Wage inequality in trade-in-tasks models

Hugo Rojas-Romagosa

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CPB Netherlands Bureau for Economic Policy Analysis

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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 extensive numerical simulations of these models we find that wage inequality is increasing for almost all endowment combinations (i.e. relative country sizes) when we use a broad range of parameter values and model specifications. The most common exception is when the country is relatively small and cannot affect international prices. In the case of relatively poor low-skill abundant countries, we find that offshoring is always welfare improving, but wage inequality effects are ambiguous. Finally, we find that a trade-in-tasks model with three skill-types can also account for wage polarization when we allow medium-skill tasks to be offshored.

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

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[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).

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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.

In this paper we analyse the impact of offshoring on wage inequality using these recent trade-in-tasks theoretical models. The complexity of the GRH and other alternative trade-in-tasks models, however, does not allow for full analytical solutions with clear-cut predictions. The only exception is a special case in the GRH model 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).

In addition, this GRH special case is at odds with the empirical evidence. 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. More recently, **?** 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] On the other hand, Firpo *et al.* (2010) find that offshoring has played a substantial role in the changes in wage inequality after the 1990s and specially, in the 2000s. Therefore, even though the magnitude of the offshoring effects on wage inequality is not clear yet, all the empirical studies found that offshoring increased wage inequality. Moreover, the magnitude and scope of the offshoring impact may increase 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.

The first objective of this paper, therefore, is to run extensive numerical simulations using GAMS to evaluate the relative wage effects of the GRH model for a wide range of parameter values and different model specifications. We want to analyse if

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[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. In a related paper, 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.

moving away from the GRH special case (i.e. small country and non-specialization) yields results that are consistent with the recent empirical evidence.

Our numerical simulations assume that low-skill tasks (L-tasks) are more easily offshorable than high-skill tasks (H-tasks), and thus, in a first round of simulations we only allow for L-task offshoring. In every simulation we vary the relative factor endowments of the domestic (high-skill abundant) country and the general offshoring costs, which produce different levels of offshoring.[3] Thereafter each set of simulations combines the use of four different offshoring cost schedules, seven combinations of factor shares, and four different elasticities of substitution between factors. In addition, we also run simulations for a selected set of parameter values where both low and high-skill tasks can be offshored.[4] In total we obtain almost 50.000 general equilibrium results for the one-country GHR model and more than 12.000 for the two-country model. Therefore, even though our simulations do not completely account for all possible parameter values, with more than 60.000 simulations we present a very exhaustive numerical analysis of the GRH model.

This rich set of parameter values and offshoring specifications is 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 always increasing (i.e. wage inequality is decreasing) when there is non-specialization in production and L-task offshoring. However, when there is specialization in production (the domestic country is producing only the high-skill intensive good), we already find that wage inequality is increasing, except at very high levels of low-skill task offshoring.

For the two-country case, we find the remarkable outcome that with such a broad range of numerical simulations, relative low-skill wages are decreasing for most relative country sizes. The common exception is that wage inequality is usually de-

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[3] Surveying recent empirical studies we calibrate our simulations to limit offshoring to an upper level of 50% and in most cases the simulations are centered on 25%. This follows the findings in Blinder (2009) and Blinder and Krueger (2009), who estimate different offshorability indexes and find that around 25% of US jobs are potentially offshorable. In addition, Jensen and Kletzer (2010) focus on the services sector and estimate that up to 27% of services jobs are likely to be offshored. 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).

[4] 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 find that offshoring costs are industry-specific. In particular, low-skill intensive industries have a higher offshorability index than high-skill intensive industries.

creasing for relatively small countries (i.e. countries that cannot affect international prices). Moreover, since we use extreme parameter values, we do not expect the results to change if we run simulations with parameter values that lay in between these extremes.[5]

Thus, the example portrayed in Grossman and Rossi-Hansberg (2008), where off-shoring levels decrease wage inequality, is indeed a special case. For the majority of endowment combinations (relative country sizes) wage inequality is increasing when the domestic high-skill abundant country offshores its low-skill tasks. The intuition for these results is that the relative price effect is dominating the productivity effect associated with offshoring. In particular, when offshoring of low-skill tasks is increased, the productivity of low-skill workers is increased but this also increases the production of the low-skill intensive good. In general equilibrium, this increase in production decreases the relative price of the low-skill intensive good with respect to the high-skill intensive good, which in turn reduces the relative wage of low-skill workers.

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. 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 ambiguous and conditional on the parameter values of the model (most importantly, on the factor shares in production). Therefore, there is no pattern of wage inequality effects of offshoring that can be generalized for the case of relatively low-skill abundant countries.

These 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.[6] The second objective of this paper is to analyse if the GRH model can accommodate this wage polarization pattern. To do so, we

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[5]In this respect, the only case where our main wage inequality results change is when we use a very high value of the elasticity of substitution between low and high-skill labour. With values of $\sigma = 3$ or larger we find that wage inequality is decreasing for a much broader set of relative country sizes, and not only for small countries. However, this elasticity value is already more than twice the value commonly accepted in the empirical labour economics literature (cf. Katz and Murphy, 1992; Caselli and Coleman, 2006).

[6]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).

need to expand the GRH model by introducing three skill-groups: low, medium and high.[7] 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 for many relative country sizes adding H-task offshoring to existing L and M-task offshoring results in wage inequality reductions.

The paper is organized as follows. Section 2 introduces the main features of the GRH model, while Section 3 explains how the model is calibrated and provides an overview of the numerical simulations. Section 4 presents the results for the case of high-skill abundant countries in the one-country model. In Section 5 we analyse the two-country model with endogenous international prices, for the cases of both the high and low-skill abundant countries. 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.[8] 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).[9] 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.

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

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[7]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.

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

[9]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.

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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.[10]

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:

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

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:

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

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

$$\tag{6}$$

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[10]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.

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 Model calibration and simulation overview

We solve the general equilibrium conditions as a mixed complementarity problem (MCP). The general equilibrium system is defined in Table 2 in the Appendix for the one-country model and in Table 3 for the two-country model.

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: $m_x + m_y = 0$, where m_j is the import (export if negative) of good j. 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. Finally, throughout our setting welfare (w) is defined as the representative consumer's utility.

3.1 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:

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

In every simulation we assume that $t(i_L)$ is fixed, while the β parameter is used as our main exogenous shock variable. So the offshoring cost at equilibrium is $t(i) = \frac{1}{\beta} \frac{p_{Ld}}{p_{Lf}}$

Using different parameter combinations in equation (12) we obtain four different offshoring cost schedules ($OC1$ to $OC4$). We start 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 yields two offshoring cost schedules that provide relatively extreme outcomes. For $OC1$ ($t_1 = 1, t_2 = 1$, and $t_3 = 1$) we have that offshoring activity is relatively sensitive to changes in β, while for $OC2$ ($t_1 = 1, t_2 = 4$, and $t_3 = 1$) offshoring slowly increases with reductions in β. The second set of cost schedules is non-linear. For $OC3$ ($t_1 = 1, t_2 = 7$, and $t_3 = 1.5$) offshoring is relatively inelastic to β changes, while for $OC4$ ($t_1 = 1, t_2 = 7$,

