Globalization and Labour Market Outcomes

23 – 24 June 2011 International Labour Office, Geneva

Wage inequality in trade-in-tasks models

Hugo Rojas-Romagosa

CESifo GmbH
Poschingerstr. 5
81679 Munich
Germany

Phone: +49 (0) 89 9224-1410
Fax: +49 (0) 89 9224-1409
E-mail: office@cesifo.de
Web: www.cesifo.de

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Hugo Rojas-Romagosa
CPB Netherlands Bureau for Economic Policy Analysis

7 February 2011

Abstract

Recent trade-in-tasks models suggest that relative low-skill wages (in rich high-skill abundant countries) may increase when low-skill tasks are offshored. However, using numerical simulations of these models we find that wage inequality is increasing for almost all endowment combinations (i.e. relative country sizes). The only exception is when the country is relatively small and offshoring levels are moderate or high. These results are robust to different offshoring cost parameters, factor production shares, elasticities of substitution, industry-specific offshoring costs, and different offshoring stages. Thus, the example portrayed in Grossman and Rossi-Hansberg (2008), where offshoring decreases wage inequality in an international price taking country with non-specialization in production, is indeed a special case. We also find, as in Markusen (2010) and Baldwin and Robert-Nicoud (2010), that offshoring can improve or decrease welfare in rich countries conditional on terms-of-trade effects. For relatively poor low-skill abundant countries, we find that offshoring is always welfare improving. However, the wage inequality effects of offshoring in these countries are conditional on the relative share of low-skill workers and the particular offshoring stage. Finally, we find that the GRH model can also account for wage polarization. This is done by expanding the model to have three skill-types and assuming that only medium-skill tasks are offshored. Moreover, when H-task offshoring is also possible, we find that overall wage inequality is decreasing with respect to the case when only M-task offshoring occurred.

Keywords: Offshoring, trade-in-tasks, wage inequality
JEL Classification: F11, F16, J31

1 Introduction

Traditional trade theory is based on final goods trade. However, the growing importance of trade in intermediate goods and services –associated with the fragmentation of production into different countries– is a well known empirical fact. Accordingly, several papers incorporated trade in intermediate goods in the Heckscher-Ohlin (HO) theoretical framework.[1] The latest contribution to this topic is the trade-in-tasks

[1] Among others, Dixit and Grossman (1982), Helpman (1984), Jones and Kierzkowski (1990), Deardorff (2001a,b), Venables (1999), Kohler (2004), Antràs *et al.* (2006), Markusen (2006), Markusen and Venables (2007).

model by Grossman and Rossi-Hansberg (2006, 2008), henceforth GRH, who introduce tasks directly into the HO framework.

The trade volumes and welfare implications of the GRH model and other recent trade-in-tasks models have been already evaluated by Baldwin and Robert-Nicoud (2010) and Markusen (2010). For instance, Markusen (2010) analyses offshoring as an expansion of trade at the extensive margin and finds that offshoring is welfare increasing when terms-of-trade are not deteriorating. When Baldwin and Robert-Nicoud (2010) use the insight that offshoring can be associated with "shadow migration", they find that the traditional HO theorems also apply to trade-in-tasks. Thus, offshoring produces similar gains-from-trade efficiency effects as in the traditional trade models. However, if offshoring is also increasing factor (wage) inequality, then a trade-off arises between efficiency and equity concerns.

The effect of offshoring on wage inequality was first empirically analyzed by Feenstra and Hanson (1999). They found that in the US in the period 1970-1990, 35% of wage inequality was due to skill-biased technological change and only 15% to offshoring. These results are in accordance to the general view that wage inequality has been strongly influenced by technology (i.e. computers), while globalization (including both traditional trade and offshoring) has had only a minor impact. In addition, Goos *et al.* (2010) find some evidence of offshoring explaining job polarization, although the impact is much smaller than the routinization effect first suggested by Autor *et al.* (2003).[2] Liu and Trefler (2008) examine the employment effects of service offshoring by US companies and find only small effects of service offshoring on wages. When they estimate the effects of inshoring, the net effect is positive. Thus, offshoring seems to have only a minor effect on wage inequality. However, Firpo *et al.* (2010) find that offshoring plays a substantial role in the changes in wage inequality. Moreover, the offshoring impact may change in the near future when high-skill jobs are expected to become more offshorable (cf. Blinder, 2006, 2009). This makes the distributional impact of offshoring an important and relevant topic.

In this paper we analyse the impact of offshoring on wage inequality using recent trade-in-tasks theoretical models. The complexity of the GRH model, however, does not allow for full analytical solutions with clear-cut predictions. The only exception is a special case where the relative wage of low-skill labour increases with offshoring for a small open economy and when there is non-specialization in production. This is an eye-catching result, but there are no wage inequality predictions when the model analyses endogenous international price determination and product specialization (i.e. corner solutions in production). Thus, there is a need to use numerical simulations to analyse more cases in which there are different model structures and parameters values.

The first objective of this paper, therefore, is to run numerical simulations using GAMS to evaluate the relative wage effects of the GRH model for different specifi-

[2] They argue that routine tasks are more easily substituted by computers, and this explains why ICT developments had a strong negative employment and wage effect on middle-skills routine jobs

cations. In every simulation we vary the relative factor endowments of the domestic (high-skill abundant) country and the general (scale) offshoring costs (or alternatively, we calibrate these general offshoring costs to yield the same offshoring levels for all endowment combinations). We check the robustness of the results employing four different offshoring cost schedules, three combinations of factor shares, three different elasticities of substitution between factors, and offshoring in one or both of the (low and high) skill types. .

We also survey recent empirical studies to obtain information about the possible shape of the functional forms and provide more structure to the GRH model. For example, Akcomak *et al.* (2010) use a rich task classification and find that tasks associated with low-skill workers are offshored more than those associated with high-skill workers. In addition, when they compare data from 1997 and 2005, they find that the task offshorability of high-skill workers has increased relatively more than for low-skill workers. Oldenski (2010) uses a routine and non-routine task classification and finds that routine tasks are more easily offshored than non-routine tasks. Using these insights, we construct two offshoring stages. In the first stage we run simulations where only low-skill tasks can be offshored. In the second offshoring stage we have sequential offshoring: both low and high-skill tasks are offshored, but L-tasks are offshored more than H-tasks.

Regarding the overall offshoring levels, Blinder (2009) and Blinder and Krueger (2009) estimate different offshorability indexes and find that around 25% of US jobs are potentially offshorable. Jensen and Kletzer (2010) focus on the services sector and estimate that up to 27% of services jobs are likely to be offshored.[3] Taking into account these findings, we calibrate our simulations to limit offshoring levels to 50% and in most cases the simulations are centered on 25%.

This rich set of model parameters, offshoring specifications and stages is then used to run the numerical simulations for both the one-country model (fixed international prices) and the two-country model (endogenous international prices). For the GRH one-country case, we replicate the analytical results in Grossman and Rossi-Hansberg (2008) and find that the relative low-skill wage is increasing (i.e. wage inequality is decreasing) when there is non-specialization in production. However, when there is specialization in production (the domestic country is producing only the high-skill intensive good), wage inequality is increasing, except at very high levels of low-skill task offshoring.

[3] One important distinction of these papers is that offshorability is defined on technical issues, but not on optimal managerial decisions. In this context Blinder (2009) and Blinder and Krueger (2009) do not find that routine work is more offshorable than other work, while Jensen and Kletzer (2010) find a positive correlation between skills and offshorability. However, that a task is technically and physically possible to offshore does not mean that it is efficient for the firm to offshore it. Following Costinot *et al.* (2010) the non-routine quality of many tasks can become an ex-post contractual friction that makes these tasks remain within the multinational headquarters. This applies in particular for high-skill non-routine tasks and consequently, even when high-skill tasks are technically possible to offshore the firm will not do it based on managerial decisions. This can explain why high-skill non-routine tasks appear to be offshorable ex-ante (as in Jensen and Kletzer, 2010), but are not actually offshored (Akcomak *et al.*, 2010; Oldenski, 2010).

When we run simulations for the GRH two-country model, we find that wage inequality is increasing for almost all relative country sizes. The only exception is when the domestic high-skill abundant country is relatively small and offshoring levels are moderate or high. These results are robust to different functional forms of the offshoring cost schedule, factor shares, elasticities of substitution between skills and if we vary the general offshoring costs or calibrate them to yield the same offshoring levels for all endowment combinations. Thus, the example portrayed in Grossman and Rossi-Hansberg (2008), where offshoring levels decrease wage inequality, is indeed a special case. In the majority of cases, wage inequality is increasing when the domestic high-skill abundant country offshores its low-skill tasks.

Moreover, we also test if the results are conditional on the assumption that offshoring costs are the same for both industries. Using estimations provided by Akcomak *et al.* (2010), we have that offshoring costs are industry-specific. In particular, low-skill intensive industries have a higher offshorability index than high-skill intensive industries. However, when we run simulations in a GRH model with industry-specific offshoring costs, we find the same results as before.

The main distinction between GRH and other models with intermediate inputs is that they use heterogeneous trade cost for intermediate inputs, instead of zero or uniform costs. Thus, we compare our results with the simplified version of the GRH model that is simulated by Markusen (2010) and with a version of the Markusen and Venables (2007) model. Using these models, the main pattern of generalized relative low-skill wage decrease is still present. However, the scope and the scale of the positive relative wage increases is bigger now, in particular for the Markusen-Venables model.

The former results concern the effects of offshoring on relatively high-skill abundant countries. When we look at the simulation outcomes for poor (relatively low-skill abundant) countries, we find different results. First, offshoring is always welfare improving in these countries. Second, the wage inequality effects of offshoring are conditional on the relative share of low-skill workers and on the offshoring stage. When only L-tasks are offshored and the ratio of low to high skill workers is large, wage inequality is decreasing. When L-workers are less abundant then wage inequality is increasing. On the other hand, when we have sequential offshoring (both L and H-tasks are offshored) then wage inequality is increasing for most endowment combinations.

The trade-in-tasks models are based on a HOS framework with two labour types. However, following Autor *et al.* (2006, 2008) recent wage inequality data for the US shows a polarization pattern where low and high skilled wages are increasing relative to medium skilled wages.[4] The second objective of this paper is to analyse if the GRH model can accommodate this wage polarization pattern. To do so, we need to expand the GRH model by introducing three skill-groups: low, medium and

[4]This pattern, however, has only been found for the US. There is no such evidence for the UK (Goos and Manning, 2007) nor Germany (Dustmann *et al.*, 2009; Antonczyk *et al.*, 2010).

high.[5] With this model extension we have a richer interplay between skill groups and offshoring stages, which provides several ways to assess the effects of offshoring on wage inequality.

We find that the GRH three-skill model can accommodate the recent empirical findings on wage polarization in the US when M-task offshoring is simulated. M-task offshoring is related to the routinization process described by Autor *et al.* (2003), where medium-skill workers perform routine tasks, which can be substituted by computers, but are also easier to offshore than low-skill manual tasks and personal services that require physical proximity (Blinder, 2006).

This version of the GRH trade-in-tasks model can also shed light on the expected effects of a new wave of globalization where high-skill tasks are increasingly offshored. In this case, we find that the wage polarization pattern is maintained, although the wages of lower skilled workers are increasing with respect to high-skill wages —when we compare M and H-task offshoring with the case when only M-task offshoring is possible. Thus, adding H-task offshoring to existing M-task offshoring results in wage inequality reductions.

The paper is organized as follows. Section 2 introduces the main features of the GRH model and the different offshoring cost schedules that are employed in the numerical simulations. Section 3 presents the general equilibrium equations and results for high-skill abundant countries in the one-country model, while Section 4 does the same for the two-country model with endogenous international prices. In Section 5 we show the simulation results for the (poor) low-skill abundant country. In Section 6 we introduce three labour types into the GRH model and identify the simulation outcomes that provide a wage polarization pattern. We summarize our results in Section 7.

2 The GRH trade-in-tasks model

The Grossman and Rossi-Hansberg paper introduces trade-in-tasks directly into a HO modelling framework. It does not deal explicitly with intermediate goods, but they are implicit in their analysis.[6] They assume the standard 2x2x2 conditions. Two countries c: domestic (d) and foreign (f), two sectors j: x and y, and two labour skill types s: low-skill (L) and high-skill (H).[7] Furthermore, there is a perfect mapping between skills and tasks: low-skill workers do L-tasks and high-skill workers H-tasks. They also assume that technologies (factor/task requirements) are the same in both countries.

[5] It is important to keep in mind that dividing workers into three –instead of two– skill groups makes the definition of each skill group different for each setting. In particular, the L and H-skill groups in the three-skill model are not the same as the L and H-skill groups in the two-skill model.

[6] This is made clear when we introduce the two-country equilibrium and the constraints to the balance of payments.

[7] Their framework has other production factors, but they do not affect the relative labour interactions. Thus, we use both labour types as the only production factors.

The main innovation of the GRH model is the introduction of a task offshoring technology. Firms can perform production tasks either at home or offshore them to the foreign country. Offshoring is preferred when one or both labour costs are cheaper in the foreign country. However, to offshore a task, the firm must pay not only the local wages but also the costs related to the monitoring and coordinating of remote workers.

In the GRH setting, $t_j(i)$ captures heterogeneous offshoring costs for the various tasks i in industry j. All tasks are indexed by $i \in [0,1]$, $t_j(i)$ is continuously differentiable, and ordered so that the costs of offshoring are non-decreasing: $\frac{\partial t_j(i)}{\partial i} \geq 0$. Finally, tasks have the same offshorability regardless of sector: $t_x(i) = t_y(i) = t(i)$. There is a general offshoring cost parameter β, that can be associated with communication and transportation improvements that proportionally reduce the cost of offshoring for all tasks.[8]

Combining these elements they obtain the offshoring zero-profit condition for low-skill tasks:

$$\beta t(i_L) p_{Lf} \geq p_{Ld} \tag{1}$$

where $t(i_L)$ is the low-skill task-specific offshoring cost schedule, p_{Lf} is the low-skill wage in the foreign country (f) and p_{Ld} is the domestic (d) low-skill wage.

With positive levels of offshoring, in equilibrium, equation (1) holds as an equality and I_L is the equilibrium marginal task for which there are equal costs in both locations.

Equivalently to the case of L-task offshoring, the equilibrium condition for H-task offshoring is given by:

$$\gamma z(i_H) p_{Hf} \geq p_{Hd} \tag{2}$$

where γ is the general offshoring cost of H-tasks, $z(i_H)$ is the offshoring cost function for H-tasks indexed by $i_H \in [0,1]$, p_{Hd} and p_{Hf} are the domestic and foreign H-skill wages, respectively. Accordingly, I_H is the value of i_H for which there is a H-task offshoring equilibrium.

We first employ a Cobb-Douglas production function: $j = AL^{\alpha_j} H^{1-\alpha_j}$ where A is a productivity parameter and α_j provides the factor shares in production of sector j. Then the unit-cost minimization problem of the firm, when there are offshoring possibilities in both L and H-tasks, results in the following unit-cost function:

$$c_j(p, I_L, I_H) \quad = \quad \frac{1}{A} \left[p_{Ld} \Omega_L(I_L) \right)^{\alpha_j} (p_{Hd} \Omega_H(I_H) \right]^{1-\alpha_j} \tag{3}$$

where $\Omega_s \leq 1$, are the cost-saving variables derived in GRH associated with L and H-task offshoring.

The factor demand, is then given by:

$$L_j \quad = \quad \frac{\partial c_j(\cdot)}{\partial p_{Ld}} = \frac{\alpha_j \Omega_L}{A} (p_{Ld} \Omega_L)^{\alpha_j - 1} (p_{Hd} \Omega_H)^{1-\alpha_j} \tag{4}$$

[8]Note that β is a parameter that affects *all* tasks equally. As pointed by Taylor (2006) shifts in β can only by achieved by very broad innovations, such as the Internet.

$$H_j = \frac{\partial c_j(\cdot)}{\partial p_{Hd}} = \frac{(1-\alpha_j)\Omega_H}{A}(p_{Ld}\Omega_L)^{\alpha_j}(p_{Hd}\Omega_H)^{-\alpha_j} \tag{5}$$

$$\tag{6}$$

Factor endowment equilibrium conditions are:

$$\frac{L}{(1-I_L)} = L_x x + L_y y \tag{7}$$

$$\frac{H}{(1-I_H)} = H_x x + H_y y \tag{8}$$

Finally, the consumption-expenditure function is given by:

$$e(p_j) = p_x^{\lambda} p_y^{1-\lambda} \tag{9}$$

where p_j are final goods prices and λ is the consumption share of good x in total consumption.

The main finding of the GRH model can be summarized by the following equation:

$$\widehat{w} = -\widehat{\Omega} + \mu_1 \widehat{p} + \mu_2 \frac{dI}{1-I} \tag{10}$$

where $\widehat{w}$ is the proportional change in the relative wage of low-skilled with respect to high-skill labour, and $\widehat{p}$ is the proportional change in relative final goods prices. The first term on the right-hand side of equation (10) is the productivity effect associated with offshoring, μ_1 is the common Stolper-Samuelson effect (i.e. relative wage changes are directly related to changes in final goods prices), while μ_2 is the labour-supply effect: offshoring increases the effective supply of labour in the domestic country.

