms in the South adopt the northern technology $Y_i^* = A_i (L_i^*)^{\alpha_i} (H_i^*)^{1-\alpha_i}$ if the production cost is lower with this technology than with the traditional southern technology

$Y_i = A_i^* (L_i^*)^{\alpha_i^*} (H_i^*)^{1-\alpha_i^*}$. Because of the Cobb-Douglas production function, the unit cost of production (and unit price) in sector i when utilising the traditional southern technology is

$c_i^* = \frac{w_L^* (w^*)^{1-\alpha_i^*}}{A_i^* (1-\alpha_i^*)^{1-\alpha_i^*} \alpha_i^{*\alpha_i^*}}$, and since $w^* = \frac{1-\alpha_i^*}{\alpha_i^*} \lambda^*$: $c_i^* = \frac{w_L^* (\lambda^*)^{1-\alpha_i^*}}{A_i^* \alpha_i^*}$. Identically, the unit

cost of production in sector i when utilising the northern technology is $c_i^* = w_L^* (\lambda^*)^{1-\alpha_i} / A_i \alpha_i$.

Hence: $c_i^* \leq c_i^* \Leftrightarrow \frac{w_L^* (\lambda^*)^{1-\alpha_i}}{A_i \alpha_i} \leq \frac{w_L^* (\lambda^*)^{1-\alpha_i^*}}{A_i^* \alpha_i^*} \Leftrightarrow \lambda^* \leq \left(\frac{A_i \alpha_i}{A_i^* \alpha_i^*} \right)^{\frac{1}{\alpha_i^* - \alpha_i}}$.

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