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and $t_3 = 2.5$) we have that offshoring is initially very sensitive to 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
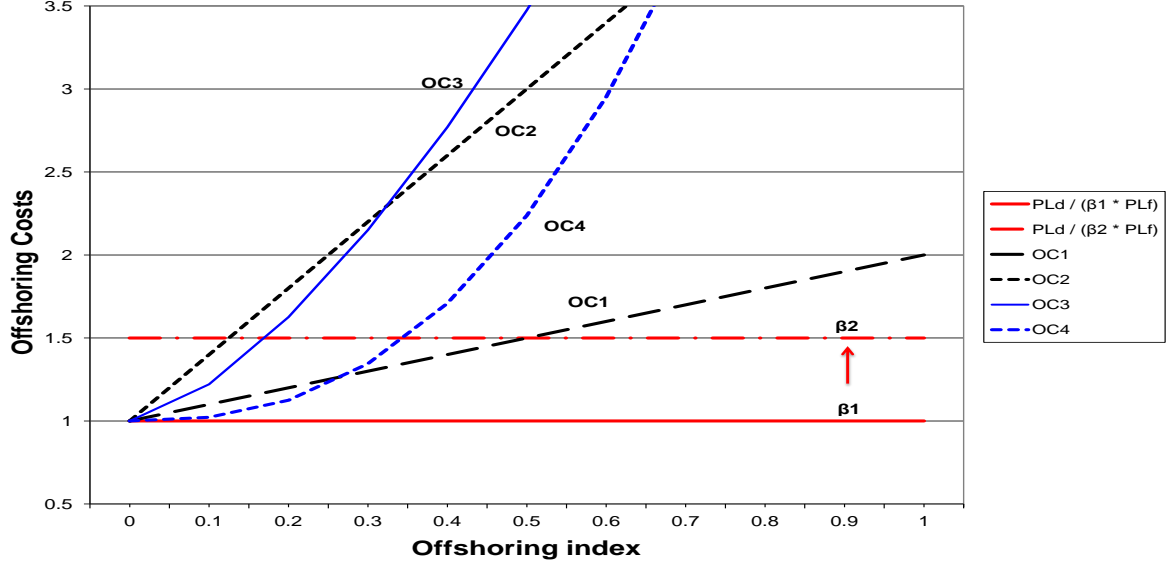
In Figure 1 we also depict two different β values (wage differentials are held constant in the figure). For β_1 we have that there is no offshoring activity at any cost schedule. When the general offshoring costs are decreased to β_2, the linear $OC1$ schedule has the biggest offshoring levels (around 0.5), while the linear schedule $OC2$ has the lowest offshoring levels (around 0.1).

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 (in our one-country model), then any wage differential value can be accommodated by adjusting β^*. For the two-country model, we need to run an additional calibration where we first find the β^* value that yields no offshoring activity at the equilibrium wage differential.

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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.[11] 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 (associated with low-skill workers) are more easily offshored than non-routine tasks (associated with high-skill workers).

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 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 Parameter changes used in the simulations

Throughout all our numerical simulations we use a series of parameter values and functional forms. In each simulation (i.e. a single output graph) we vary our main exogenous variable: the general offshoring cost parameter (β for L-skill tasks and γ for H-skill tasks); and we also change 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.[12]

Then we have simulation-specific parameter values, which we present as a different output graph. First, we always use the four offshoring cost schedules described above ($OC1$ to $OC4$). Second, we use up to seven sets of factor shares of production.[13] Third, we initially use Cobb-Douglas production functions ($\sigma = 1$). However, the empirical labour economics literature commonly uses an elasticity of 1.44 (Katz

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[11]Their results are presented in Figure 6 in the Appendix.

[12] Hence, for the one-country model we present our results in three-dimensional graphs, where the x-axis gives the β values, the y-axis the relative factor abundance L/H and the z-axis the variable of interest, which usually is the relative wage (p_{Ld}/p_{Hd}). For the two-country model we also have three-dimensional graphs where the z-axis shows the variable of interest, but the x and y-axis give the relative share of low and high-skill workers. While we use different graphs for three different offshoring levels associated with different changes in the β values.

[13]These are: ($\alpha_x = 0.2, \alpha_y = 0.7$), ($\alpha_x = 0.3, \alpha_y = 0.6$), ($\alpha_x = 0.3, \alpha_y = 0.7$), ($\alpha_x = 0.4, \alpha_y = 0.6$), ($\alpha_x = 0.2, \alpha_y = 0.8$), and what define as the extreme values: ($\alpha_x = 0.4, \alpha_y = 0.5$) and ($\alpha_x = 0.1, \alpha_y = 0.9$).

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 and we evaluate three additional elasticity values (i.e. $\sigma = 1.44, 2, 3$). We consider $\sigma = 3$ to be an extreme value since it is more than double the standard value used in the literature.

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. $I_L \geq I_H$).

This broad selection of parameters allows us to provide a very exhaustive analysis of the general equilibrium results when offshoring is increased in the GRH model. For instance, in the one-country model we have 21 relative factor combinations (L/H values) and 21 β values for each simulation. Then we can use our four different offshoring costs ($OC1$ to $OC4$), the seven different sets of factor shares, and the four different elasticities of substitution. In total, this yields 49.392 different general equilibrium points. In addition, for a selected set of parameters we also run simulations using two offshoring sequences (only L-task offshoring and both L and H-task offshoring), and two different combinations of industry-offshoring (one with equal offshoring costs by industry and another with different offshoring costs). For the two-country model we limit the change in β to only three values, and as explained later we divide total world endowments into 81 endowment combinations, of which 36 correspond to the home country being relatively high-skill abundant. In total, and using the same changes in the other parameter as in the one-country model, this yields 12.096 different general equilibrium points.

To sum up, even though our simulations do not completely account for all the possible parameter variations, with more than 60.000 simulations we present a very exhaustive numerical analysis of the GRH model. What is truly remarkable is that with this very broad range of parameter variation, our main results are still robust. Moreover, we do not expect that increasing the available range for certain parameters can change our main results. For instance, we already use extreme cases when evaluating factor shares (α values), elasticity of substitution between low and high-skill labour (σ), general offshoring cost values (β), relative country size (i.e. relative factor abundance), and offshoring cost schedules ($t(i_L)$).So the only option left is to increase the number of values within these extremes, but this is very unlikely to change the main results. Only when we use a very high value of $\sigma = 3$ do the results change in qualitative terms.

4 GRH one-country model results

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 $\alpha_x < \alpha_y$.

4.1 GRH one-country simulations 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 7 in the Appendix we present the changes in offshoring levels, welfare and production when we allow only for L-task offshoring (i.e. β is decreasing). In this initial set of simulations we also calibrate the factor shares and the relative factor abundance to obtain general equilibrium outcomes with non-specialization in production (i.e. both countries produce both final goods). In this case, increased offshoring (as a results of reductions in β) increase the production of the L-intensive good y and reduces x. In other words, offshoring of L-skill tasks, makes the H-skill abundant country increase the production of the low-skill intensive good. This is the opposite result of a traditional trade in final goods liberalization (if for instance, there is an initial tariff on the import of the low-skill intensive good y). As a consequence, this shift in the production patterns of the small-open economy yields another interesting result: offshoring reduces trade in final goods. Offshoring by a small-country erodes its endowment-abundancy differential with the rest of the world, since it now has more low-skill labour available, 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.

Next, we analyse the effects of increased offshoring on relative wages. Figure 2 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 offshoring cost schedules ($OC1$ and $OC2$) are above and the non-linear ($OC3$ and $OC4$) below. In all cases relative low-skill wages are increasing.