In a small open economy $\mu_1 = 0$ and when there is non-specialization in production $\mu_2 = 0$. Thus, in this special case only the productivity effect is positive and we have the GRH eye-catching result that relative low-skill wages increase when L-task offshoring is positive.

3 GRH one-country model

We first assume that the domestic country (d) is a small open economy for which international price are exogenous. In addition, since we want to analyse the effects of offshoring on developed countries, we assume that the domestic country is high-skill labour abundant and exports the high-skill intensive good, which we assume is x, since we calibrate our numerical simulations using $\alpha_x < \alpha_y$. Throughout our setting welfare (w) is defined as the representative consumer's utility.

We solve the general equilibrium conditions as a mixed complementarity problem (MCP). The general equilibrium system is defined in Table 2 in the Appendix

It is important to note that in the MCP we include an offshoring payment equation:

$$\rho = p_{Ld} L \frac{I_L}{(1-I_L)} + p_{Hd} H \frac{I_H}{(1-I_H)} \tag{11}$$

where ρ is the payment to offshored labour. When $\rho = 0$ we have balanced trade in final goods: $m_x + m_y = 0$.[9] However, if there is offshoring activities then $\rho > 0$ and this produces a wedge between the initial final goods trade balance, such that $m_x + m_y = -\rho$. Then ρ can be associated with imported intermediate inputs, which in turn create that $-m_x > m_y$: exports of final goods must exceed imports in order to pay for the imported intermediate inputs ρ.

3.1 Model calibration and specific functional forms

3.1.1 Offshoring costs

To run numerical simulations on the GRH model we need to specify the offshoring cost function. In the GRH model $t(i)$ is only constrained to be non-decreasing in i. This leaves several modelling possibilities. We use a general offshoring cost function and apply four different parameter combinations, which yield four offshoring cost schedules. These parameters are calibrated using information we gather from the literature.

We begin with a general functional form that can allow both linear and non-linear offshoring costs:

$$t(i_L) = t_1 + t_2 i_L^{t_3} \tag{12}$$

Combining equations (1) and (12), and taken I_L to be the task level at which equation (1) holds as a strict equality, we have that the β^0 upper bound limit, at which there is no offshoring ($I_L = 0$) is:

$$\beta^0 = \frac{p_{Ld}}{p_{Lf} t_1} \tag{13}$$

Accordingly, a positive initial offshoring value ($I_L > 0$) requires that: $t_1 + t_2 I_L^{t_3} \geq \frac{p_{Ld}}{\beta p_{Lf}}$, then:

$$I_L = \left[\frac{1}{t_2} \left(\frac{p_{Ld}}{\beta p_{Lf}} - t_1 \right) \right]^{\frac{1}{t_3}} \tag{14}$$

Given that at the equilibrium offshoring task I_L, we have that the total offshoring costs $T(I_L) = \int_0^{I_L} \beta t(i_L) di_L$, we obtain:

$$T(I_L) = t_1 I_L + \frac{t_2 I_L^{t_3+1}}{t_3 + 1} \tag{15}$$

Finally, the offshoring cost-saving parameter (Ω_L) is:

$$\Omega = 1 - I_L + \frac{T(I_L)}{t(i_L)} \leq 1 \tag{16}$$

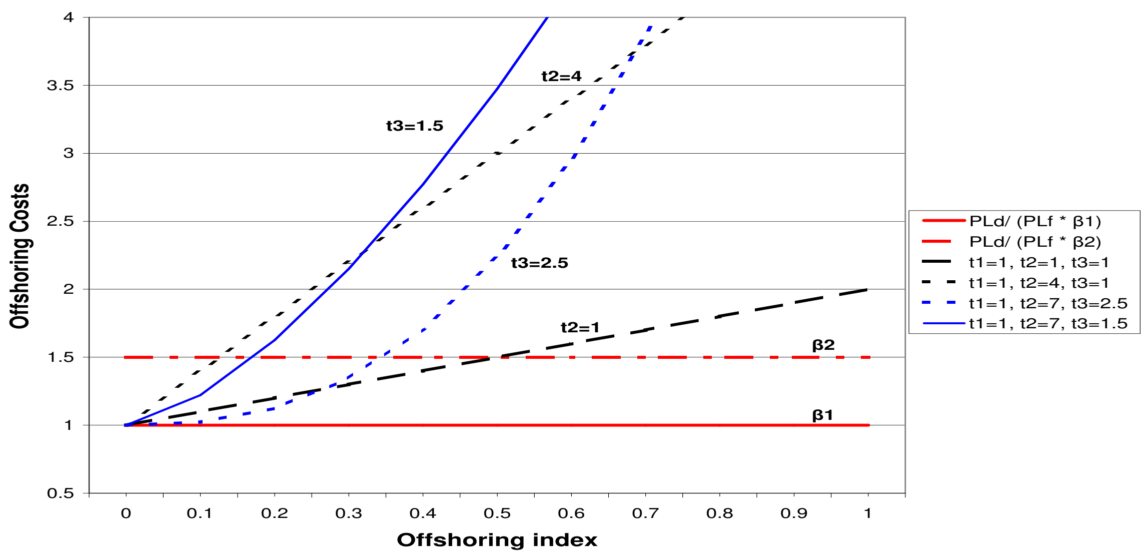
We use four different parameter combinations for the offshoring cost function $t(i_L)$. Furthermore, for each simulation we assume that $t(i_L)$ is fixed, while the β

[9] m_j is the import (export if negative) of good j

parameter is used as our main exogenous shock variable. We begin with two linear specifications where $t_3 = 1$. Then we calibrate $t_1 = 1$ so at $\beta = p_{Ld}/p_{Lf}$ we have no offshoring activity. Then we use two different values for $t_2 = \{1, 4\}$. This gives two cost schedules that provide relatively extreme outcomes. For $t_2 = 4$ offshoring slowly increases with reductions in β, while for $t_2 = 1$ we have that offshoring activity is relatively sensitive to changes in β (see Figure 1).

The second set of cost schedules is non-linear, with $t_1 = 1$, $t_2 = 7$ and $t_3 = \{1.5, 2.5\}$. With $t_3 = 1.5$ offshoring is relatively inelastic to β changes. With $t_3 = 2.5$ we have that offshoring is initially very sensitive for changes in β, but later on only large reductions in β increase offshoring. The four offshoring cost schedules are depicted in Figure 1.

Figure 1: Linear and non-linear offshoring cost schedules

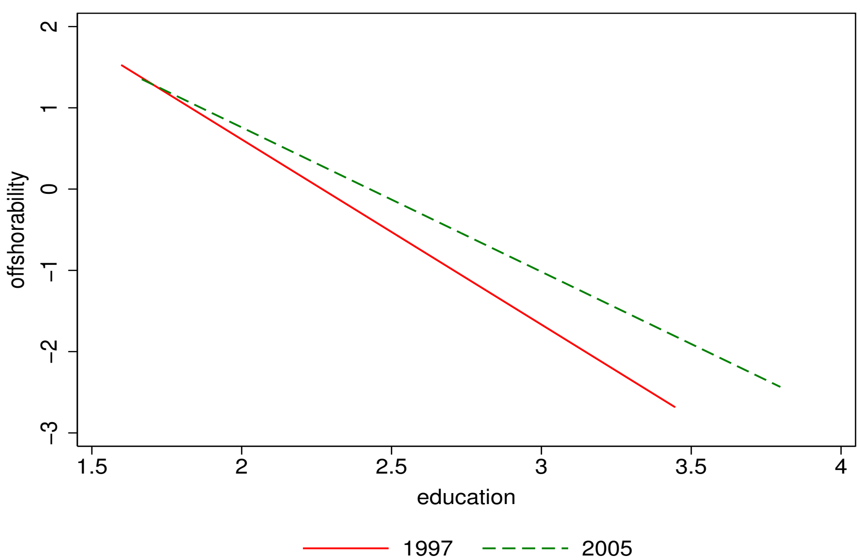


In Figure 1 we also depict two different β values (wage differentials are held constant in the figure). For β_1 we have that there is no offshoring for any cost schedule. When the general offshoring costs are decreased to β_2, the linear schedule with $t_2 = 1$ has the biggest offshoring levels (around 0.5), while the linear schedule with $t_2 = 4$ has the lowest offshoring levels (around 0.1).

Throughout this paper we assume that the offshoring cost function is the same for L and H-tasks: $t(i_L) = z(i_H)$. But the general offshoring parameters for both skill types are different: $\beta \neq \gamma$. Using these parameters we can change the offshoring levels for both types of workers.

However, we need more information about the offshoring costs of L and H-tasks. Intuitively one expects lower skilled jobs to be more easy to offshore, since these jobs are usually not critical to the organization of the firm. Surveying the empirical literature, we find support for more offshoring in L-tasks than in H-tasks. For instance, Akcomak *et al.* (2010) use a rich task classification and find that tasks associated with low-skill workers are more offshorable than those associated with high-skill workers.[10] Their results are presented in Figure 2. In addition, when they compare data from 1997 and 2005, they find that the task offshorability of high-skill workers has increased relatively more than for low-skill workers. In addition, Oldenski (2010) uses a routine and non-routine task classification and finds that routine tasks (associated with low-skill workers) are more easily offshored than non-routine tasks (associated with high-skill workers).

Figure 2: United Kingdom, offshorability index by industries ranked by average education levels, for 1997 and 2005, linear fit[a]



[a] Notes: The offshorability index is standardized with mean zero. Education levels are: 1: Primary; 2: Secondary incomplete; 3: Secondary complete; 4: Tertiary; 5: Post-graduate.

Using these results, we first assume in our simulations that only L-tasks are being offshored. We do this by assuming a γ value large enough to make H-task offshoring too costly. Later we have a sequential offshoring stage where both L and

[10] The offshorability index is constructed using detailed UK task data from the British Skills Survey (BSS, rounds 1997, 2001 and 2006). The occupation-task specific index is based on two measures: task-occupation wage differential and task-occupation connectivity. The former is based on the difference between occupation specific and task specific wages. The latter measures how a task is connected to other tasks in the same occupation. The offshorability index is an interaction of both measures. For instance, occupations with high task-occupation wage differentials and low task-occupation connectivity are more likely to be offshored. To build the industry-level offshorability index they use a weighted average of occupations using industry employment data.

H-tasks are offshored, but the offshoring costs of L-tasks are lower than for H-tasks (i.e. $\beta < \gamma$), which yields more offshoring of L-tasks than H-tasks ($I_L > I_H$).

3.2 Calibration and functional forms

Throughout all our numerical simulations we use a series of parameter values and functional forms. In each simulation we vary our main exogenous variable: the general offshoring cost parameter (β for L-skill tasks and γ for H-skill tasks), this results in higher offshoring levels. We also vary in each simulation the relative factor endowment (L/H) to check if the results are sensitive to relative factor abundance. However, L/H is calibrated to always ensure that the domestic country is exporting the H-intensive good and thus, can still be defined as the high-skill abundant (rich) country.

Then we have simulation-specific parameter values. First, we always use the four offshoring cost schedules described above. Second, we use three sets of factor shares of production: $\{\alpha_x = 0.2, \alpha_y = 0.7\}$, $\{\alpha_x = 0.3, \alpha_y = 0.6\}$, and $\{\alpha_x = 0.4, \alpha_y = 0.5\}$. In the initial simulations we use Cobb-Douglas production functions ($\sigma = 1$) and later we introduce CES functions with $\sigma > 1$. We simulate three different offshoring levels (b), which are associated with relative changes in the exogenous general offshoring costs parameter (β). Finally, we initially allow only L-task offshoring, and later we have sequential offshoring, where both labour types can be offshored but in a way that L-task offshoring always precedes and is larger than H-task offshoring (i.e. $I_L \geq I_H$).

We also assume that the domestic wage for each factor s is higher than the foreign wage, in particular $p_{sd}/p_{sf} = 1.5$. This wage differential is the main driving force in the offshoring process, only hindered by the level of the β parameter. However, note that the magnitude of this inter-country wage differential does not affect the results of our simulations. From equation (1), in equilibrium, we have that:

$$t(I_L) = \frac{1}{\beta^*} \frac{p_{Ld}}{p_{Lf}} \tag{17}$$

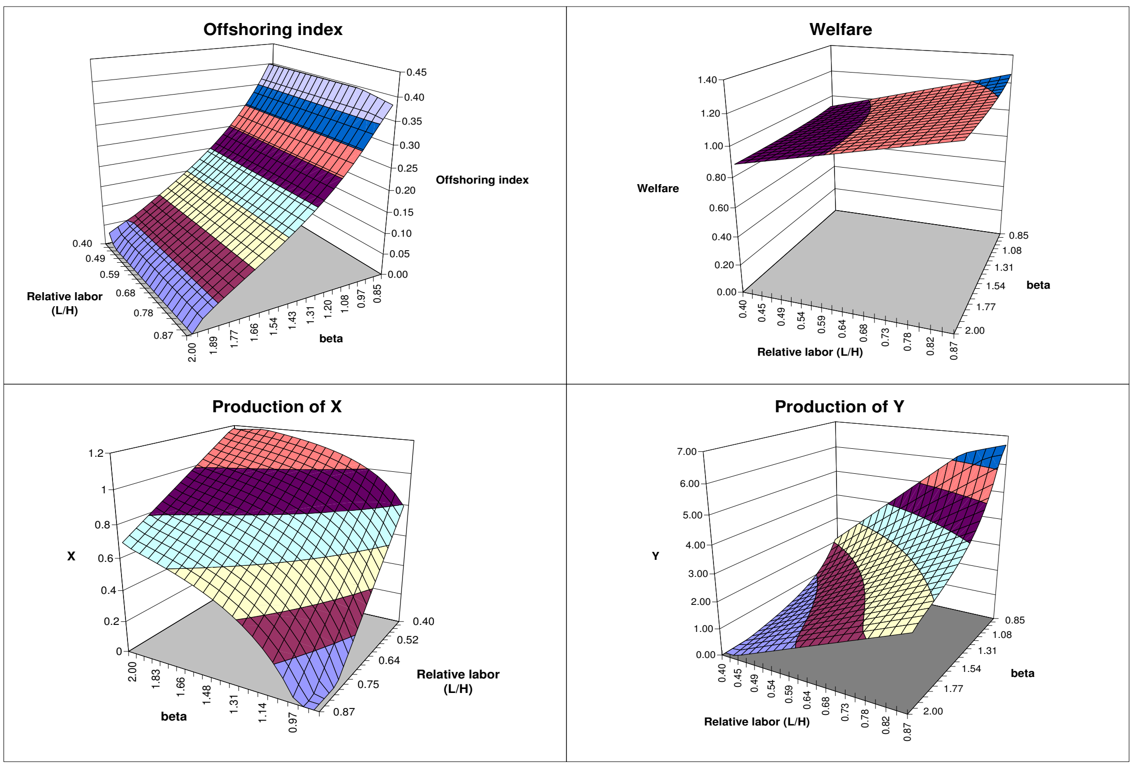
where β^* is the equilibrium value of the general offshoring cost parameter. Since the wage differential is fixed by the internationally determined prices of final goods, then any wage differential value can be accommodated by adjusting β^*.

3.3 Simulation results for the one-country model with only L-task offshoring

We run a series of simulations on the one-country model using the functional forms and parameter values described above. In Figure 3 we present the relative changes of the four variables of interest. In the x (or y-axis) offshoring costs are increasing along with decreases in β, and we are varying the relative labour abundance ratio L/H. In the z-axis we have the variations in the variables of interest. First, in the upper left graph of Figure 3 offshoring levels are steadily increasing with reductions in β.

Second, welfare is increasing with respect to L/H (this is expected since changes in L/H are simulated by increasing the endowment of low-skill labour in the domestic economy). More importantly, there is a slight increase in welfare when β decreases (and offshoring levels are rising). We also present changes in sectoral production. Note that increased offshoring (reductions in β) increases the production of the L-abundant good y and reduces x.

Figure 3: GRH model, changes in offshoring levels, welfare and production ($\alpha_x = 0.3$ and $\alpha_y = 0.6$), with non-linear offshoring costs ($t_1 = 1$, $t_2 = 7$ and $t_3 = 1.5$).[a]

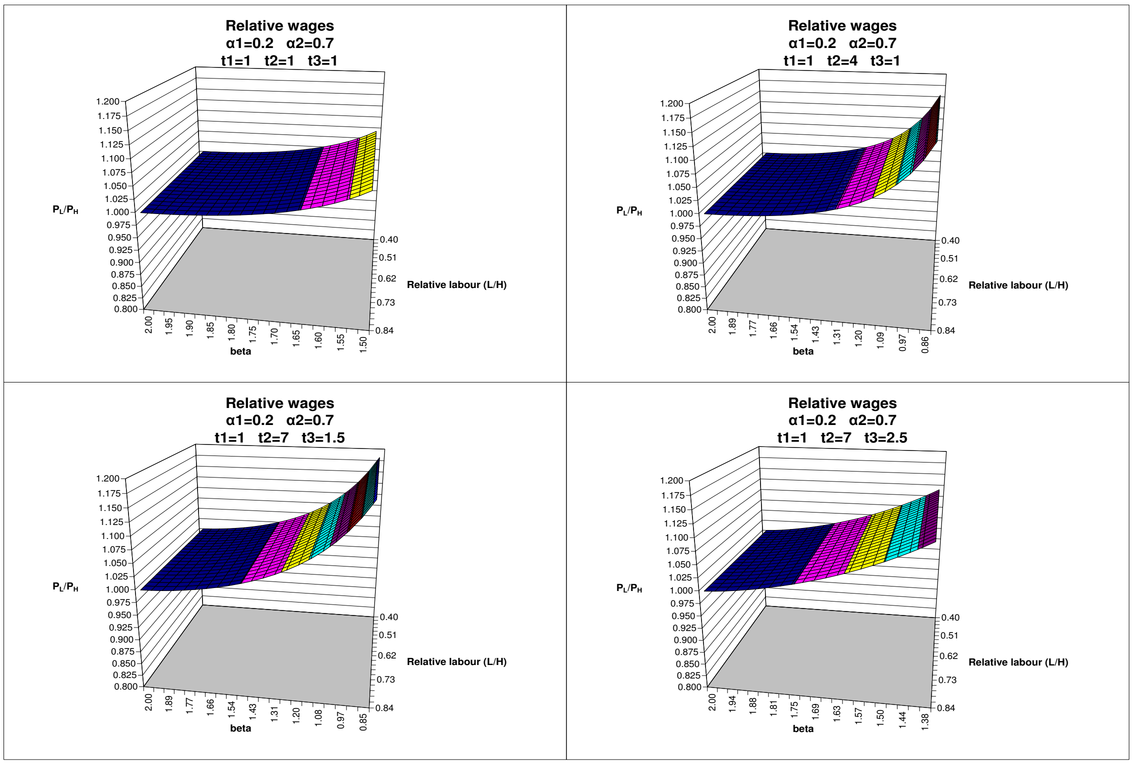


[a]Note: For presentation reasons the axes in the graph labelled "Production of X" is rotated.

This shift in the production patterns of the small-open economy yields an interesting result: offshoring reduces trade. Offshoring by a small-country erodes its endowment-abundancy differential with the rest of the world, since it now has more low-skill labour to produce its goods with, and consequently it produces relative more of the labour-abundant good and thus, reduces its imports of this good and trades less in final goods.

Figure 4 presents the changes in relative wages (p_{Ld}/p_{Hd}) when we only allow for L-task offshoring. In each of the graphs we have the four different offshoring costs. The linear functions are above and the non-linear below. In all cases relative low-skill wages are increasing.[11]

Figure 4: GRH model, changes in relative wages with only L-tasks offshoring, $\alpha_x = 0.2$ and $\alpha_y = 0.7$ and four different offshoring cost schedules



With this particular combination of factor shares (α values) and relative low-skill labour ratios, we only have cases where the domestic country has non-specialized production (i.e. there is positive production of both goods).

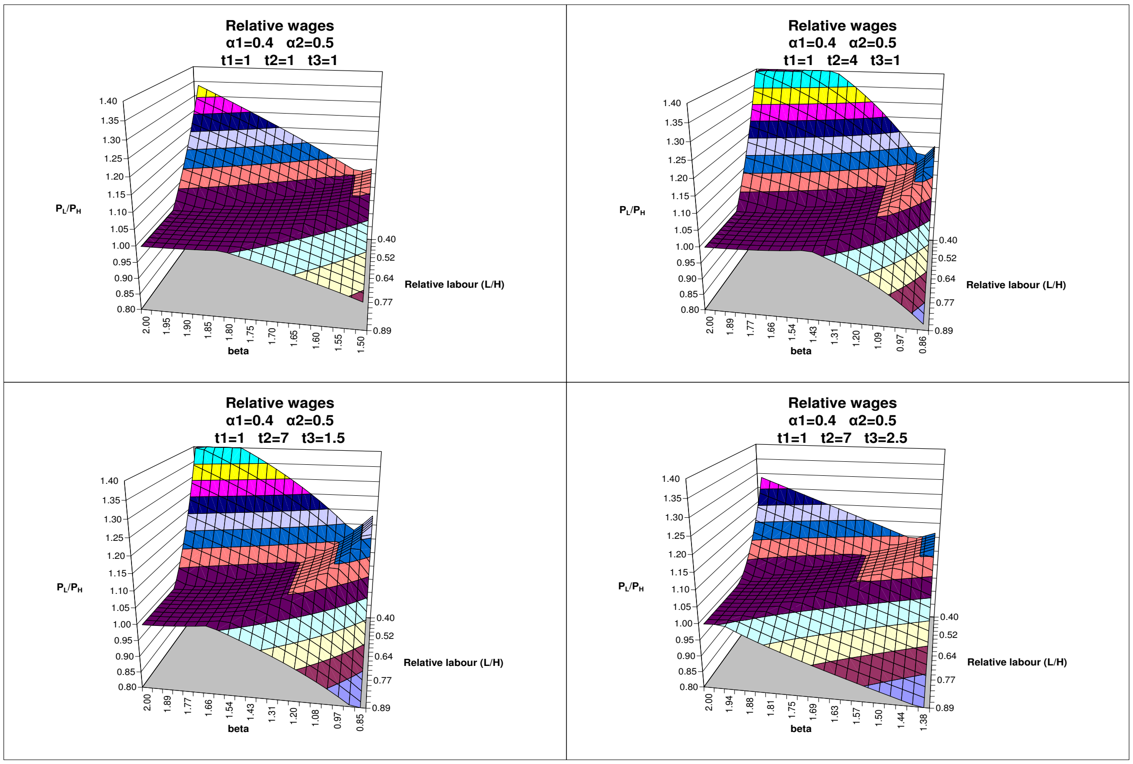
This is the special case in Grossman and Rossi-Hansberg (2008), where only the offshoring productivity effect (Ω_L) is present and we have the counter-intuitive result that increased offshoring of low-skill tasks results in a an increase in the relative wages of low-skill workers with respect to high-skill workers. Recall that this is the only general wage inequality result that can be derived analytically from the GRH model.

However, in Figure 5, with $\alpha_x = 0.4$ and $\alpha_y = 0.5$, the production functions of both goods are similar and the ranges of specialized production are increased.

[11]Note that we change β in a way that for all four functions the offshoring levels are similar (beginning with no offshoring and ending with levels around 0.45). This means that β has to decrease more for the inelastic cost schedules: linear with $t_2 = 4$ and non-linear with $t_3 = 2.5$. Then the wage increases are more pronounced for lower β values.

Hence, we obtain corner solutions where the domestic country is producing only one of the goods.

Figure 5: GRH model, changes in relative wages with L-tasks offshoring, $\alpha_x = 0.4$ and $\alpha_y = 0.5$ and four different offshoring cost schedules



The specialization region that we are interested in is the corner where relative labour (L/H) is low, and the domestic country is specialized in the production of the high-skill abundant good x. The other corner solution is of no interest to us, since it means that the domestic country is only producing the low-skill abundant good y and thus, it does not make sense to associate this specialization region with a high-skill labour abundant country.

In the case of specialization in the high-skill intensive good x, we have the GRH positive labour supply effect (from equation (10) $\mu_2 > 0$). In all the different simulations we conduct (with different factor shares α and offshoring cost schedules) we find that the labour supply effect is larger than the productivity effect and low-skill relative wages are decreasing for low and median offshoring levels. Only at very high offshoring levels (usually above 0.4) are relative wages increasing.

3.4 GRH one-country model with CES functions

The previous result in relative wages could be partially driven by the fact than with a Cobb-Douglas production function, the elasticity of substitution between low and high-skill labour (σ) is equal to one and equal between sectors. Thus, offshoring of L-tasks results in proportional changes in the low-skill demand in both sectors.

However, the empirical labour economics literature commonly uses an elasticity of 1.44 (Katz and Murphy, 1992; Caselli and Coleman, 2006) between both skill levels. Therefore, in order to evaluate relative wage changes with other values for σ, we include CES functions in our general equilibrium system. In addition, we also run simulations with an even higher value of $\sigma = 2$, to analyse how sensitive our results are to this parameter.

We then re-run our numerical simulations for the one-country model. We find that using different σ values does not alter the results in a significant matter (figures not shown). Since international prices fix domestic prices, then factor prices are only changing in response to the offshoring-cost savings effect provided by the reductions in Ω.

3.5 Allowing both low and high-skill task offshoring

We now allow for the offshoring of H-tasks as a sequential event to the initial offshoring of L-tasks (i.e. $I > I_H$). In these simulations we obtain similar results as before: low-skill relative wages are increasing when there is non-specialization in production (figures are not shown). However, the main difference is that now the increases in relative low-skill wages are smaller at high L-task offshoring levels. This is a result of having positive H-task offshoring only at high L-task offshoring levels and here, the positive productivity effect of high-skill workers (Ω_H) is increasing H wages.

In the cases with complete specialization in the production of x, we still find that the labour supply effect is stronger than the productivity effect for most offshoring levels.

3.6 Summary of the GRH one-country model simulations

In the one-country GRH model simulation we replicate numerically the counter-intuitive analytical result of Grossman and Rossi-Hansberg (2008): for a small open economy that produces both goods, with a positive level of offshoring, reductions in the general offshoring cost parameter (β) result in an increase if the relative wage of low-skill with respect to high-skill workers. For the case where the capital-abundant small country does not produce both goods, and is specialized in the capital-intensive good, we find that low-skill relative wage is decreasing for the initial phase of offshoring, and begins to increase only at very high levels of offshoring. When low-skill wages are decreasing in this case, we have that the labour-supply effect (μ_2) is larger than the productivity effect (Ω).

However, Grossman and Rossi-Hansberg (2008) call this one-country example as "pedagogic", since it is not plausible that β can decrease for one country while it remains constant for the rest of the world. Recall that β is a general offshoring parameter that reduces the cost to offshore all tasks, and thus, can only be related to broad technology advances (e.g. ICT technologies) that reduce at the same time the offshorability possibilities for all tasks. Therefore, the wage inequality implications of increased offshoring possibilities can only be fully analyzed with a two-country model where β is decreasing for all countries (or set of countries). We calibrate and numerically simulate such a model in the next section.

4 GRH two-country model

When we model both countries, we assume that only the high-skill abundant domestic country offshores labour to the other country. Thus, all our offshoring equations from the one-country MCP remain the same. This also implies that only the domestic country benefits from the cost-reducing variables Ω_L and Ω_H. International prices are now determined as part of the general equilibrium system, and they depend on the relative sizes of each country, the demand for final goods and trade volumes. When one or both skill types are producing offshored tasks for the domestic economy the foreign country has less available labour for their production. In return, it receives the offshoring payments ρ.

The new general equilibrium system (excluding the offshoring equations) is presented in Table 3 in the Appendix. We calibrate the productivity parameter A_c such that the domestic country is 50% more productive than the foreign country. Therefore, we have as in the one-country model that domestic wages are 50% larger than foreign wages.

4.1 GRH two-country simulations with only L-task offshoring

For the two-country simulations we simulate different divisions of the total endowments between both countries. We do keep the restriction that the domestic country is always relatively high-skill abundant with respect to the foreign country. We also restrict the endowment set such that each country has at least 10% of total endowments for one of the factors. The possible endowment combinations are shown in Table 1. There are 35 different combinations where the domestic country is relatively high-skill abundant and we use four different general offshoring costs (β) values. This gives 140 simulations for each model specification (i.e. different offshoring cost schedules, and α and σ values). Using this total endowment sharing mechanism we obtain different relative country sizes and thus, different effects on trade volumes and terms-of-trade effects.

As before, we reduce the value of β to increase offshoring activity in L-tasks. However, since we are also changing relative endowments, factor prices are different for each endowment point and thus, β_0 —the value of β for which there is no

Table 1: Endowment sets, "+" denotes the low and high-skill endowments for which the domestic country is relatively high-skill abundant and for which we run the numerical simulations

	H-skill share of total								
L-skill share of total	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
0.9	0	0	0	0	0	0	0	0	0
0.8	+	0	0	0	0	0	0	0	0
0.7	+	+	0	0	0	0	0	0	0
0.6	+	+	+	0	0	0	0	0	0
0.5	+	+	+	+	0	0	0	0	0
0.4	+	+	+	+	+	0	0	0	0
0.3	+	+	+	+	+	+	0	0	0
0.2	+	+	+	+	+	+	+	0	0
0.1	+	+	+	+	+	+	+	+	0

offshoring— is also changing. Therefore, we first need to find the marginal β_0 no-offshoring equilibrium value for each endowment point and from this value, we apply relative reductions. We run four different simulations, in which the general offshoring costs are changing. For $b = 0$ we have no offshoring activities, with $b = 1$, β_0 is reduced by 10%, in $b = 2$ by 20% and in $b = 3$ by 30%.

In Figure 6 we have the changes in L-task offshoring when different reductions are applied to β. The left-hand side graphs use the non-linear offshoring cost schedule $t_1 = 1, t_2 = 7, t_3 = 1.5$, while the right-hand side graphs uses: $t_1 = 1, t_2 = 7, t_3 = 2.5$. As shown in this figure, and following the cost schedule shape presented in Figure 4, when t_3 is higher, then costs are lower. Thus, for equal reductions in β, the left-hand side graphs with higher offshoring costs, have lower offshoring activity increases. We have chosen these values so they represent extreme situations. With $t_3 = 2.5$ offshoring is very sensitive to β changes, and with $t_3 = 1.5$ offshoring changes slowly with β reductions. We also observe that offshoring is more sensitive to endowment sets that are closer to the diagonal of equal relative endowments between countries. The closer to this diagonal, offshoring is higher, and it is reduced as endowments go toward the extreme where the domestic country has almost all the total high-skill workers and relatively few low-skill workers.

Figure 7 presents the results for relative wages (P_{Ld}/P_{Hd}). Again, we use the two non-linear offshoring cost schedules, and the decreases in β are larger as we move from the top to the bottom rows in the figure. In the following graphs, we use the no-offshoring scenario ($b = 0$) as our baseline, and we graph the results of each b scenario with respect to $b = 0$. In other words, we compare how reductions in the general offshoring cost β affects each variable in relation with the case where there is no offshoring.

Figure 6: GRH two-country model, changes in L-task offshoring with $\alpha_x = 0.2$ and $\alpha_y = 0.7$, non-linear offshoring costs (left hand side $t_3 = 1.5$, right hand side $t_3 = 2.5$) at three different β levels ($b = 1, 2, 3$)