This is the special case in Grossman and Rossi-Hansberg (2008) for a small open country with non-specialization. Here only the offshoring productivity effect (Ω_L) is present and we have the counter-intuitive result that increased offshoring of low-skill tasks increases 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, when we move away from the non-specialization assumption, this special case does not hold any more. In Figure 3, 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. Hence, we obtain corner solutions where the domestic country is producing only one of the goods. 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, we cannot 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

Figure 2: GRH one-country model, changes in relative wages with only L-task off-shoring and non-specialization, for four different offshoring cost schedules
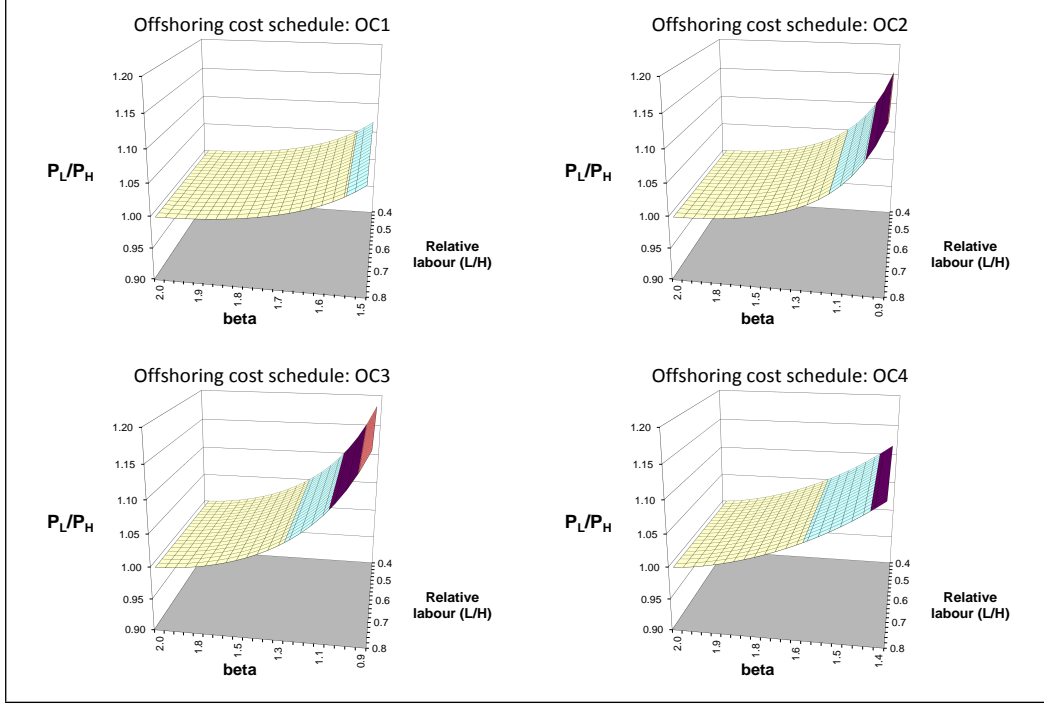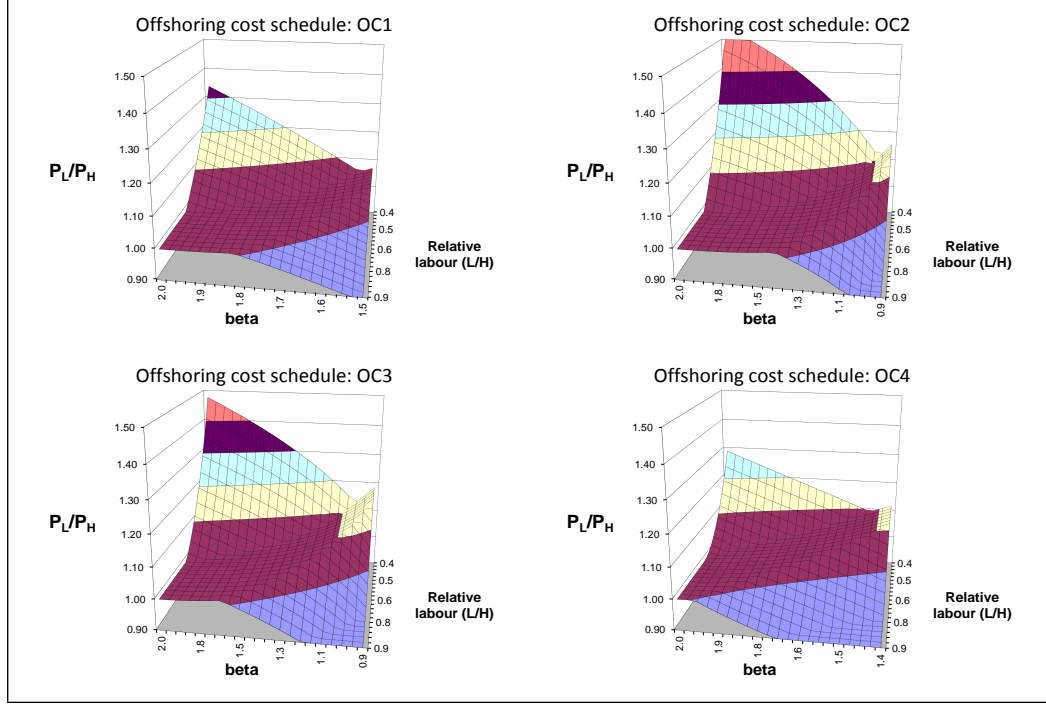

Notes: We change β in a way that for all four functions the offshoring levels are similar (beginning with no offshoring and ending with levels around 0.45). This means that β has to decrease more for the inelastic cost schedules: $OC2$ and $OC3$. Common parameters in all graphs: $\sigma = 1$, $\alpha_x = 0.2$ and $\alpha_y = 0.7$.

relative wages are decreasing for low and median offshoring levels. Only at very high offshoring levels (usually above 0.4) are relative wages increasing. Thus, just moving away from the non-specialization assumption we do not find that increased offshoring of L-tasks increases the relative L-skill wage.

4.2 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 of 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.

Figure 3: GRH one-country model, changes in relative wages with only L-task off-shoring and production specialization, for four different offshoring cost schedules

Notes: 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: $OC2$ and $OC3$. Common parameters in all graphs: $\sigma = 1$, $\alpha_x = 0.4$ and $\alpha_y = 0.5$.

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).[14]

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).

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[14]Note that these results are independent of the parameter choices (i.e. production shares and the elasticity of substitution σ).

5 GRH two-country model results

In this section we calibrate and numerically simulate the GRH model with two countries, and 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.

To keep the numerical simulations tractable, we now simulate only three different offshoring levels. As before, we reduce the value of the general offshoring costs parameter (β) to increase offshoring activity in L-tasks. Therefore, each of our three offshoring level is associated with relative changes in β. Hence, in the low-offshoring case β is reduced 10% with respect to β_0 (the value of β for which there is no offshoring). In the medium and high offshoring cases the corresponding reductions in β are 20% and 30%, respectively.[15]

For the two-country simulations we simulate different divisions of the total endowments between both countries. We 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 36 different combinations where the domestic country is relatively high-skill abundant. As before we use four different offshoring cost schedules ($OC1$ to $OC4$), seven different sets of factor shares, four different elasticities of substitution, two offshoring sequences (only L-task offshoring and both L and H-task offshoring), and two different combinations of industry-offshoring. In total, this yields 12.096 different general equilibrium points. Using this total endowment sharing mechanism we obtain different relative country sizes and thus, different effects on trade volumes and terms-of-trade (i.e. relative price) effects.

Figure 4 presents the results for relative wages (P_{Ld}/P_{Hd}) when we use our two linear offshoring cost schedules ($OC1$ and $OC2$). The left hand side column uses the more sensitive $OC1$ schedules that yields higher offshoring levels, while the right

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[15]However, since we are also changing relative endowments, factor prices are different for each endowment point and thus, β_0 is also changing. Therefore, we first find the marginal β_0 value for each endowment point and take this value as the starting point to apply the relative reductions.

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

hand side column presents the less sensitive $OC2$ schedule.[16] We also present three offshoring levels (low, medium and high), and thus, the decreases in β are larger as we move from the top to the bottom rows in the figure.

In all the following graphs, we use the no-offshoring case (β_0) as our baseline, and we graph the results of the variable of interest (e.g. relative wages) with respect to this no-offshoring case. Therefore, for $P_{Ld}/P_{Hd} > 1$ we have that the relative wage of low-skill workers is increasing with respect to the case with no offshoring, while $P_{Ld}/P_{Hd} < 1$ denotes a decrease in the relative wage of low-skill workers. We analyse now the wage inequality effects of increased offshoring of low-skill tasks.[17]

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[16]As explained in the previous section we have chosen the offshoring cost schedules so they represent extreme situations. Thus, for equal reductions in β, the left-hand side graphs show much higher offshoring activity. For the particular case depicted in Figure 4, the right hand side $OC2$ schedule yields increases in the offshoring index from 0.05 (for the low offshoring case) to 0.15 (for the high offshoring case). In other words, 5 to 15% of L-tasks are being offshored. For the $OC1$ schedule that is more sensitive to changes in β the offshoring index increases much more and also has more variation by relative endowments (see Figure 8 in the Appendix). In addition, 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. This implies a additional set of loops where β is changed in small steps until the desired offshoring level is attained. However, the results are very similar to when we just use proportional changes in β.