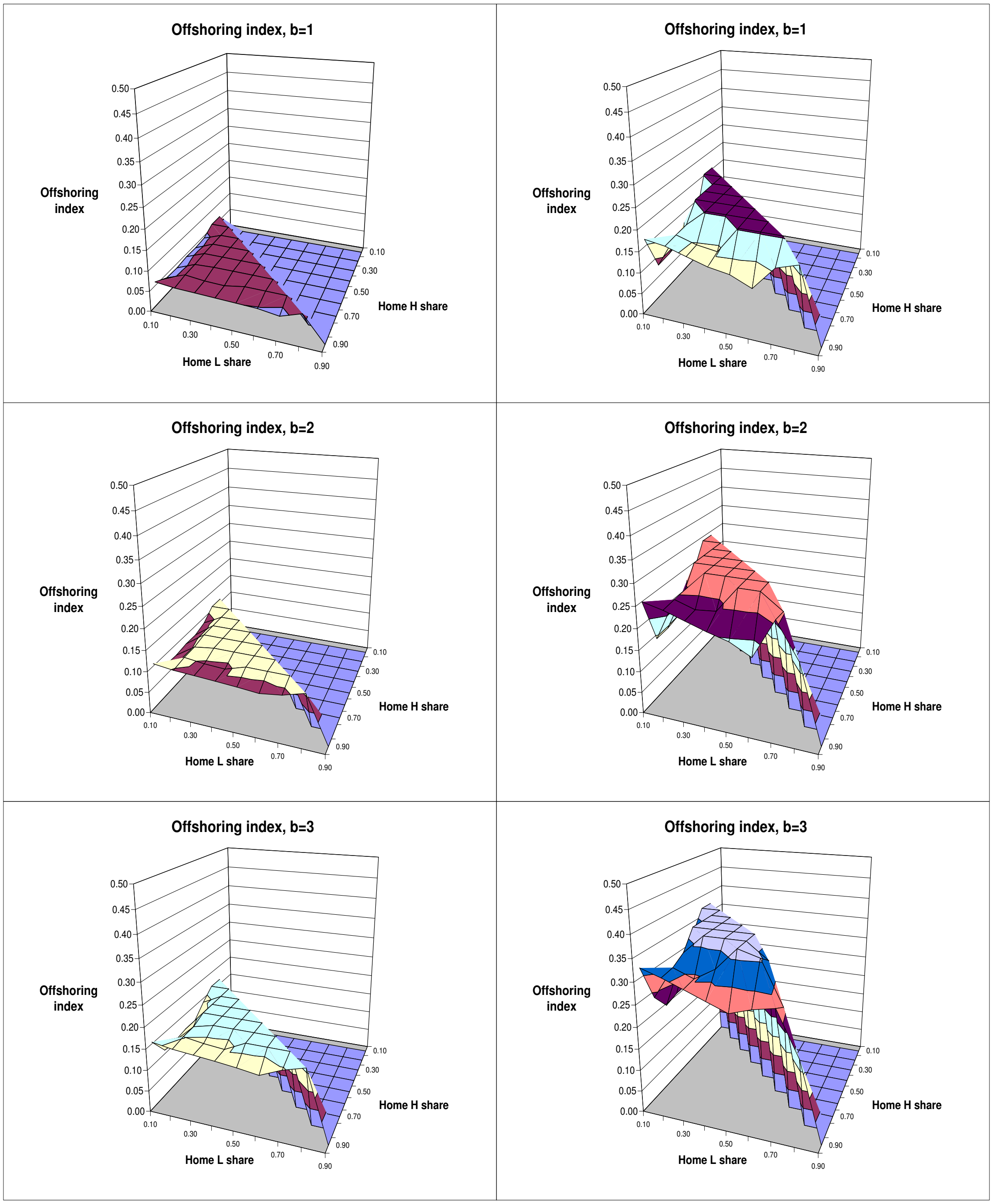
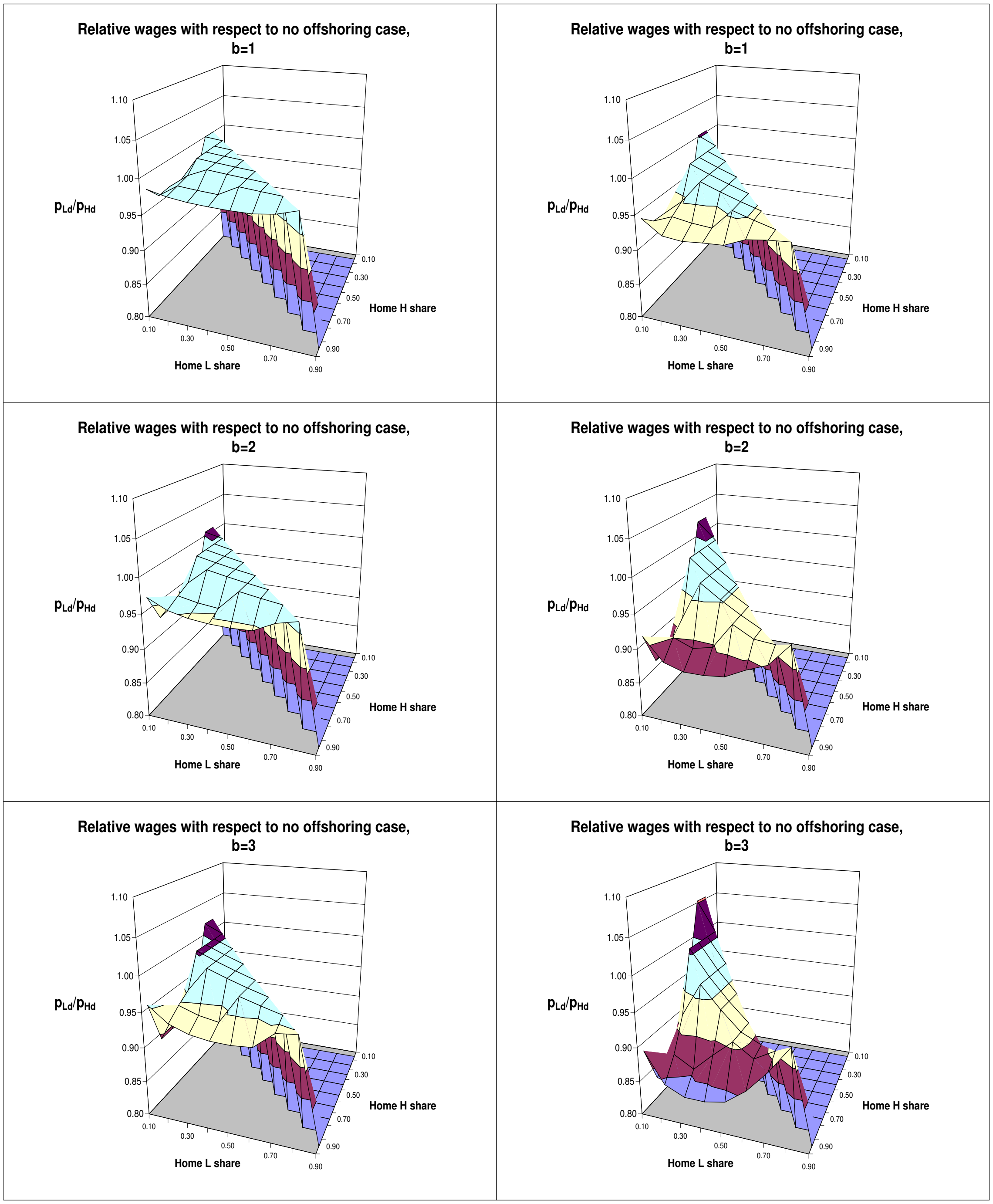


Figure 7: GRH two-country model, changes in relative wages with respect to no-offshoring scenario with $\alpha_x = 0.2$ and $\alpha_y = 0.7$, non-linear offshoring costs (left hand side $t_3 = 1.5$, right hand side $t_3 = 2.5$) at three different β levels ($b = 1, 2, 3$)



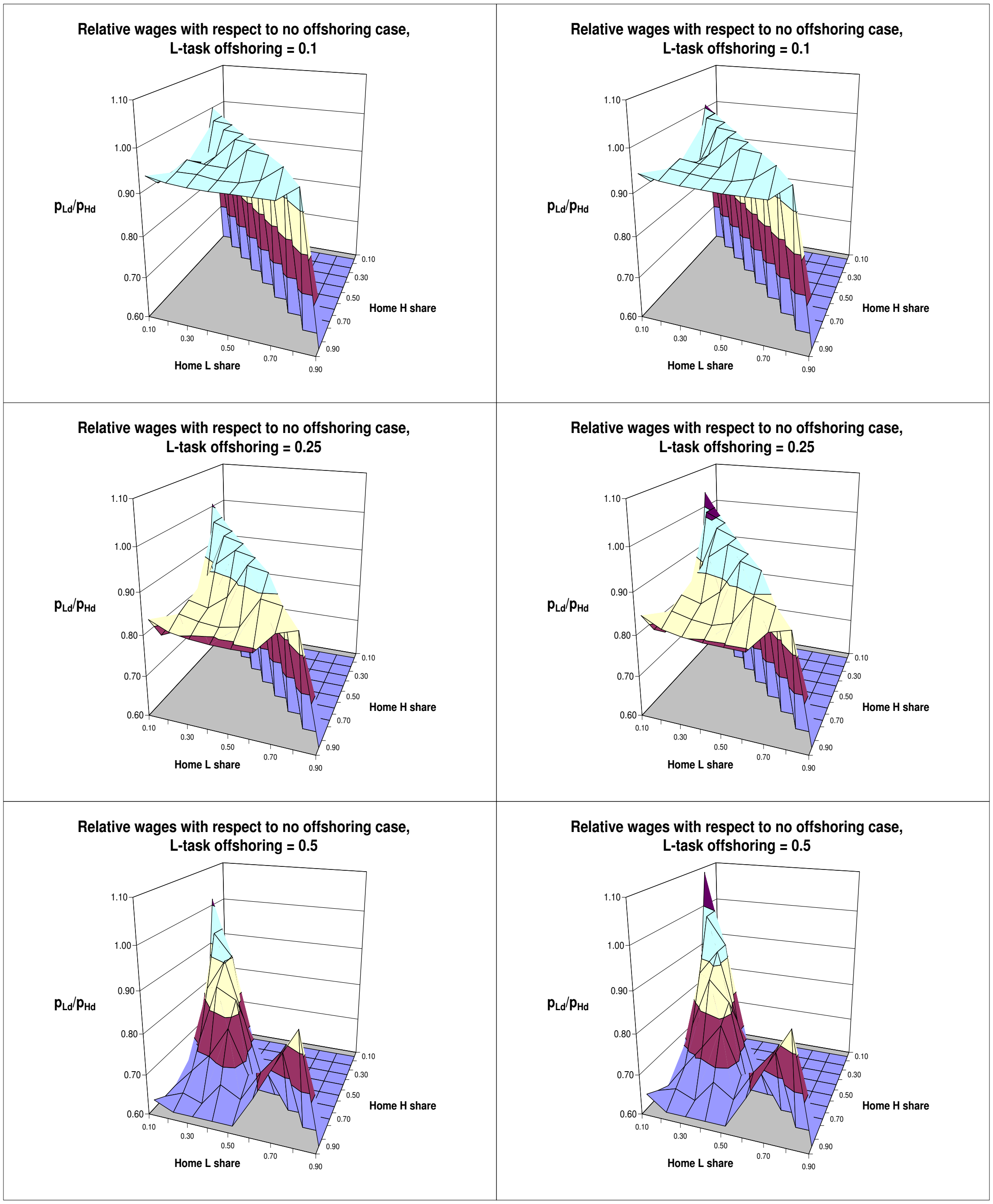
We observe that the relative low-skill wage is decreasing (the value is below one, and thus, lower than the wage level with no-offshoring) for almost all endowment combinations and the decline becomes more pronounced as β decreases and we have higher offshoring levels. The only exception is for a few endowment sets where the domestic country is relatively very small (with fewer than 20% of total endowments for both factors). Only for these particular endowment combinations is there a relative increase in low-skill wages; and the increase is higher and slightly expands to include other endowment sets with low β values (higher L-task offshoring levels). The general pattern of decreasing relative low-skill wages is repeated for both the linear and non-linear offshoring costs, and for different combinations of α.

In the Appendix we present the results for welfare (Figure 15) and terms-of-trade (Figure 16). Figure 15 shows the welfare effects for each value of b (amounts of β decreases). Welfare is almost unchanged (it is equal to one) for most endowment sets, and there is only a welfare reduction in the area where the domestic country has relatively low endowments of L (less than 20% of the total). This welfare changes are mainly driven by the changes in the terms-of-trade (TOT). In Figure 16 we observe an almost identical pattern of change in terms-of-trade, as in welfare. These results are very similar to those in Markusen (2010) where the welfare changes of increased offshoring are strongly correlated with terms-of-trade effects. The results for offshoring levels, welfare and TOT are also similar when we use the two linear offshoring cost schedules and when we use other factor share parameters (α). These results are not presented here. These results are in strong contrast to the relative low-skill wage increases presented in the GRH one-country model.

Since we have different L-task offshoring levels with different relative changes in β, we run another group of simulations where we calibrate the changes in β to obtain the same changes in L-task offshoring for all the endowment combinations.[12] With this set of simulations we control for the effect of offshoring levels on relative wages. The results are shown in Figure 8. Again, we find that the relative wage of low-skill workers is decreasing for almost all endowment sets, except for very small high-skill abundant countries. This result holds for different α values, and for the other three offshoring cost schedules.

[12] This implies a additional set of loops where β is changed in small steps until the desired offshoring level is attained. In practical terms these loops can run until more than 700 times, increasing greatly the number of simulations that need to be run.

Figure 8: GRH two-country model, relative wage changes with respect to no-offshoring scenario, with $\alpha_x = 0.3$ and $\alpha_y = 0.6$, linear offshoring costs (left hand side $t_2 = 1$, right hand side $t_2 = 4$) at three different L-task offshoring levels



4.2 GRH two-country model with CES functions

Again we reformulate the general equilibrium equations to include CES instead of Cobb-Douglas functions. We then take two additional values of σ, the commonly used elasticity value in the literature: $\sigma = 1.44$ and $\sigma = 2$. We assume that this elasticity is the same in both sectors. When we re-run our simulations using both values we observe the same pattern of relative wage changes (figures not shown). Relative low-skill wages are diminishing with respect to the no-offshoring scenario, for all endowment sets with the exception of some cases where the domestic country has a relatively small share of total endowments. When we compare other variables, such as welfare, terms-of-trade and production changes, we observe the same patterns as when using Cobb-Douglas production functions.

4.3 Simulations with industry-specific offshoring cost functions

In the GRH model it is assumed that the offshoring cost function is the same for each industry: $t_x(i) = t_y(i)$. The assumption is based on lack of evidence on the contrary. However, using the offshorability indexes developed in Akcomak *et al.* (2010) in Figure 9 we plot industries ranked by their average education levels (as a proxy for skill levels).[13] The figure suggests that low-skill intensive industries have higher offshorability possibilities than high-skill intensive industries. We also run simple regressions of the offshorability index on the education levels and find a significant negative relationship between both. In terms of the GRH model this means that: $t_x(i) > t_y(i)$. It is more difficult to offshore tasks in the high-skill intensive industry x.[14]

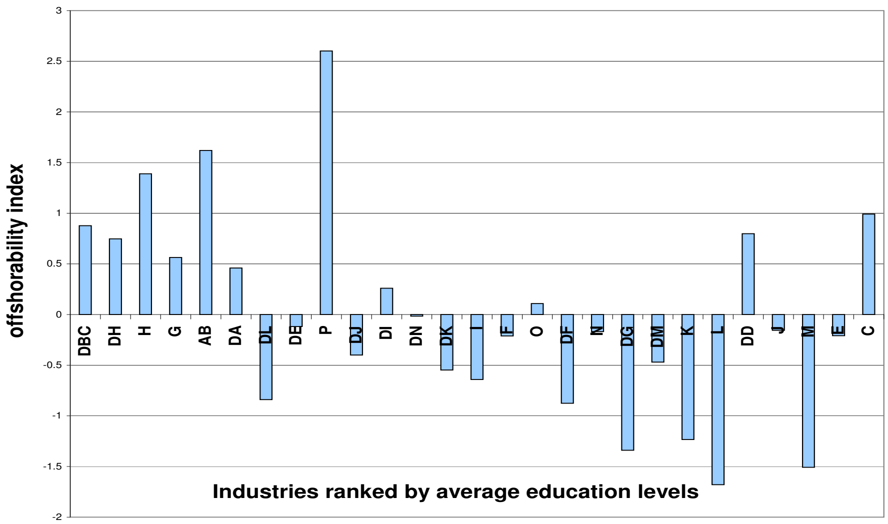
Using the insights from Figure 9 we run a new round of simulations where each industry has different offshoring cost functions with the restriction that $t_x(i) > t_y(i)$. In Figure 10 we show the relative wage results for a specific non-linear function. We observe that the pattern of decreasing relative low-skill wages (with respect to the no-offshoring case) is qualitatively the same. For most of the endowment combinations wage inequality is increasing, while it only decreases for small-country (relatively low total endowment) combinations. However, with differentiated offshoring cost functions by industry the scope of wage inequality decreases is larger. This pattern is robust to both linear and non-linear functions, using different parameter values in differences between both industries.

The intuition behind these results, is that when the low-skill intensive industry can more easily offshore tasks than the high-skill intensive industry, then the overall offshoring levels are increased (with respect to the case where offshoring costs are equally high in both sectors) and thus, the wage inequality results are also exacerbated. When the domestic country is relatively small, then wage inequality decreases

[13] The offshorability index is the same as in Figure 2.

[14] Using US data Ottaviano *et al.* (2010) also find industry-level differences when they estimate a proxy for offshoring costs.

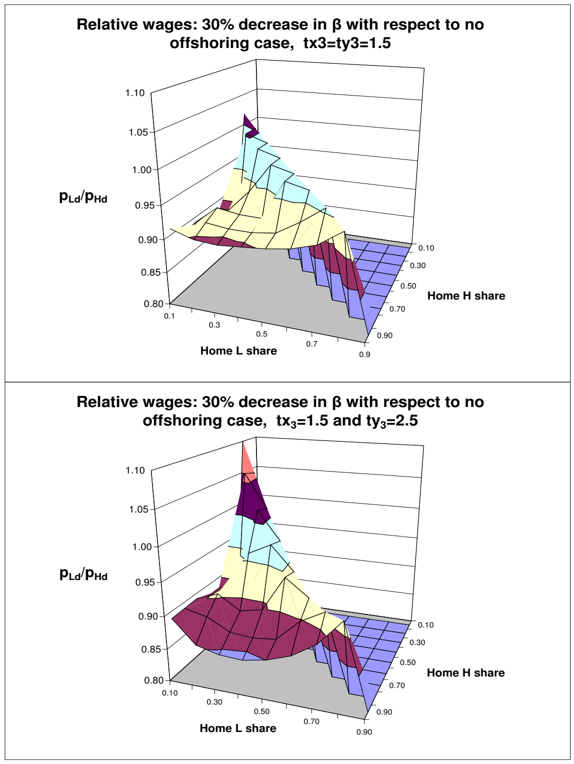
Figure 9: United Kingdom, offshorability index for 27 industry division, with industries ranked by average education levels, average values from 1997, 2000 and 2006 data[a]



[a] Notes: The offshorability index is standardized with mean zero. Education levels are: 1: Primary; 2: Secondary incomplete; 3: Secondary complete; 4: Tertiary; 5: Post-graduate. Industry codes: AB: Agriculture & fishing; C: Mining; DA: Food, beverages & tobacco; DBC: Textiles & leather; DD: Wood & wood products; DE: Paper, publishing & printing; DF: Coke & refined petroleum; DG: Chemicals; DH: Rubber & plastic; DI: Other non-metallic minerals; DJ: Basic metals; DK: Machinery & equipment nec; DL: Electrical & optical; DM: Transport equipment; DN: Manufacturing nec E: Electricity, gas & water; F: Construction; G: Wholesale & retail trade; H: Hotels & restaurants; I: Transport, storage & communication J: Financial intermediation; K: Real estate, renting & business activities; L: Public administration & defence; M: Education N: Health and social work; O: Other community, social & personal services; P: Private households with employed persons.
Source: Akcomak *et al.* (2010).

more (relative to the case of equal offshoring costs by industry), and the increases in wage inequality for other endowment combinations are also larger.