[17] For the same parameter values as in Figure 4, in the Appendix we present the results for welfare (Figure 9) and terms-of-trade (Figure 10). Figure 9 shows that welfare is increasing 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 10 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. These pattern of results for welfare and TOT are roughly the same when we change the main parameter values.

Figure 4: GRH two-country model, changes in relative wages with respect to no-offshoring scenario, with linear offshoring cost schedules (one per column), at three different offshoring levels.
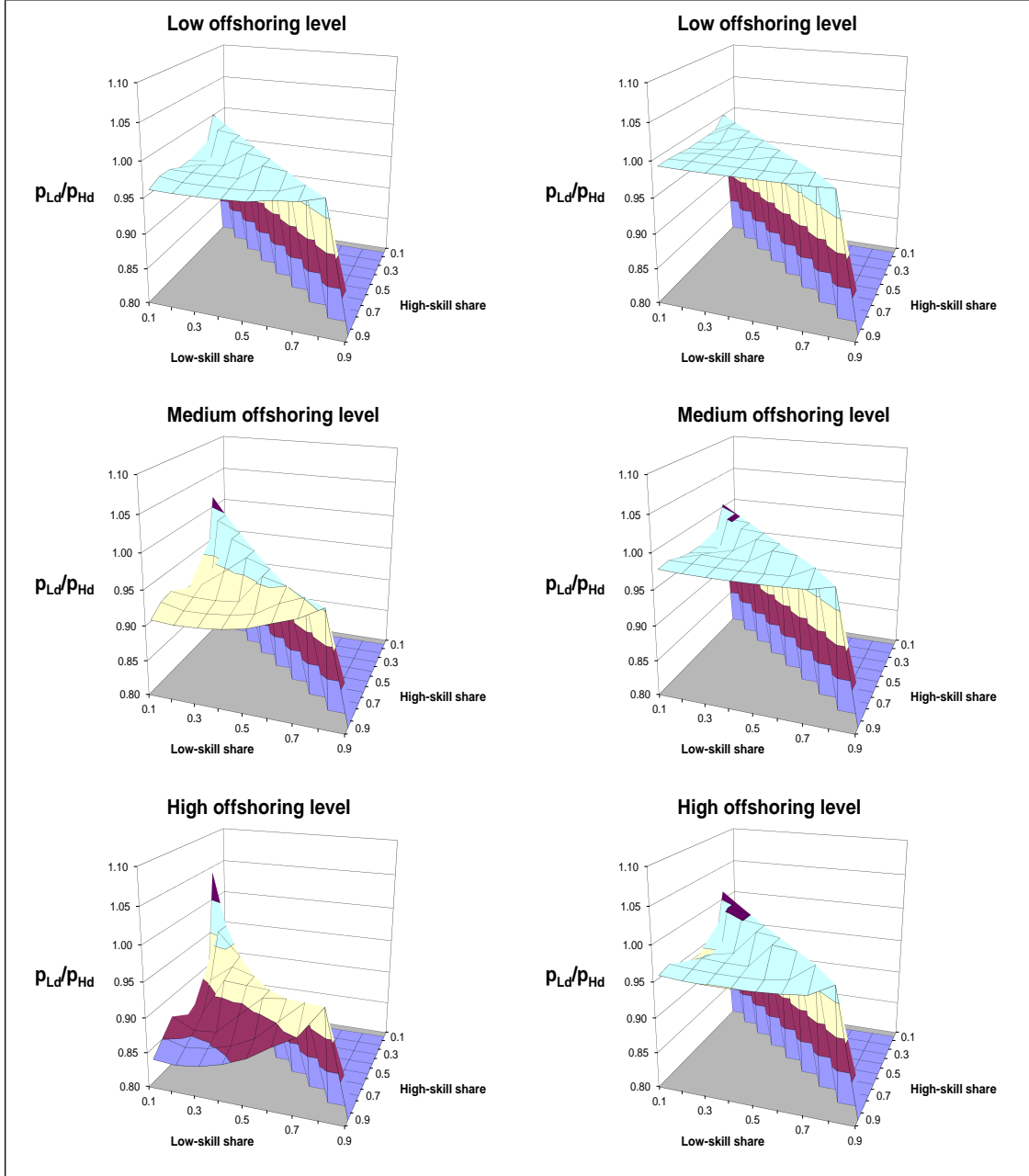
Notes: Left column has more sensitive offshoring cost parameters ($OC1$: $t_1 = 1$, $t_2 = 1$, $t_3 = 1$) and right column less sensitive parameters ($OC2$: $t_1 = 1$, $t_2 = 1$, $t_3 = 1$). Common parameters in all graphs: $\sigma = 1.44$, $\alpha_x = 0.3$ and $\alpha_y = 0.6$. In the low offshoring cases β is reduced 10% with respect to β_0, in the medium and high offshoring cases the reduction is 20% and 30%, respectively.

From Figure 4 we observe that the relative low-skill wage is decreasing ($P_{Ld}/P_{Hd} <$ 1) for almost all endowment combinations and the decline becomes more pronounced as β decreases and we move down to 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 as we have higher L-task offshoring levels.

5.1 Main result for the GRH two-country model

This pattern of decreasing relative low-skill wages for all but the small-country endowment set is consistent throughout all our simulations. We find it for both the linear and non-linear offshoring costs, for different combinations of production shares (α values) and different elasticities of substitution between both skills (σ values). As an example, in Figure 11 in the Appendix we show the simulations when using a different elasticity ($\sigma = 1$), different production shares and the two non-linear offshoring cost schedules ($OC3$ and $OC4$) .[18] But we still obtain the same pattern of decreasing relative low-skill wages for most endowment sets and increases only for relatively small country sizes.

These results are in strong contrast to the overall relative low-skill wage increases presented in the GRH one-country model. 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) increased low-skill task offshoring reduces the relative low-skill wage for almost all endowment combinations (i.e. different relative country sizes).

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-country assumption prices react to the exogenous change in offshoring activities and we now have a negative and strong relative price effect. In particular, when offshoring of low-skill tasks is increased, the productivity of low-skill workers is increased but this also increases the production of the low-skill intensive good (y). In general equilibrium, this increase in production decreases the relative price of y with respect to x (the high-skill intensive good). Thus, we have a negative price effect ($\mu_1 \widehat{p} < 0$) and our results show that this relative price effect is stronger than the productivity effect ($-\widehat{\Omega}$). In addition, with the broad number of endowment combinations we simulate there are cases for which the domestic country specializes in the production of only one good. In these cases we also have a negative labour-supply effect ($\mu_2 \frac{dI}{1-I} < 0$), which reinforces the decrease of relative low-skill wages.

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[18] The use of different σ values implies that we need to reformulate the general equilibrium equations. When $\sigma = 1$ we have Cobb-Douglas production functions (these are the equations shown in Table 3 in the Appendix), and for $\sigma > 1$ we use CES functions instead. In both cases, we assume that this elasticity is the same for both sectors.

5.2 Sensitivity of the results to extreme parameter values and different model specifications

To assess the robustness of these results, we use the most extreme parameter values to assess if the pattern of general decreasing relative low-skill wages is maintained. First, we use two extreme production share combinations, which are shown in Figure 12 in the Appendix. With $\alpha_x = 0.4$ and $\alpha_y = 0.5$ we have that production in both sectors has very similar low and high-skill requirements, and production specialization is more common. Therefore, we have that the labour-supply effect is usually positive and in this case the relative low-skill wage (P_{Ld}/P_{Hd}) is decreasing for all endowment sets. On the other hand, the other extreme production shares are $\alpha_x = 0.1$ and $\alpha_y = 0.9$, where the skill requirements in production are completely different and non-specialization is common. In this case we have that P_{Ld}/P_{Hd} is only increasing for countries with low-skill shares.