Figure 10: GRH two-country model, relative wage changes with respect to no-offshoring scenario, with different non-linear offshoring cost schedules by industry (top $tx_3 = ty_3 = 1.5$, bottom $tx_3 = 1.5; ty_3 = 2.5$) with 30% reductions in β

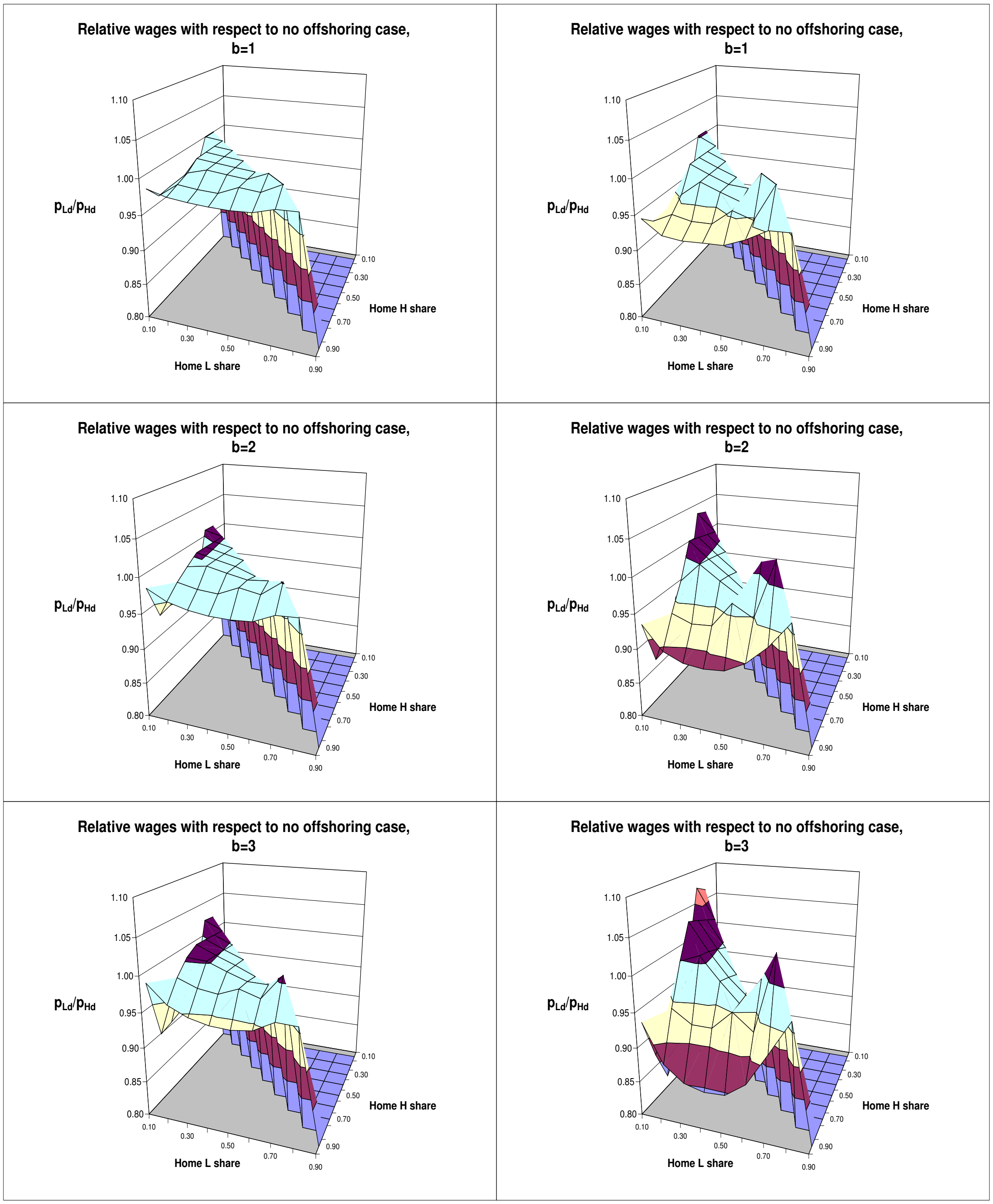


4.4 Simulations with both L-task and H-task offshoring

Next we allow for sequential H-task offshoring, i.e. offshoring of H-tasks follows with a lag the offshoring of low-skill tasks. This is simulated by setting four stages (g) of γ decreases. For $g = (0, 1)$ γ is not changing, but it is decreased by 2% for $g = 2$ and by 5% for $g = 3$. Although these decreases seem relatively small, they translate into H-task offshoring of around 10% and 15% respectively. Thus, when β is reduced to increase L-task offshoring, γ will be higher and H-task offshoring will be zero or lower than L-task offshoring.

From Figure 11 we observe that when we allow both types of offshoring, we have similar qualitative results as before, but now we have a new set of endowments where relative low-skill wages are increasing at high offshoring levels. These results are the same when we use non-linear offshoring costs and different α values. Otherwise, the welfare and terms-of-trade effects are also qualitatively unchanged (results not shown).

Figure 11: GRH two-country model, relative wage changes with respect to no-offshoring scenario, allowing for both L and H-task offshoring with $\alpha_x = 0.2$ and $\alpha_y = 0.7$, non-linear offshoring costs (left hand side $t_3 = 1.5$, right hand side $t_3 = 2.5$) at three different β levels ($b = 1, 2, 3$)



4.5 Summary of the GRH two-country model simulations

When we introduce two-countries and thus changes in the relative price of final goods (which in this context correspond to terms-of-trade, since the GRH model assumes that trade-in-tasks does not incur transport costs) we obtain a completely different pattern of relative wage changes than for the one-country model. In the two-country model increased offshoring results in a decrease in the relative low-skill wage for almost all endowment combinations (i.e. different relative country sizes). The only exception is when the domestic (high-skill abundant) country is very small and offshoring levels are moderate or high.

The intuition for these results comes directly from equation 10, which summarizes the wage effects of the GRH model. When we move away from the small open economy (one-country) model, relative final good prices change and the Stolper-Samuelson effect is at work ($\mu_1 \neq 0$). Moreover, with the broad number of endowment combinations we simulate there are many cases for which the domestic country produces only one good and then the labour-supply effect is also in place ($\mu_2 \neq 0$). Since we obtain overall reductions in the relative low-skill wage these two effects are negative and larger than the offshoring productivity effect ($\widehat{\Omega}$).

The results are robust to the four different offshoring cost schedules we employ, to different factor shares (α values) and with different elasticities of substitution between factors ($\sigma = 1$ in Cobb-Douglas case and $\sigma = 1.44, 2$ in the CES case). It also holds for either relative changes in the general offshoring costs (β) or when β is calibrated to produce the same offshoring levels for all endowment sets. The same wage inequality pattern is found when we allow industry-specific offshoring costs functions.

In the case where we allow the sequential offshoring of H-tasks (i.e. following the initial offshoring of L-tasks) we find very similar results. Only that now we also have an increase in the relative low-skill wage for a wider number of endowment combinations.

Markusen (2010) constructed a simplified version of the GRH model, where there are two factor-specific tasks in the production function, and one of each factor-tasks can be offshored if their trade costs are low enough. This is a discreet version of the GRH model, where offshoring costs are just trade costs on the factor-specific task that can be traded. In the Appendix we show the results for this modified GRH version and also for the Markusen and Venables (2007) model. As explained there, the results are qualitatively the same as for the GRH two-country model.

5 GRH two-country model results for low-skill abundant countries

Until now we have only analyzed the effects for relatively high-skill abundant countries (i.e. developed countries). However, using the GRH two-country model we also obtain results for developing countries (the foreign relatively low-skill abundant country in our framework). Note that since we are using the same model, we have the same offshoring levels (Figure 6) and terms-of-trade effects (the inverse of Figure 16 in the Appendix) as for the H-abundant country.

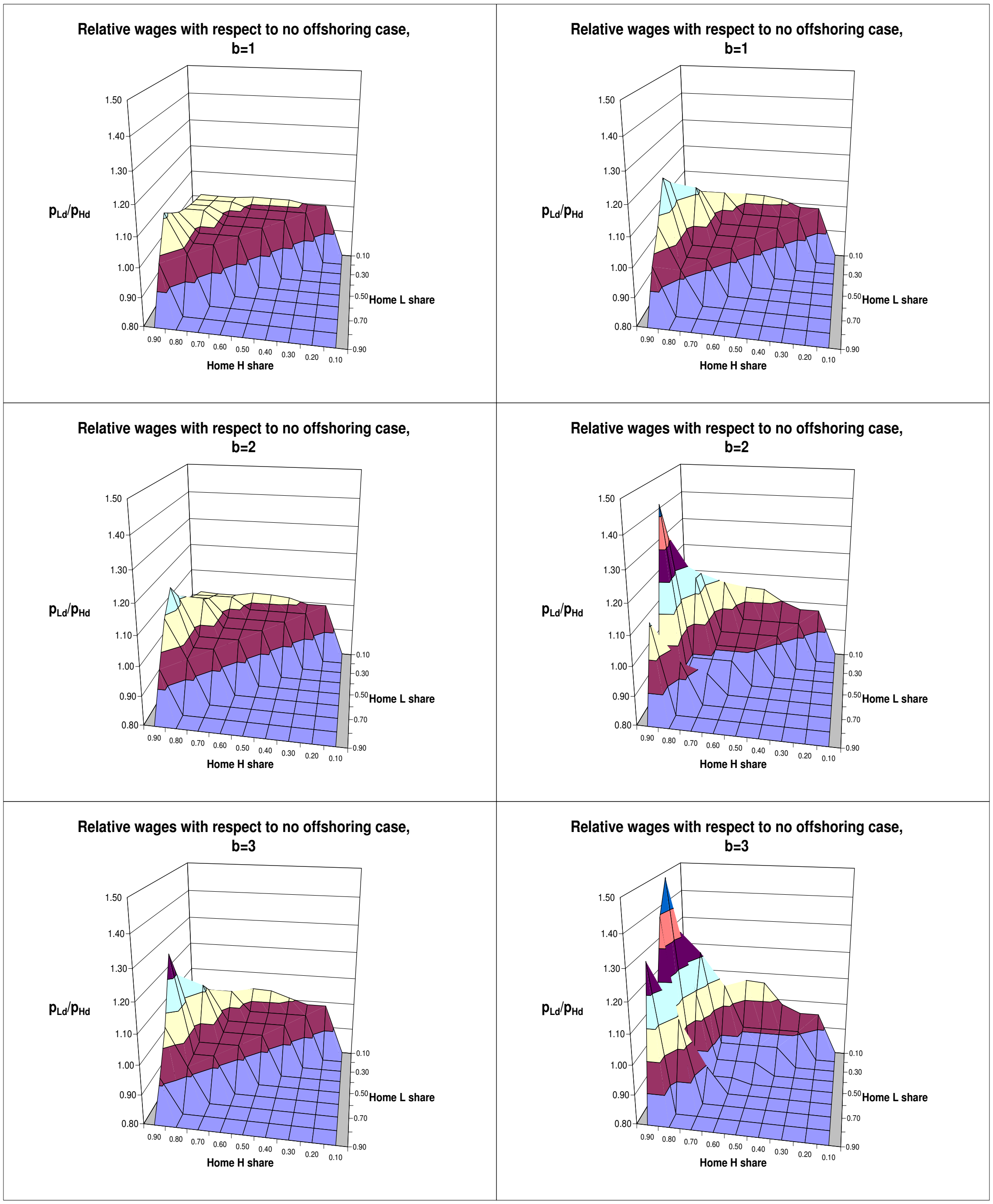
First, we analyse wage inequality and we find that in the L-abundant country wage inequality is increasing in endowment combinations along the symmetric factor abundance axis (see Figure 12). The endowment combinations close to the axis are associated with countries that have similar factor ratios, and thus, do not have large income differences. On the other hand, wage inequality is decreasing for countries that have relatively large shares of low-skill workers. In particular, relative low-skill wages are increasing the most for foreign countries with 50% of the world's share of low-skill workers, but only 10% of high-skill workers.

Moreover, for low-skill abundant countries we find that offshoring is always welfare improving. Figure 17 in the Appendix shows that welfare is increasing in L-task offshoring for all endowment combinations. The biggest welfare gains, however, are for relatively small countries. Thus, unlike the welfare changes for the rich H-abundant country, welfare in L-abundant countries is not primarily driven by terms-of-trade effects.

Next, we allow both L and H-tasks to be offshored in a sequential way, such that $I_L > I_H$. Welfare is again improving for all endowment combinations, and it is robust to different specifications of the model. However, relative low-skill wages are now decreased for most relative country sizes (see Figure 13).

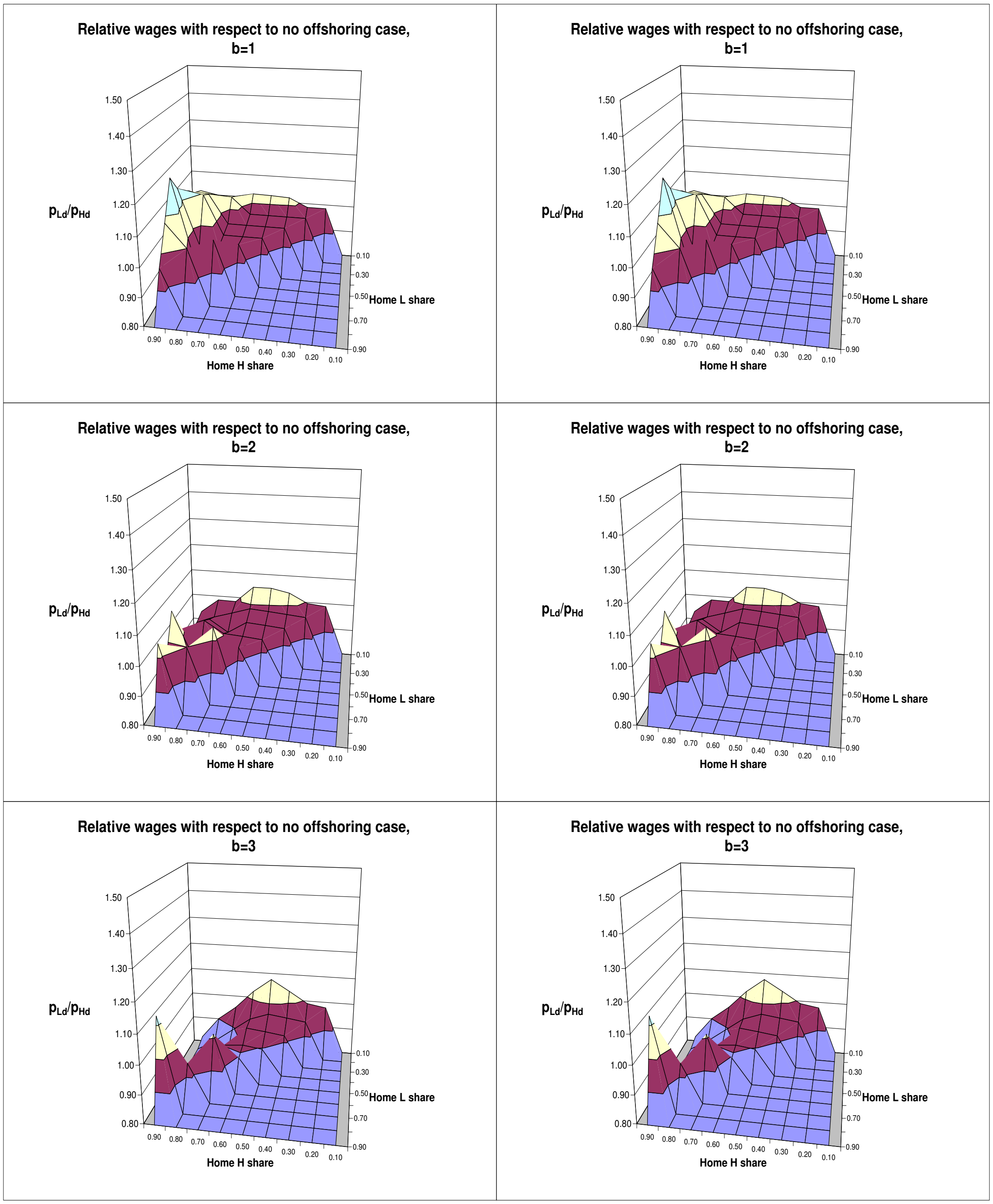
To sum up the case for the relatively low-skill (poor) abundant country, we have that offshoring is always welfare improving. The wage inequality effects of offshoring, however, are conditional on the relative share of low-skill workers and on the offshoring stage. Wage inequality is decreasing when L-tasks are offshored and the ratio of low to high skill workers is large. Conversely, it is increasing when L-workers are less abundant. On the other hand, when we have sequential offshoring (both L and H-tasks are offshored) then wage inequality is increasing for most endowment combinations. These results are robust to the four offshoring cost schedules, and different α and σ values.

Figure 12: GRH two-country model, L-abundant country, changes in relative wages with respect to no-offshoring scenario with $\alpha_x = 0.2$ and $\alpha_y = 0.7$, non-linear offshoring costs (left hand side $t_3 = 1.5$, right hand side $t_3 = 2.5$) at three different β levels $(b = 1, 2, 3)^a$



[a] Note: the L and H shares refer to the home (H-abundant) countries, so the shares for the foreign (L-abundant) country are one minus the home shares.

Figure 13: GRH two-country model, L-abundant country, changes in relative wages with respect to no-offshoring scenario allowing for both L and H-task offshoring with $\alpha_x = 0.2$ and $\alpha_y = 0.7$, non-linear offshoring costs (left hand side $t_3 = 1.5$, right hand side $t_3 = 2.5$) at three different β levels $(b = 1, 2, 3)$[a]



[a]Note: the L and H shares refer to the home (H-abundant) countries, so the shares for the foreign (L-abundant) country are one minus the home shares.

6 GRH with three skill types

In this section we introduce a variant of the GRH where we include a third skill type: medium-skilled workers (M). With three factors we can analyse richer wage inequality interactions, including wage polarization: the increase of L-skill and H-skill wages with respect to M-skill wages. We can also simulate different offshoring stages, where the offshoring of skill-specific tasks is more complex.

First, we start with a simple Cobb-Douglas function:

$$j_{ss} = A_h L^{\alpha_j} M^{\phi_j} H^{1-\alpha_j-\phi_j} \tag{18}$$

where ϕ_j is the production share of the M-skill workers. We also use a CES specification with three factors, where we use elasticities of substitution between skills larger than one (i.e. 1.44 and 2).[15]

Equivalently to the case of L and H-task offshoring, the equilibrium condition for M-task offshoring is given by:

$$\mu v(i_M) p_{Mf} \geq p_{Md} \tag{19}$$

where μ is the general offshoring cost of M-tasks, $v(i_M)$ is the offshoring cost function for M-tasks indexed by $i_M \in [0, 1]$. This offshoring equilibrium condition results in the productivity (M-labour cost saving) parameter Ω_M.

We include these new M-task offshoring equations into the general equilibrium MCP system and adjust the cost schedules and include the labour market clearing conditions for M-skill workers. Again, we use the four specific cost schedules of section 3.1.1. However, since we have now three different endowment combinations, the numerical simulations are based on a variation of the endowment combinations in Table 1. To maintain a two-dimension endowment set, we assume that the share of total medium-skill workers is an arithmetic average of the low and high-skill share of the domestic country.

6.1 Only M-task offshoring

First we simulate increases in offshoring assuming that only M-tasks are offshorable. Such a view is consistent with the routinization process suggested by Autor *et al.* (2003). In this setting, skill levels and tasks are matched in the following way: low-skill workers perform manual tasks and/or tasks that need physical proximity, medium-skill workers do routine tasks and high-skill workers do non-routine tasks. Using this classification one can assume that only routine M-tasks are offshorable.

Following this insights of Blinder (2006) that offshorability is directly related to physical proximity, then we assume that it is not possible to offshore L-tasks.[16] For

[15] To the best of our knowledge, there are no empirical estimates that can inform about the substitution possibilities between three different labour types for developed countries. Thus, there are no estimates of the elasticity of substitution, nor of the desirability of nested functions. Given the large amount of combinations that nesting gives, we do not analyse nested functions.

[16] This is also closely related to the setting used in Ottaviano *et al.* (2010) where manually low-skill tasks are performed domestically (in their US case) by immigrant workers.

the case of H-task, we can use the findings by Costinot *et al.* (2010) and Oldenski (2010) that H-skill non-routine tasks are harder to offshore than routine tasks.

The simulation results when only M-tasks are offshored are presented in the first column in Figure 14. The first row shows the relative low-skill wage with respect to high-skill wage, the second row shows the low-skill relative to the medium-skill wage and the last row the medium-skill relative to the high-skill wage. The first column has only M-task offshoring and it presents a wage polarization pattern: medium-skill wages are losing relatively to both low and high-skill wages.

Thus, in order to reconcile the recent empirical findings of wage polarization for the US with the GRH model, we just need three-skill types and only M-task offshoring.

These results are qualitatively similar when we use different factor shares of production (α and ϕ values), when we have higher elasticities of substitution in a CES production function, and when using our four different offshoring costs schedules. The welfare implications, however, are very similar to those of the 2x2x2 GRH model: welfare is directly related to terms-of-trade effects, and is usually increasing (results not shown).

6.2 Both M and H-task offshoring

This GRH model expansion with three skill-types can also shed light on the expected effects of a new wave of globalization where high-skill tasks are increasingly offshored. This follows the insights by Blinder (2006, 2009).

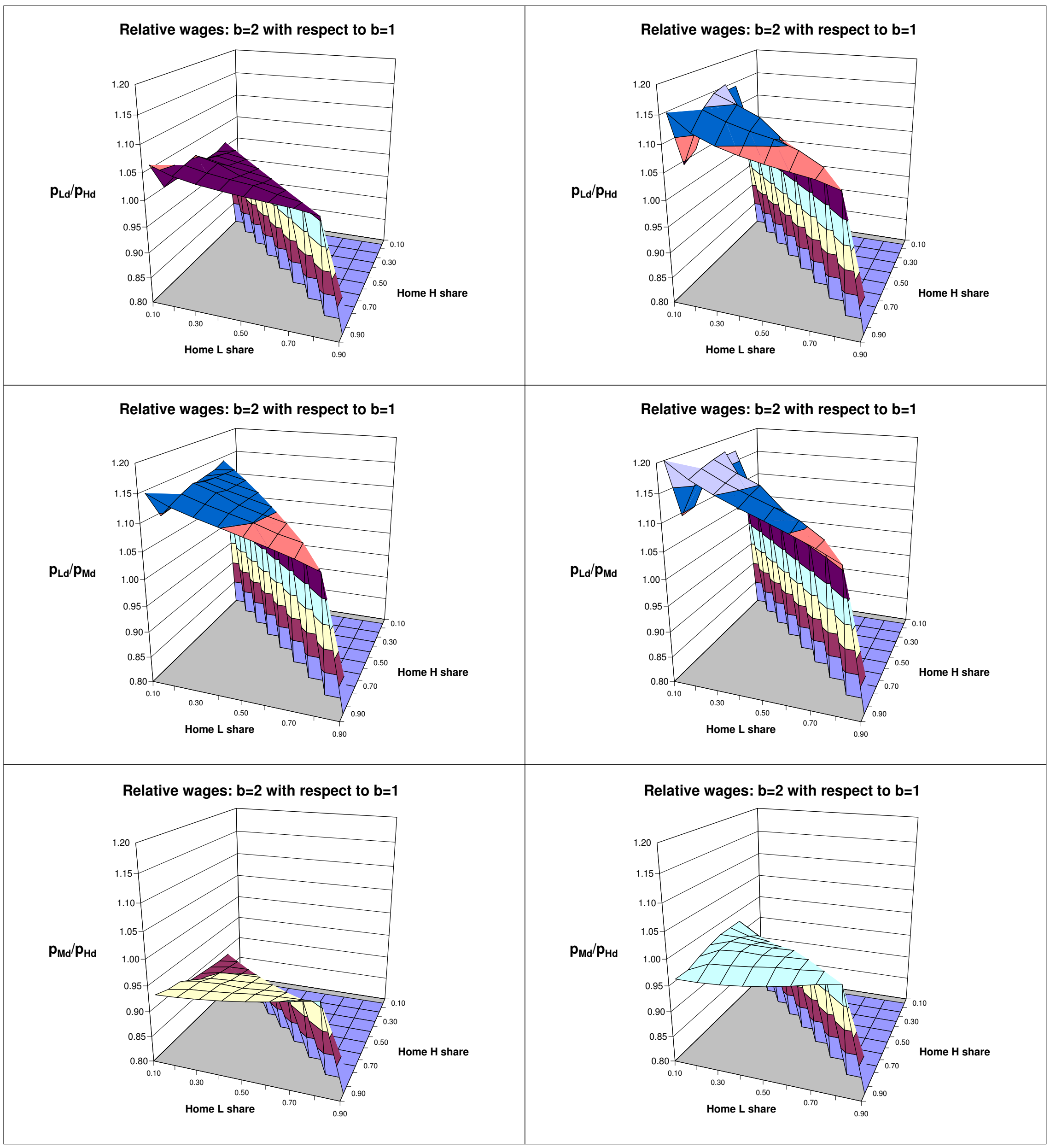
The simulation results are presented in the second column of Figure 14. Here we have both M and H-task offshoring, but we assume that M-tasks have higher levels of offshoring than H-tasks.

In this case we find the same polarization pattern. However, we also observe that the lower skills are gaining relative to the higher skill wages. For instance, low-skill wages are experiencing a significant increase with respect to high-skill wages. This increase is much bigger than in the first column (with only M-task offshoring). The low-skill wages are also increasing relative to the medium-skill wages when compared to the first column with only M-task offshoring. Finally, the relative decrease of medium-skill wages with respect to high-skill wages is less pronounced now. This means than overall wage inequality is decreasing when H-task offshoring is possible after M-task offshoring has already taken place.

Therefore, although the M-task offshoring produces the wage polarization pattern found for the US, if we allow for both M and H-task offshoring we find that overall wage inequality is decreasing. Using the insights of the GRH three-skill model we expect that a new globalization wave that includes H-tasks offshoring that follows existing M-task offshoring could reduce wage inequality.

Finally, for illustrative reasons we also run simulations using an alternative offshoring schedule were all three skill types are offshored. The results are presented in the Appendix. In this setting we only find wage polarization in very special cases.

Figure 14: GRH model with three factors, changes in relative wages with a truncated offshoring stage, with non-linear offshoring costs ($t_3 = 1.5$). Rows indicate different relative wage combinations. The first column has only M-task offshoring and the second both M and H-task offshoring compared to no-offshoring case (with $I_M > I_H$, and $\alpha_x = 0.2$, $\phi_x = 0.3$, $\alpha_y = 0.5$, $\phi_y = 0.3$)



7 Summary

Offshoring is often associated with declining wages and lost jobs. In their influential paper Grossman and Rossi-Hansberg (2008) suggest that this may not be always so. They find a special case where low-skill workers in a small but rich (high-skill abundant) country benefit when low-skill tasks are being offshored. However, using numerical simulations of their model to include a richer set of specifications, we find that relative low-skill wages are decreasing in most cases. In this respect, their special case is indeed very special.

In particular, the distributional effects of offshoring are related to country size. For small rich countries offshoring is increasing welfare and reducing wage inequality (the special GRH case), however, for medium and big-size countries we find that wage inequality is increasing, while welfare can also decrease when terms-of-trade are deteriorating. These results are robust to different parameters in the model (factor shares, elasticities of substitution between factors), and offshoring specifications (different offshoring levels, offshoring costs functional forms and offshoring stages).

When looking at low-skill abundant (poor) countries the results are somehow different. Offshoring is associated with welfare increases in all our numerical simulations –i.e. using different model parameters and with different offshoring specifications. However, the distributional effects of offshoring are dependent on the low to high-skill endowment ratio and if only L-tasks or both L and H-tasks are being offshored.

Finally, we also run simulations on a variant of the GRH model with three different skill types. We find that this trade-in-task version can reconcile offshoring with a wage polarization pattern when we have only M-task offshoring. We also find wage polarization when both M and H-tasks are offshored. However, in this last case the possibility to offshore high-skill tasks results in an overall wage inequality decrease when compared to the case where only M-tasks are offshored.

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8 Appendix

8.1 MCP equations

8.1.1 GRH one-country model

The MCP formulation means that when an equation holds as an equality the complementary variable is positive, and if the equation holds as a strict inequality then the complementary variable is zero.[17]

Table 2: General equilibrium system for the one-country GRH model

Inequality	Equation	Comp. var.
L-tasks offshoring eq.1	$\beta p_{lf} t(I_L) = p_{Ld}$	I_L
L-tasks offshoring eq.2	$t(I_L) = t_1 + t_2 I_L^{t_3}$	$t(I_L)$
L-tasks offshoring eq.3	$T(I_L) = t_1 I_L + \frac{t_2 I_L^{t_3+1}}{t_3+1}$	$T(I_L)$
L-tasks offshoring eq.4	$\Omega_L = (1 - I_L) + \frac{T(I_L)}{t(I_L)}$	Ω_L
H-tasks offshoring eq.1	$\gamma p_{Hf} z(I_H) = p_{Hd}$	I_H
H-tasks offshoring eq.2	$z(I_H) = z_1 + z_3 I_H^{z_2}$	$z(I_H)$
H-tasks offshoring eq.3	$Z(I_H) = z_1 I_H + \frac{z_3 I_H^{z_2+1}}{z_2+1}$	$Z(I_H)$
H-tasks offshoring eq.4	$\Omega_H = (1 - I_H) + \frac{Z(I_H)}{z(I_H)}$	Ω_H
Zero profits for x	$\frac{1}{A} \left[\Omega_L p_{Ld}\right]^{\alpha_x} \left(\Omega_H p_{Hd}\right)^{1-\alpha_x} \geq p_{xd}$	x
Zero profits for y	$\frac{1}{A} \left[\Omega_L p_{Ld}\right]^{\alpha_y} \left(\Omega_H p_{Hd}\right)^{1-\alpha_x} \geq p_{yd}$	y
Expenditure function	$p_{xd}^{\lambda} p_{yd}^{1-\lambda} \geq p_w$	w
Supply $\geq$ Demand x	$x + m_x \geq w \lambda p_{xd}^{\lambda-1} p_{yd}^{1-\lambda}$	m_x
Supply $\geq$ Demand y	$y + m_y \geq w(1-\lambda) p_{xd}^{\lambda} p_{yd}^{-\lambda}$	m_y
Supply $\geq$ Demand w	$w \geq \frac{C}{p_w}$	p_w
Supply $\geq$ Demand L	$\frac{L}{1-I_L} \geq x \frac{\alpha_x \Omega_L}{A} (\Omega_L p_{Ld})^{\alpha_x - 1} (\Omega_H p_{Hd})^{1-\alpha_x}$ $+ y \frac{\alpha_y \Omega_L}{A} (\Omega_L p_{Ld})^{\alpha_y - 1} (\Omega_H p_{Hd})^{1-\alpha_y}$	p_{Ld}
Supply $\geq$ Demand H	$\frac{H}{1-I_H} \geq x \frac{(1-\alpha_x)\Omega_H}{A} (\Omega_L p_{Ld})^{\alpha_x} (\Omega_H p_{Hd})^{-\alpha_x}$ $+ y \frac{(1-\alpha_y)\Omega_H}{A} (\Omega_L p_{Ld})^{\alpha_y} (\Omega_H p_{Hd})^{-\alpha_y}$	p_{Hd}
Income balance	$C = p_{Ld} \frac{L}{(1-I_L)} + p_{Hd} \frac{H}{(1-I_H)} - \rho$	C
Domestic price for x	$p_{xd} = p_{xf}$	p_{xd}
Domestic price for y	$p_{yd} = p_{yf}$	p_{yd}
Offshoring payments	$\rho = p_{Ld} L \frac{I_L}{(1-I_L)} + p_{Hd} H \frac{I_H}{(1-I_H)}$	ρ

where m_j is the import (export if negative) of good j, ρ is the offshoring payment made by the domestic country d to foreign (f) labour.

[17]Note that even if we define the general equilibrium system as an MCP, some of the equations below are not strictly speaking complementarity relations. Some of them are simple equalities associated with system definitions.

The first eight equations in Table 2 are the offshoring equilibrium conditions taken from the GRH model. We explain these equations in detail when we define the specific offshoring cost schedules we use (Section 3.1.1). The other twelve equations are standard general equilibrium conditions. In this particular one-country model, we assume that domestic prices are determined by international prices (p_{jf}).