Next, we use a very high value for the elasticity of substitution ($\sigma = 3$) to see how sensitive the results are to this particular parameter. As explained above, the common value in the literature is 1.44, but we want to assess how the wage inequality results hold with an extreme value. The results are presented in Figure 13 in the Appendix. For this case, we observe that wage inequality (i.e. $P_{Ld}/P_{Hd} < 1$) is still increasing for most endowment sets, but now wage inequality is not only decreasing for relatively small countries, but also for countries that are close to the symmetric diagonal, which includes some medium and big countries. However, $\sigma = 3$ is already a value more than double of what is accepted in the literature and with $\sigma = 2$ our results are still robust.

Our next step is to analyse how sensitive the results are when we run 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 off-shorability indexes developed in Akcomak *et al.* (2010) in Figure 14 in the Appendix we plot industries ranked by their average education levels (as a proxy for skill levels). 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: $t_x(i) > t_y(i)$, and it is more difficult to offshore tasks in the high-skill intensive industry x.[19] Using the insights from Figure 14 we run a new round of simulations where each industry has different offshoring cost functions with the restriction that $t_x(i) > t_y(i)$. We find, however, that the pattern of decreasing relative low-skill wages (with respect to the no-offshoring case) is qualitatively the same as before.

In the Appendix we present two additional sets of simulations. First, in Section 8.4 we allow for both the offshoring of low-skill and high-skill tasks (Figure 15). Second, in Section 8.5 we present the simulation results using alternative trade-in-

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

tasks models. 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. We also show the results for the Markusen and Venables (2007) model. As explained there, the results are qualitatively very similar to the GRH two-country model results.

Finally, even though the focus of this paper is on wage inequality, it is also of interest to analyse the effect of offshoring on low-skill real wages (P_{Lh}/P, where P is a simple final goods price average). In Figure 18 in the Appendix we present the results using standard parameter values. Comparing with the results for relative wages (see Figure 4), we find that the scope of low-skill real wage increases ($P_{Lh}/P > 1$) is much larger than for relative wages. Thus, even though wage inequality is increasing with offshoring for most endowment combinations, real low-skill wages are increasing for a larger set of endowment combinations. However, this also means that for many cases (depending on particular parameter values), low-skill real wages are also decreasing.

5.3 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, we also have results for the foreign relatively low-skill abundant country, who is inshoring tasks and receiving the corresponding payment (ρ in our general equilibrium system).[20]

We first analyse wage inequality and find very different results from the H-abundant country cases. For many parameter combinations, we find that in the L-abundant country the relative low-skill wage is increasing for endowment combinations away , from the symmetric factor abundance axis (see Figure 19 in the Appendix). The endowment combinations close to the axis are associated with countries that have similar factor ratios, and thus, do not have large income differences. In other words, wage inequality is usually decreasing for countries that have relatively large shares of low-skill workers.

However, this pattern is not robust to changes in parameter values and in particular, wage inequality results are very sensitive to the production shares (α values). When we use extreme production shares, the wage inequality results described above are radically different. For the combination $\alpha_x = 0.4$ and $\alpha_y = 0.5$ we have that wage inequality is always decreasing. But when we use the combination $\alpha_x = 0.1$ and $\alpha_y = 0.9$ we find that wage inequality is almost always increasing. Therefore, the results vary much between these two extremes and we do not find any generalized wage inequality results for the low-skill abundant country.

The only result that can be generalized is that offshoring is always welfare improving in the L-abundant country. Figure 20 in the Appendix shows that welfare

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[20]Note that the terms-of-trade effects are just the inverse of those for the H-abundant country.

is increasing in L-task offshoring for all endowment combinations. This result is robust to changes in the production shares, the elasticity of substitution and the four offshoring cost schedules. 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. The biggest welfare gains, moreover, are for relatively small countries.

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 skills 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. For instance, this GRH model extension can also shed light on the expected effects of a new wave of globalization where high-skill tasks are increasingly offshored.

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

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

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).[21]

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. 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.

We first model the offshoring changes in the three-skill GRH model as a sequence of offshoring stages. This sequential offshoring procedure is consistent with the findings that offshorability is monotonically decreasing in skill levels (Akcomak *et al.*,

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[21] 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.

2010). This offshoring sequence is also consistent with the findings by Costinot *et al.* (2010) and Oldenski (2010) that H-skill non-routine tasks are harder to offshore than routine tasks.

In the first stage only L-task are being offshored, in the second stage both L-task and M-tasks are offshored with the level of L-tasks offshored being higher (i.e. $I_L > I_M$), and in the final third stage all three skill tasks are being offshored, although a hierarchy of offshoring levels is maintained, such that: $I_L > I_M > I_H$.[22]

The wage inequality results are presented in Figure 5.[23] 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. Each column represents one of the three sequential offshoring stages and each stage is compared with the previous one. For instance, the first columns shows L-task offshoring with respect to the no-offshoring case. The second column has both L and M-task offshoring, and the results are compared with stage 1. Finally, the third column has offshoring in all labour skills, and we compare these results with respect to stage 2. Note that in the graphs relative wage values above one indicate increases with respect to the previous offshoring stage.

In the first column (stage 1) we observe that low-skill wages are decreasing with respect to both medium and high-skill wages. Thus, this result is in line with the two-skill model where relative low-skill wages is decreasing (for most cases) when only L-tasks are being offshored. Moreover, relative medium-skill wages are increasing with respect to the other two skill wages.

In stage 2 (with both L and M-task offshoring) we observe wage polarization. Medium-skill wages are decreasing with respect to both low and high-skill wages. Finally, in the last column (stage 3) we find that for many endowment combinations overall wage inequality is decreasing, since lower skill wages are decreasing to the higher ones. However, there are some endowment combinations for which this is not the case, and thus, we cannot generalize this result.

Therefore, using this intuitive offshoring sequence we find that the three-skill extension of the GRH model can produce wage polarization when we allow for both low-skill and medium-skill tasks to be offshored. In the Appendix we also present an alternative offshoring sequence (truncated offshoring) where low-skill tasks are no longer offshorable and only medium and high-skill tasks can be offshored. In this case, we also find wage polarization, and moreover, when both M and H-task are offshored we find an overall decrease in wage inequality for all endowment combinations.

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[22] In practical terms, each offshoring stage is simulated by changing the general offshoring parameters (β for L-tasks, μ for M-tasks and γ for H-tasks). In Stage 1 only L-task offshoring is allowed and we reduce β by 10%. In Stage 2 we reduce β by 20% and μ by 10%. Finally, in Stage 3, β is reduced by 30%, μ by 20% and γ by 10%.

[23] The results shown in this Figure are qualitatively similar with changes in the elasticity of substitution (σ), different production share combinations, and when we use our four offshoring cost schedules.