8.1.2 GRH two-country model

Table 3: General equilibrium system for the two-country GRH model

Inequality	Equation	Comp. var.
Zero profits for x_{dd}	$\frac{1}{A_d}\left[\Omega_L p_{Ld}\right]^{\alpha_x}(\Omega_H p_{Hd})^{1-\alpha_x} \geq p_{xd}$	x_{dd}
Zero profits for y_{dd}	$\frac{1}{A_d}\left[\Omega_L p_{Ld}\right]^{\alpha_y}(\Omega_H p_{Hd})^{1-\alpha_x} \geq p_{yd}$	y_{dd}
Zero profits for x_{ff}	$\frac{1}{A_f} p_{Lf}^{\alpha_x} p_{Hf}^{1-\alpha_x} \geq p_{xf}$	x_{ff}
Zero profits for y_{ff}	$\frac{1}{A_f} p_{Lf}^{\alpha_y} p_{Hf}^{1-\alpha_x} \geq p_{yf}$	y_{ff}
Zero profits for $x_{c_1c_2}$	$p_{xc_1} \geq p_{xc_2}$	$x_{c_1c_2}$
Zero profits for $y_{c_1c_2}$	$p_{yc_1} \geq p_{yc_2}$	$y_{c_1c_2}$
Expenditure function	$p_{xc}^{\lambda} p_{yc}^{1-\lambda} \geq p_{wc}$	w_c
Supply $\geq$ Demand x_c	$x_{c_1c_1} + x_{c_1c_2} - x_{c_2c_1} \geq w\lambda p_{xc}^{\lambda-1} p_{yc}^{1-\lambda}$	p_{xc}
Supply $\geq$ Demand y_c	$y_{c_1c_1} + y_{c_1c_2} - y_{c_2c_1} \geq w(1-\lambda) p_{xc}^{\lambda} p_{yc}^{-\lambda}$	p_{yc}
Supply $\geq$ Demand w_c	$w_c \geq \frac{C_c}{p_{wc}}$	p_{wc}
Supply $\geq$ Demand L_d	$\frac{L}{1-I_L} \geq x_{dd}\frac{\alpha_x\Omega_L}{A_d}(\Omega_L p_{Ld})^{\alpha_x-1}(\Omega_H p_{Hd})^{1-\alpha_x}$	
	$+y_{dd}\frac{\alpha_y\Omega_L}{A_d}(\Omega_L p_{Ld})^{\alpha_y-1}(\Omega_H p_{Hd})^{1-\alpha_y}$	p_{Ld}
Supply $\geq$ Demand H_d	$\frac{H}{1-I_H} \geq x_{dd}\frac{(1-\alpha_x)\Omega_H}{A_d}(\Omega_L p_{Ld})^{\alpha_x}(\Omega_H p_{Hd})^{-\alpha_x}$	
	$+y_{dd}\frac{(1-\alpha_y)\Omega_H}{A_d}(\Omega_L p_{Ld})^{\alpha_y}(\Omega_H p_{Hd})^{-\alpha_y}$	p_{Hd}
Supply $\geq$ Demand L_f	$L_f \geq x_{ff}\frac{\alpha_x}{A_f} p_{Lf}^{\alpha_x-1} p_{Hf}^{1-\alpha_x} + y_{ff}\frac{\alpha_y}{A_f} p_{Lf}^{\alpha_y-1} p_{Hf}^{1-\alpha_y}$	p_{Lf}
Supply $\geq$ Demand H_f	$H_f \geq x_{ff}\frac{(1-\alpha_x)}{A_f} p_{Lf}^{\alpha_x} p_{Hf}^{-\alpha_x} + y_{ff}\frac{(1-\alpha_y)}{A_f} p_{Lf}^{\alpha_y} p_{Hf}^{-\alpha_y}$	p_{Hf}
Income balance in d	$C_d = p_{Ld}\frac{L}{(1-I_L)} + p_{Hd}\frac{H}{(1-I_H)} - \rho$	C_d
Income balance in f	$C_f = p_{Lf}(L_f - L_d\frac{I_L}{(1-I_L)})$	
	$+p_{Hf}(H_f - H_d\frac{I_H}{(1-I_H)}) + \rho$	C_f
Offshoring payments	$\rho = p_{Ld}L\frac{I_L}{(1-I_L)} + p_{Hd}H\frac{I_H}{(1-I_H)}$	ρ

We distinguish between the producing (exporting) country c_1 and the consuming (importing) country c_2 (e.g. y_{fd} are exports of y from f to d).

Tables 2 and 3 use Cobb-Douglass functions. When we use the CES functions to check the sensitivity of the results to the elasticity of substitution between factors, most equations are adjusted. In particular, the new unit-cost function becomes:

$$c_j(\cdot) = \frac{1}{A_d}\left[\alpha_j(\Omega_L p_{Ld})^{1-\sigma_j} + (1-\alpha_j)(\Omega_H p_{Hd})^{1-\sigma_j}\right]^{\frac{1}{1-\sigma_j}} \tag{20}$$

where σ_j is the elasticity of substitution between both skills in sector j. We assume that there are no differences in elasticities between sectors: $\sigma_x = \sigma_y = \sigma$.

8.2 Welfare and terms-of-trade simulations

Figure 15: GRH two-country model, welfare changes with respect to no-offshoring scenario with $\alpha_x = 0.2$ and $\alpha_y = 0.7$, non-linear offshoring costs (left hand side $t_3 = 1.5$, right hand side $t_3 = 2.5$) at three different β levels ($b = 1, 2, 3$)

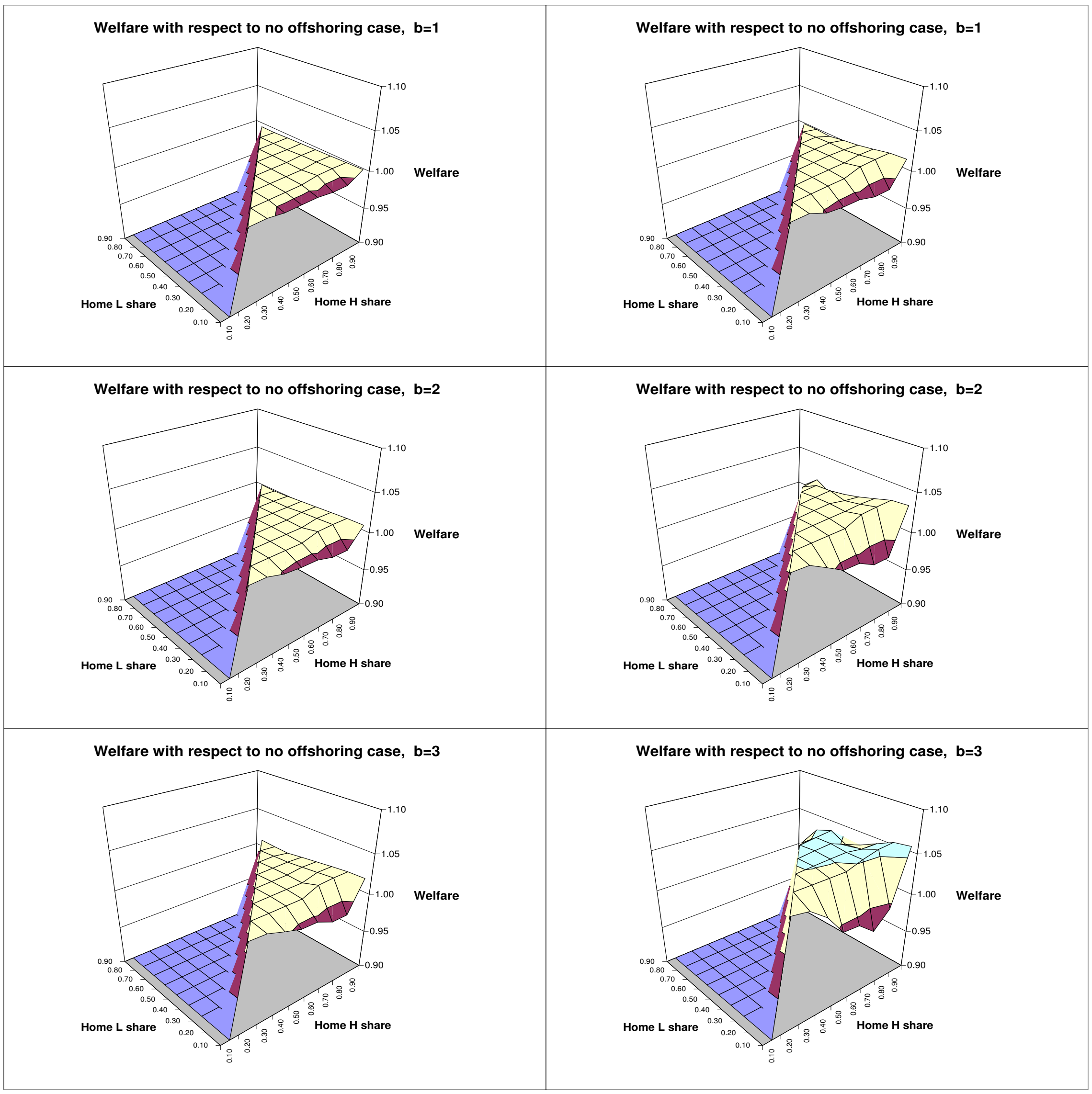


Figure 16: GRH two-country model, terms-of-trade changes with respect to no-offshoring scenario with $\alpha_x = 0.2$ and $\alpha_y = 0.7$, non-linear offshoring costs (left hand side $t_3 = 1.5$, right hand side $t_3 = 2.5$) at three different β levels ($b = 1, 2, 3$)

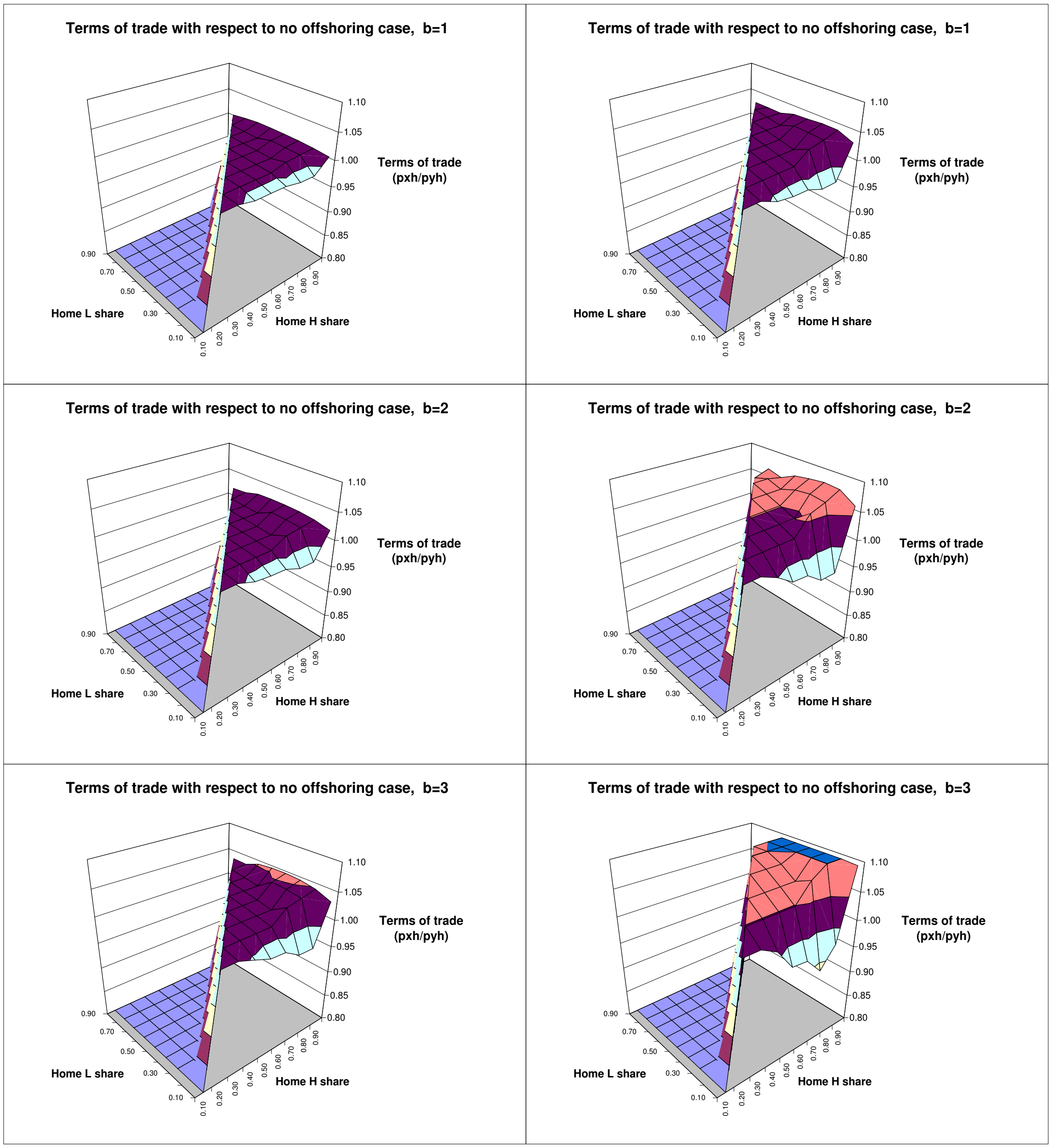
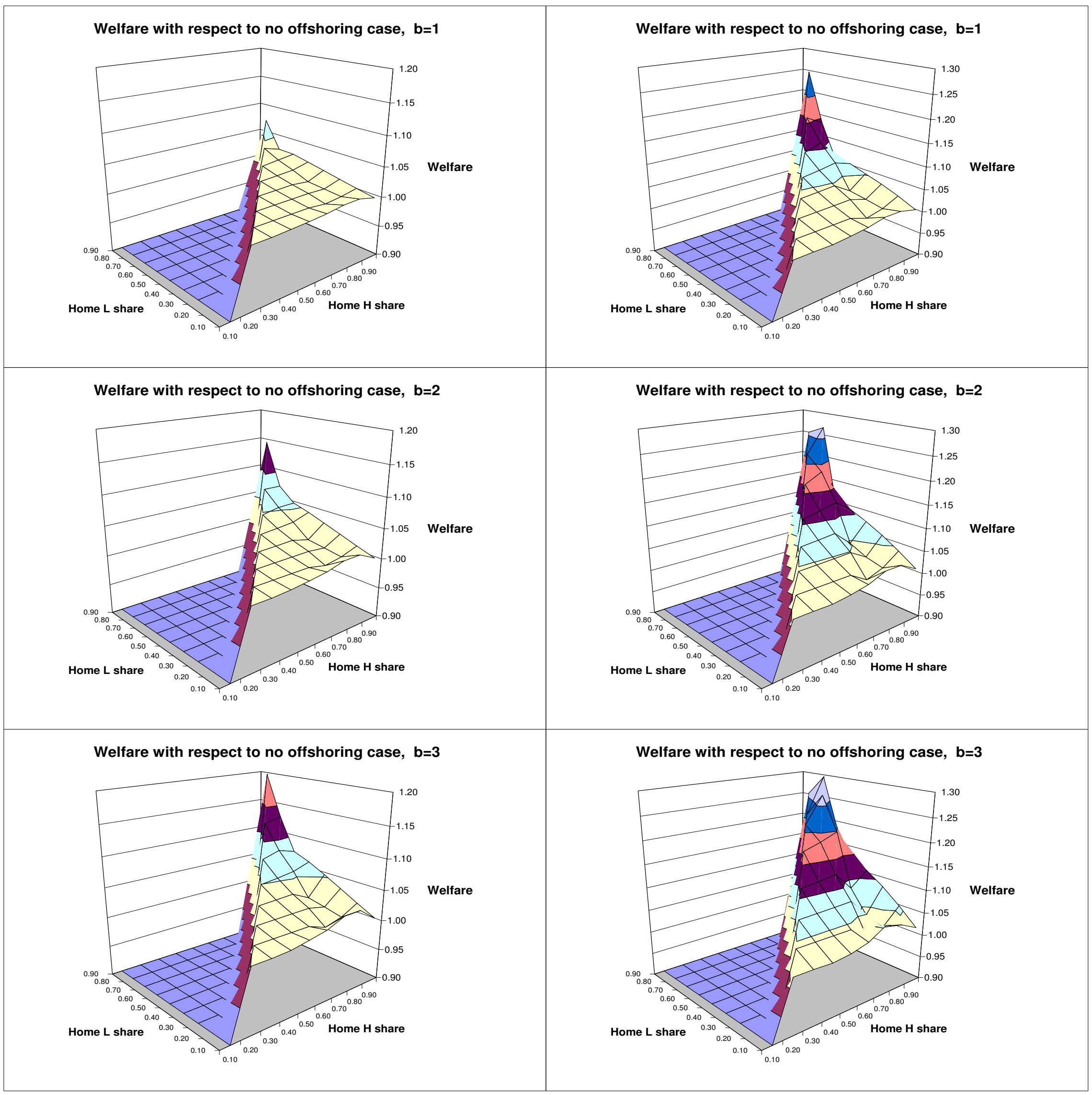


Figure 17: GRH two-country model, L-abundant country, welfare changes with respect to no-offshoring scenario with $\alpha_x = 0.2$ and $\alpha_y = 0.7$, non-linear offshoring costs (left hand side $t_3 = 1.5$, right hand side $t_3 = 2.5$) at three different β levels ($b = 1, 2, 3$)