Figure 5: GRH model with three factors, changes in relative wages with sequential offshoring.
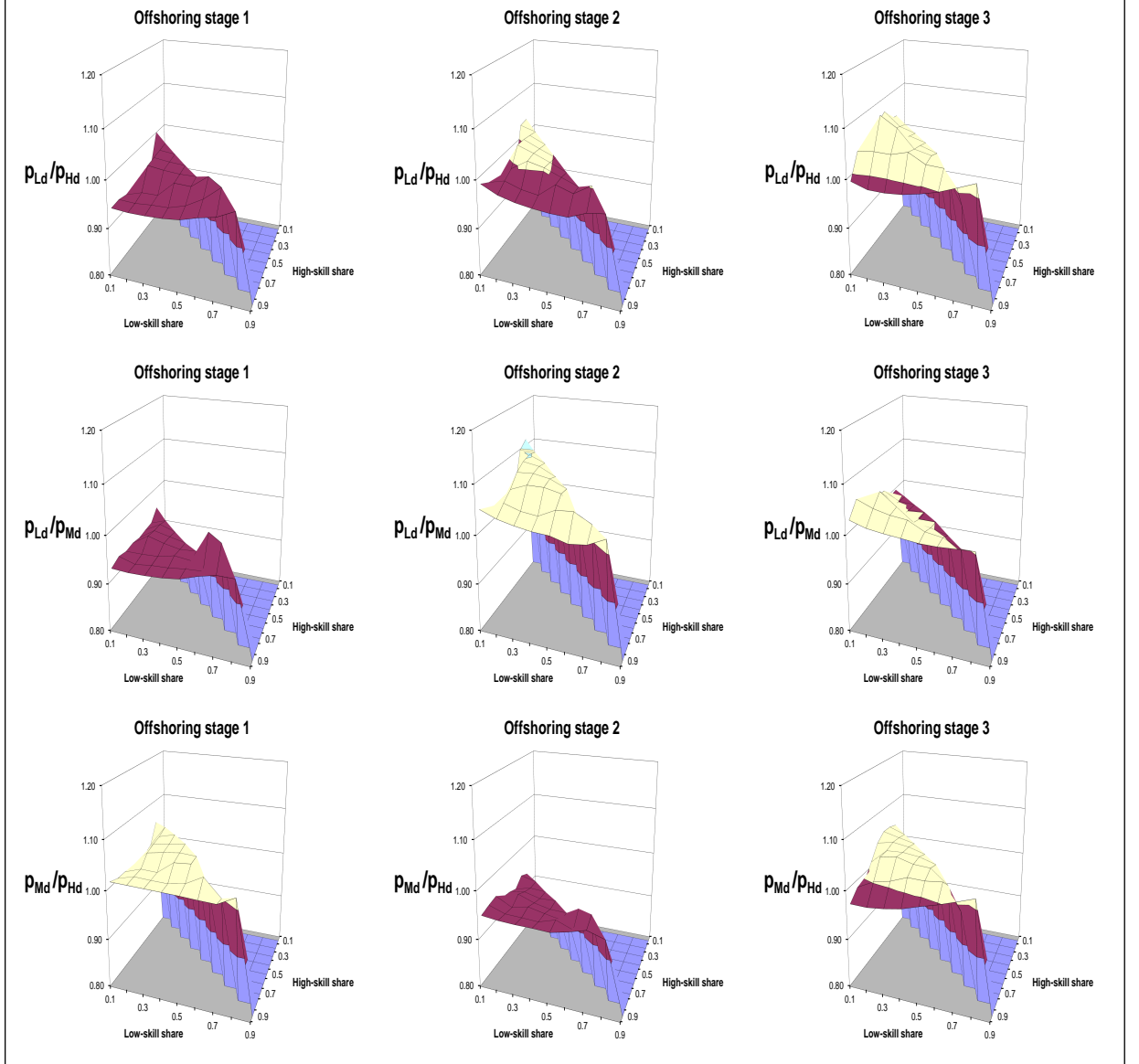
Notes: Left column has Stage 1 (only L-task offshoring), middle column has Stage 2 (both L and M-task offshoring with $I_L > I_M$), and right column has Stage 3 (all skill-types can be offshored, with $I_L > I_M > I_H$). Each offshoring stage is compared with the previous, so values above one represent relative wage increases with respect to the previous stage. Rows indicate different relative wage combinations. Common parameters in all graphs: Non-linear offshoring schedule $OC4$ ($t_1 = 1$, $t_2 = 7$, $t_3 = 2.5$), $\sigma = 1.44$, $\alpha_x = 0.2$, $\phi_x = 0.3$, $\alpha_y = 0.5$, and $\phi_y = 0.3$.

To sum up, we find that 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 the possibility that medium-skill tasks are offshored. 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.

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 extensive numerical simulations of their model –which include a wide range of parameter variation and different model specifications– we find that relative low-skill wages are decreasing in most cases. In this respect, the possibility of relative low-skill wages increasing when low-skill tasks are being offshored is indeed a very special case.

In particular, the distributional effects of offshoring are related to country size (i.e. relative endowments). For small rich countries offshoring is increasing welfare and reducing wage inequality (the special GRH case), however, for most relatively medium and big 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 (i.e. factor shares, elasticities of substitution between factors), and offshoring specifications (e.g. different offshoring levels, offshoring cost schedules 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 and for all relative country sizes. However, the distributional effects of offshoring cannot be generalized and the results are dependent on relative country size and on the parameters of the model –in particular, the factor shares in production.

Finally, we also run a wide range of simulations on a variant of the GRH model with three different skill types (low, medium and high). We find that this version of the trade-in-tasks model can reconcile offshoring with a wage polarization pattern when we allow the possibility to offshore medium-skill tasks. The wage polarization pattern even holds when M-task offshoring is part of sequential offshoring stages (preceded by L-task offshoring) or when we have a truncated offshoring stages (no L-task offshoring allowed). We also find that when H-task offshoring is allowed, there is a general tendency for overall wage inequality to decrease, although this result does not hold for all relative country sizes.

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8 Appendix

Figure 6: United Kingdom, offshorability index by industries ranked by average education levels, for 1997 and 2005, linear fit[a]
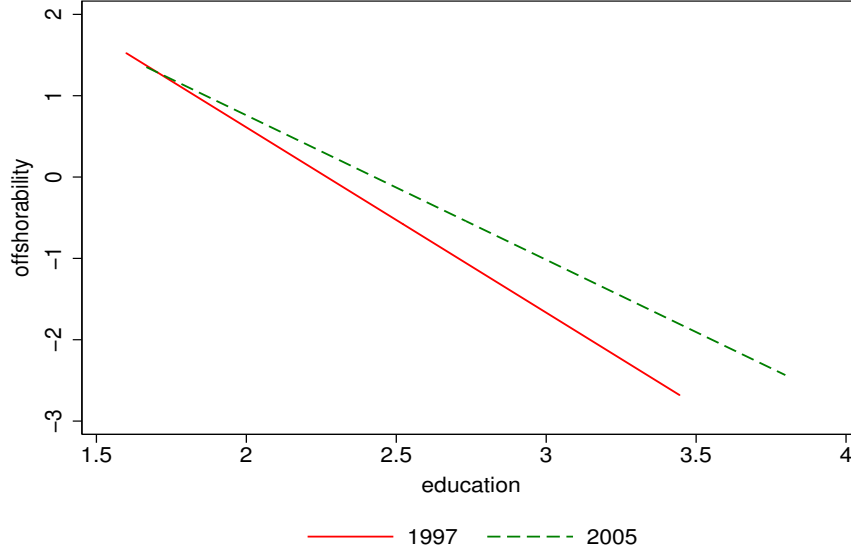
The offshorability index is constructed using detailed UK task data from the British Skills Survey (BSS, rounds 1997, 2001 and 2006). The occupation-task specific index is based on two measures: task-occupation wage differential and task-occupation connectivity. The former is based on the difference 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.

8.1 GRH one-country model in a MCP setting

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.[24]

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	$\frac{1}{A} \left[\Omega_L p_{Ld} \right]^{\alpha_x} (\Omega_H p_{Hd})^{1-\alpha_x} \geq p_{xd}$	x
Zero profits for y	$\frac{1}{A} \left[\Omega_L p_{Ld} \right]^{\alpha_y} (\Omega_H p_{Hd})^{1-\alpha_x} \geq p_{yd}$	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.

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). The other twelve equations

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[24]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.

are standard general equilibrium conditions. In this particular one-country model, we assume that domestic prices are determined by international prices (p_{jf}).

8.2 GRH one-country model results with non-specialization

In Figure 7 we present the relative changes of 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 7 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.