8.3 Alternative trade-in-tasks models

8.3.1 Simplified GRH model

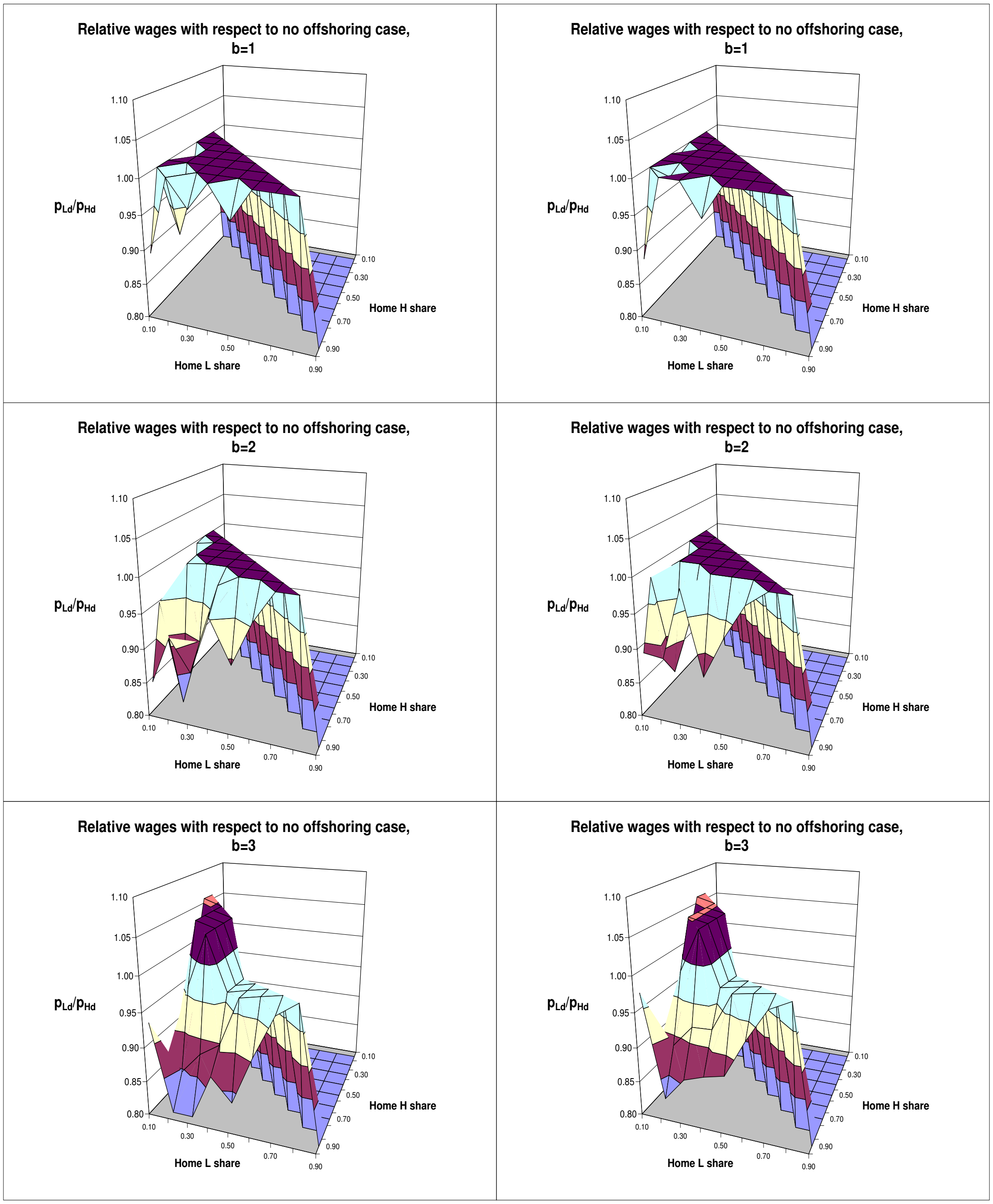
We slightly modify the GRH model version from Markusen (2010) by allowing the home country to be 50% more productive than the foreign country ($A_d/A_f = 1.5$). Then we run numerical simulations following the same approach as with the GRH two-country model. For instance, the domestic countries endowments are changed as in Table 1 and we again run four different scenarios with different offshoring costs. For $b = 0$ we calibrate the value of the trade costs of the low-skill factor-specific task so there is no offshoring of this L-task. Then we reduce these trade costs by different percentages. For $b = 1$ the reduction is of 10% with respect to the trade costs that assures no offshoring, $b = 2$ has a 20% and $b = 3$ a 30% decrease.

The results of this GRH-Markusen model are shown in Figure 18. Since this is a discrete version of GRH, there are some endowment combinations for which a decrease in L-task trade costs is not traduced in task offshoring. These areas are the flat portions in the first two rows in Figure 18, where there is no offshoring and thus, relative wages remain constant (equal to one). However, with a sufficient decrease in L-task trade costs, offshoring increases in the third row of this figure.

Besides these non-continuous effects, the GRH-Markusen model yields very similar results as with the GRH two-country model: when offshoring increases, then we observe the same pattern of decreasing relative low-skill wages for most of the endowment combinations, except for those where the domestic country is relatively very small. These results are robust to changes in the factor shares and for different σ values. The welfare and terms-of-trade effect follow also the same pattern as in the GRH unmodified model.

Another difference between both models, is that given the discontinuities in the discrete GRH-Markusen model, it is not possible to calibrate the L-task trade costs so every endowment combination has the same offshoring levels.

Figure 18: GRH-Markusen model, relative wage changes with respect to no-offshoring scenario with $\alpha_x = 0.2$ and $\alpha_y = 0.7$, (left hand side $\sigma = 1$, right hand side $\sigma = 1.44$) at three different β levels ($b = 1, 2, 3$)



8.3.2 Markusen and Venables (2007) model

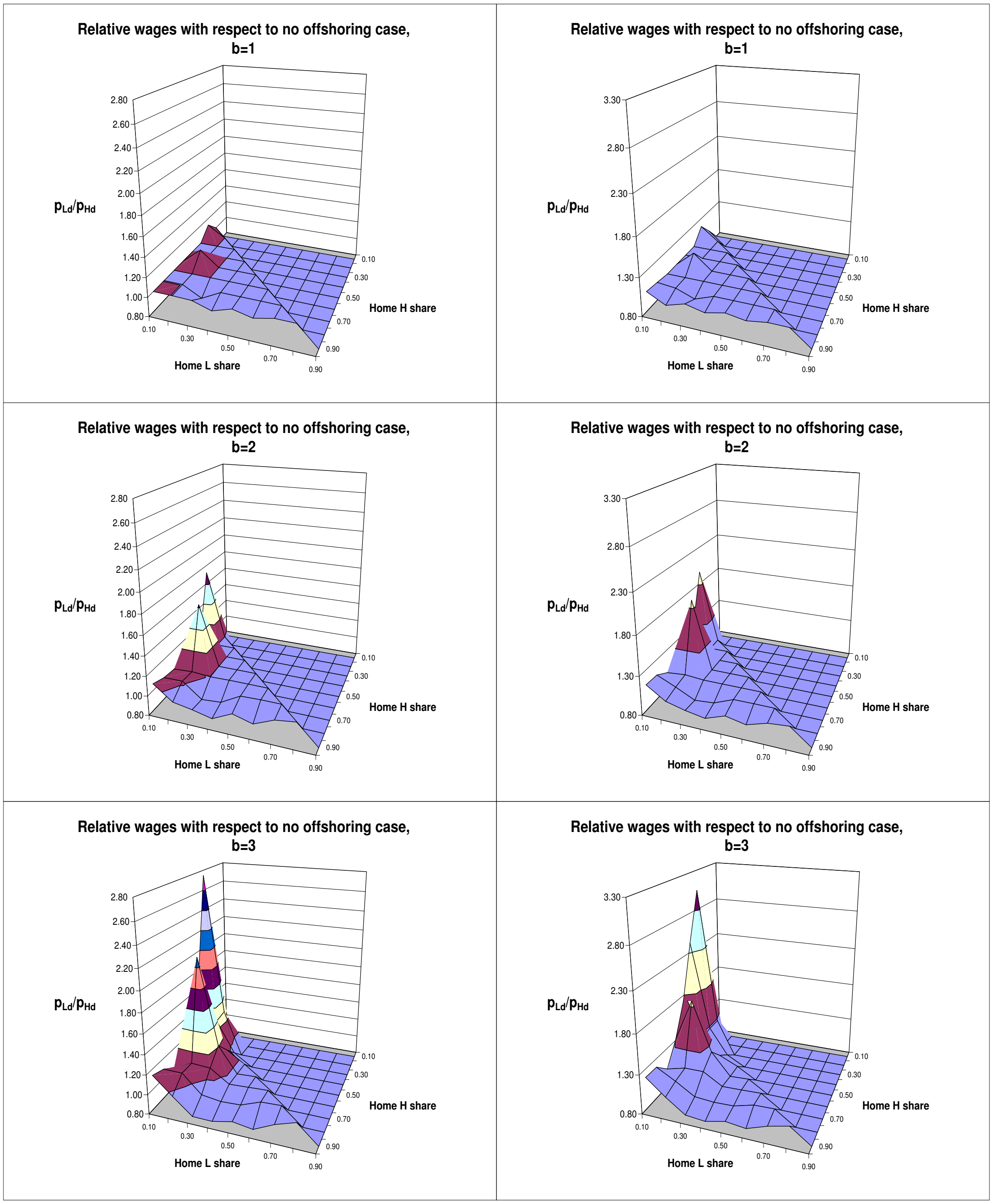
In Markusen (2010), the Markusen and Venables (2007) model, henceforth MV, is also modified to analyse the welfare implications of decreasing trade costs for both final and intermediate goods. The MV model is also set in a 2x2x2 Heckscher-Ohlin framework, but it has three intermediate inputs (A, B, C), of which A is high-skill intensive, C is low-skill intensive and B is in the middle. Again we modify the model to allow productivity difference between both countries (i.e. $A_d/A_f = 1.5$) and we run numerical simulations using the same changes in endowment combinations and in trade costs as with the previous models. In particular, for the MV model we only change the trade costs of the low-skill intensive intermediate.

In Figure 19 we show the changes in relative wages with different offshoring stages. Again, the pattern of relative low-skill wage changes is similar as before. However, now the scope of positive changes is bigger. Also note that the scale in the vertical axis is different from previous graphs, and now the positive relative wages increases are of a much larger magnitude.

Finally, given that this model is also discrete (only three intermediates, instead of a continuum of tasks as in GRH), it is not possible to calibrate the L-task trade costs to obtain similar offshoring levels for all endowment combinations.

It is important to note that both these models use a discontinuous offshoring cost function. For each task (or intermediate input) there is an offshoring cost, but the limited number of tasks produces a very rigid model where crossing certain trade costs thresholds produces big changes in offshoring, final goods trades and diverse effects on wages.

Figure 19: Markusen-Venables (2007) model, relative wage changes with respect to no-offshoring scenario with $\alpha_x = 0.2$ and $\alpha_y = 0.7$, (left hand side $\sigma = 1$, right hand side $\sigma = 1.44$) at three different β levels ($b = 1, 2, 3$)



8.4 Sequential offshoring stage in the three-skill GRH model

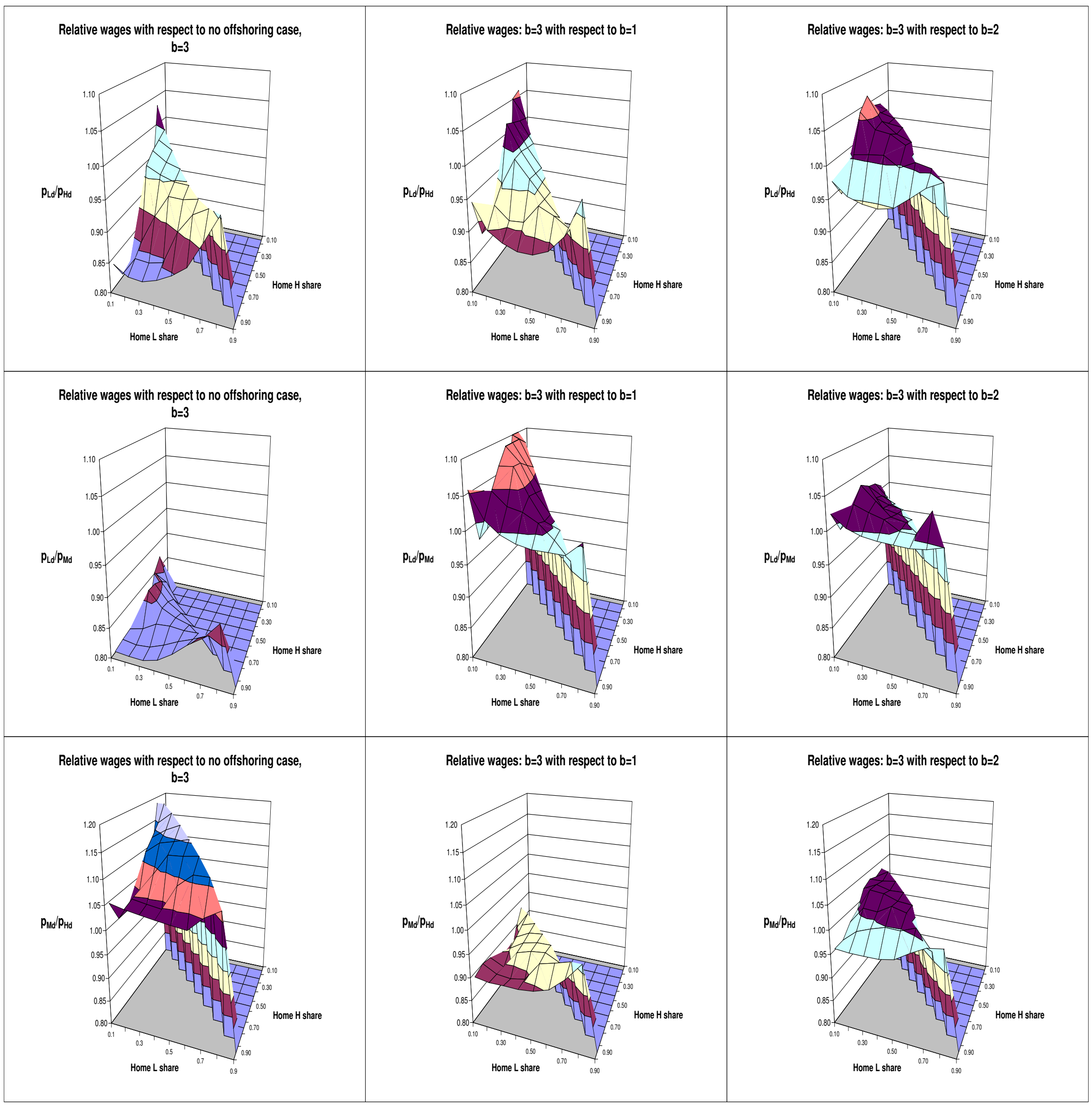
An alternative way to model offshoring in the three-skill GRH model is to use sequential offshoring. In a first stage we simulate changes in L-task offshoring, in a second stage both L-task and M-tasks are offshored (with the level of L-tasks offshored being higher), and in the final third stage all tasks are being offshored, although a hierarchy of offshoring levels is maintained, such that: $I_L > I_M > I_H$. This sequential offshoring stage is consistent with the findings that offshorability is monotonically decreasing in skill levels (Akcomak *et al.*, 2010).

Therefore, we have three offshoring stages (b) where the general offshoring cost parameters (β, μ and γ) are reduced. In $b = 1$, we only have L-task offshoring by reducing β by 10%. In the second stage ($b = 2$) we reduce β by 20% and μ by 10%. Finally, in $b = 3$, β is reduced by 30%, μ by 20% and γ by 10%.

In Figure 20 we present the wage inequality results for non-linear offshoring costs (with $t_3 = 1.5$). The first row shows the relative low-skill wage with respect to high-skill wage, the second row shows the low-skill relative to the medium-skill wage and the last row the medium-skill relative to the high-skill wage. The columns have different offshoring stages and each stage is compared with the previous one. For instance, the first columns show L-task offshoring with respect to the no-offshoring case (i.e. $b = 1$ with respect to no-offshoring). The second column has both L and M-task offshoring keeping $I_L > I_M > 0$ and the results are compared with the previous stage of only L-task offshoring (i.e. $b = 2$ with respect to $b = 1$). Finally, the third column has offshoring in all labour skills, but the offshoring magnitudes decrease for higher skill workers (i.e. $I_L > I_M > I_H$) and we compare these results with respect to the previous stage ($b = 3$ against $b = 2$).

In the first column we observe that the M-skill wages are increasing relative to both low and high-skill wages. For the second column (i.e. $I_L > I_M > 0$) we observe an overall wage inequality increase, since for most of the endowment combinations, lower skill wages are decreasing to the higher ones. However, for a set of relative small country sizes we observe a polarization pattern, where M-skill wages are decreased relative to both L and H-skill wages. Finally, in the last column we observe again that for most endowment combinations wage inequality is increasing. For relatively small country sizes wage inequality is decreasing ($\Delta P_{Ld} > \Delta P_{Md} > \Delta P_{Hd}$); and for medium-sized symmetric countries there is a polarization pattern. These results hold the same pattern when we use different production shares, and for the four different offshoring cost schedules. It is also important to note that welfare and term-of-trade effects following a very similar pattern as with the 2x2x2 GRH model. Welfare is always increasing, unless there are negative terms-of-trade effects.

Figure 20: GRH model with three factors, changes in relative wages with sequential offshoring stage, with non-linear offshoring costs ($t_3 = 1.5$). Rows indicate different relative wage combinations. The first column has only L-task offshoring compared to the case of no offshoring. The second column has both L and M-task offshoring, compared to the L-task offshoring case. The third column has all three factors being offshored compared to the previous offshoring level (in all cases: $\beta<\mu<\gamma$, and $\alpha_x = 0.2$, $\phi_x = 0.3$, $\alpha_y = 0.7$, $\phi_y = 0.3$)



When we use CES functions with elasticities of substitution of two, we obtain similar results for the first stage offshoring (relative M-skill wages are increasing), but in the case of the second stage, the polarization pattern (relative M-skill wages decreasing with respect to L and H-skill wages) is generalized to almost all endowment combinations and not restricted to the small-country combinations (as in the Cobb-Douglass case).

In any case, there is no empirical evidence of relative wage gains of M-skills with respect to the other two skill types. Thus, this sequential offshoring schedule is not in line with the empirical evidence on wage inequality.