Figure 7: GRH one-country model, changes in offshoring levels, welfare and production, for non-linear offshoring schedule $OC3$.
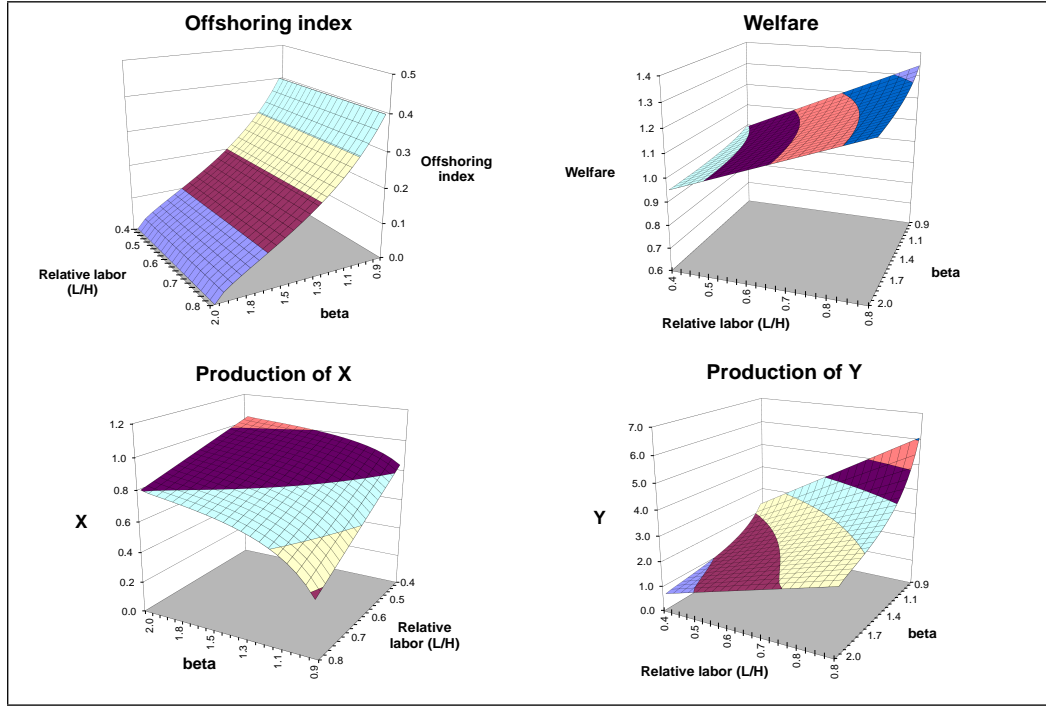
Notes: For presentation reasons the axes in the graph labelled "Production of X" is rotated. Common parameters in all graphs: $\sigma = 1$, $\alpha_x = 0.2$ and $\alpha_y = 0.7$; $OC3$: $t_1 = 1$, $t_2 = 7$, $t_3 = 1.5$.

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8.3 GRH two-country model in a MCP setting

<div align="center">

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

</div>

INEQUALITY	EQUATION	COMP. VAR.
Zero profits for x_{dd}	$\frac{1}{A_d}\left[\Omega_L p_{Ld}\right]^{\alpha_x}\left(\Omega_H p_{Hd}\right)^{1-\alpha_x} \geq p_{xd}$	x_{dd}
Zero profits for y_{dd}	$\frac{1}{A_d}\left[\Omega_L p_{Ld}\right]^{\alpha_y}\left(\Omega_H p_{Hd}\right)^{1-\alpha_x} \geq p_{yd}$	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:

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

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: $\sigma_x = \sigma_y = \sigma$.

Figure 8: GRH two-country model, changes in offshoring index, with linear off-shoring cost schedules (one per column), at three different offshoring levels.
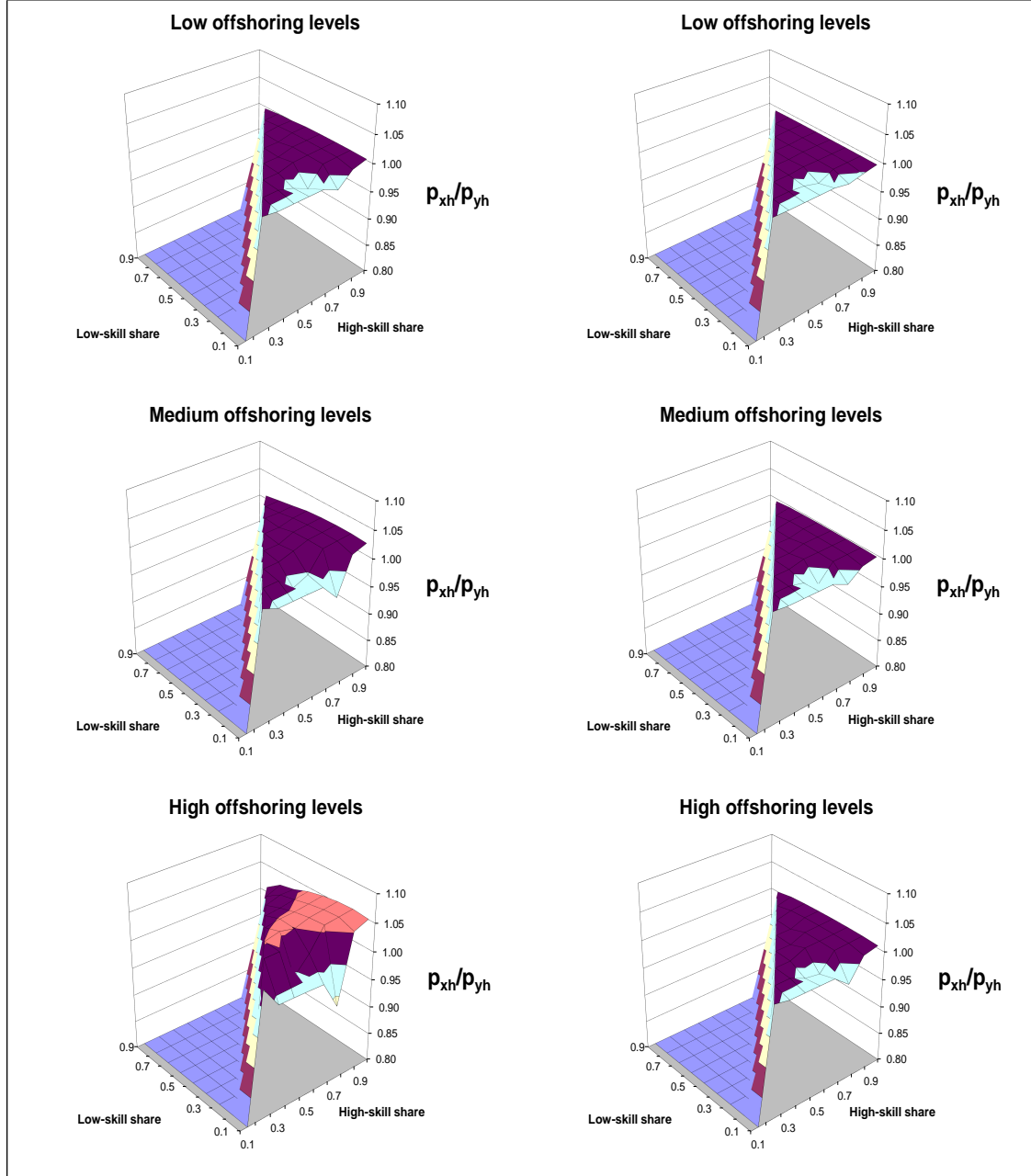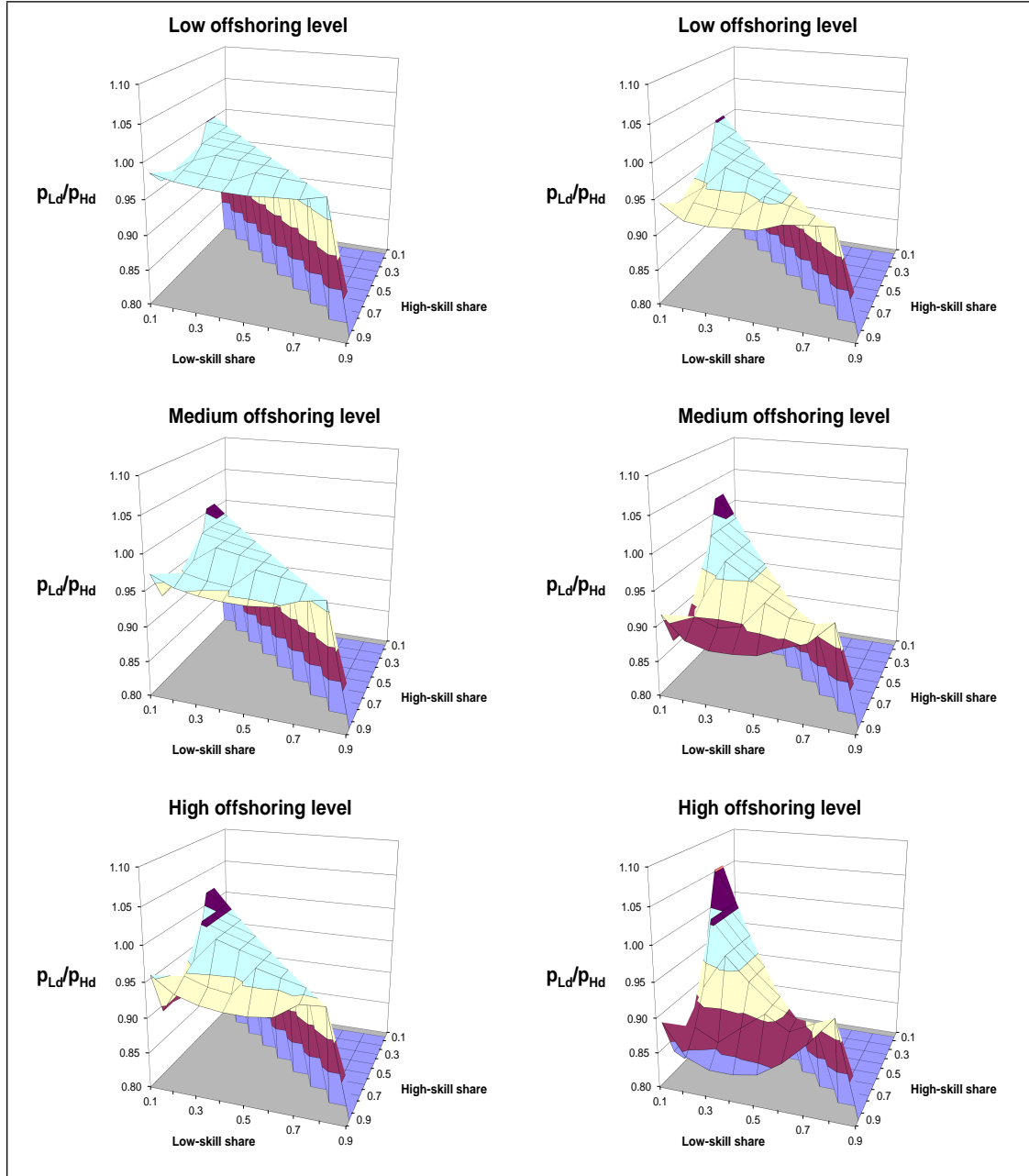

Notes: Left column has more sensitive offshoring cost parameters ($OC1$: $t_1 = 1$, $t_2 = 1$, $t_3 = 1$) and right column less sensitive parameters ($OC2$: $t_1 = 1$, $t_2 = 4$, $t_3 = 1$). Common parameters in all graphs: $\sigma = 1.44$, $\alpha_x = 0.3$ and $\alpha_y = 0.6$. In the low offshoring cases β is reduced 10% with respect to β_0, in the medium and high offshoring cases the reduction is 20% and 30%, respectively.

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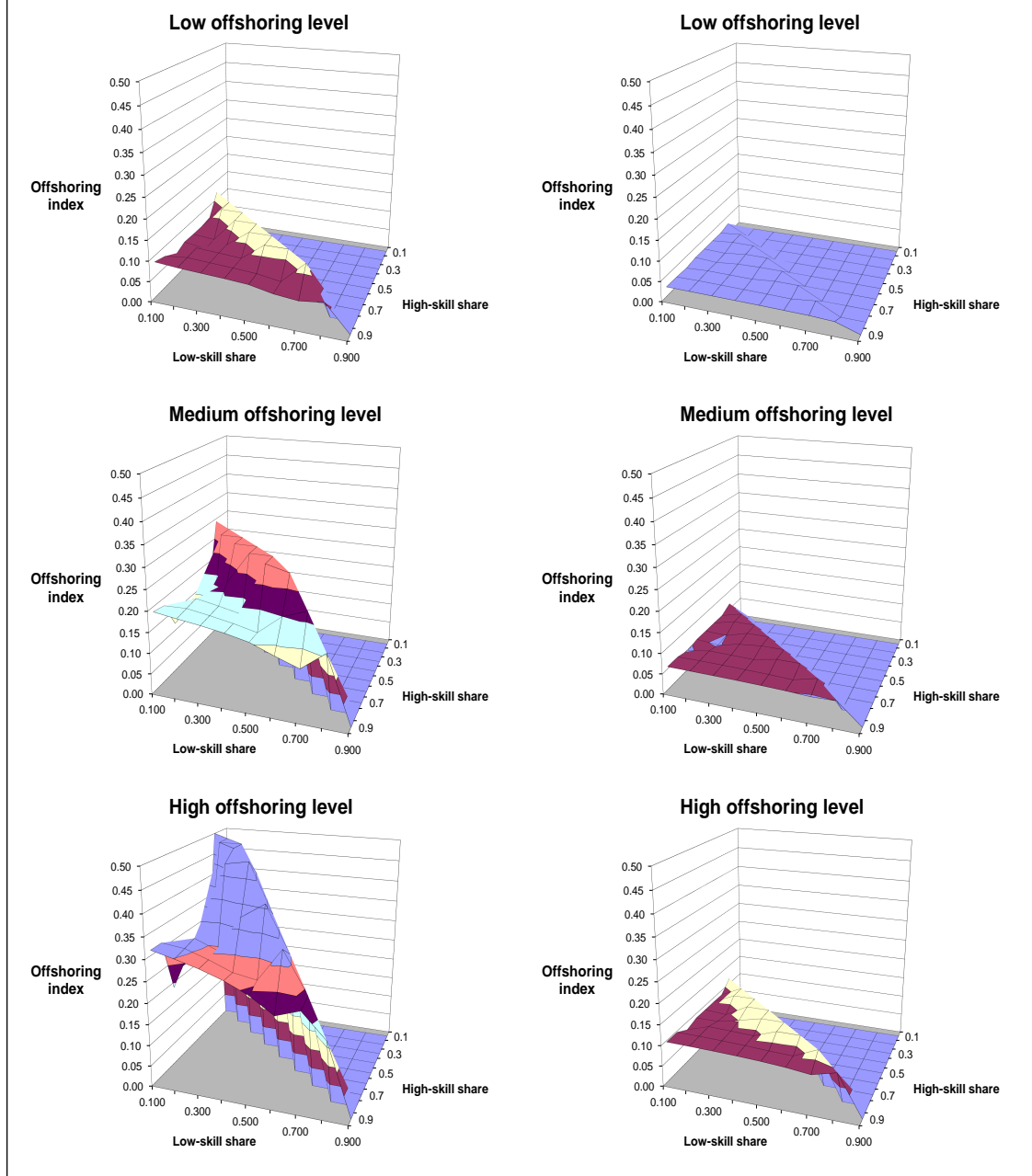
Figure 9: GRH two-country model, welfare changes with respect to no-offshoring scenario, with linear offshoring cost schedules (one per column), at three different offshoring levels.
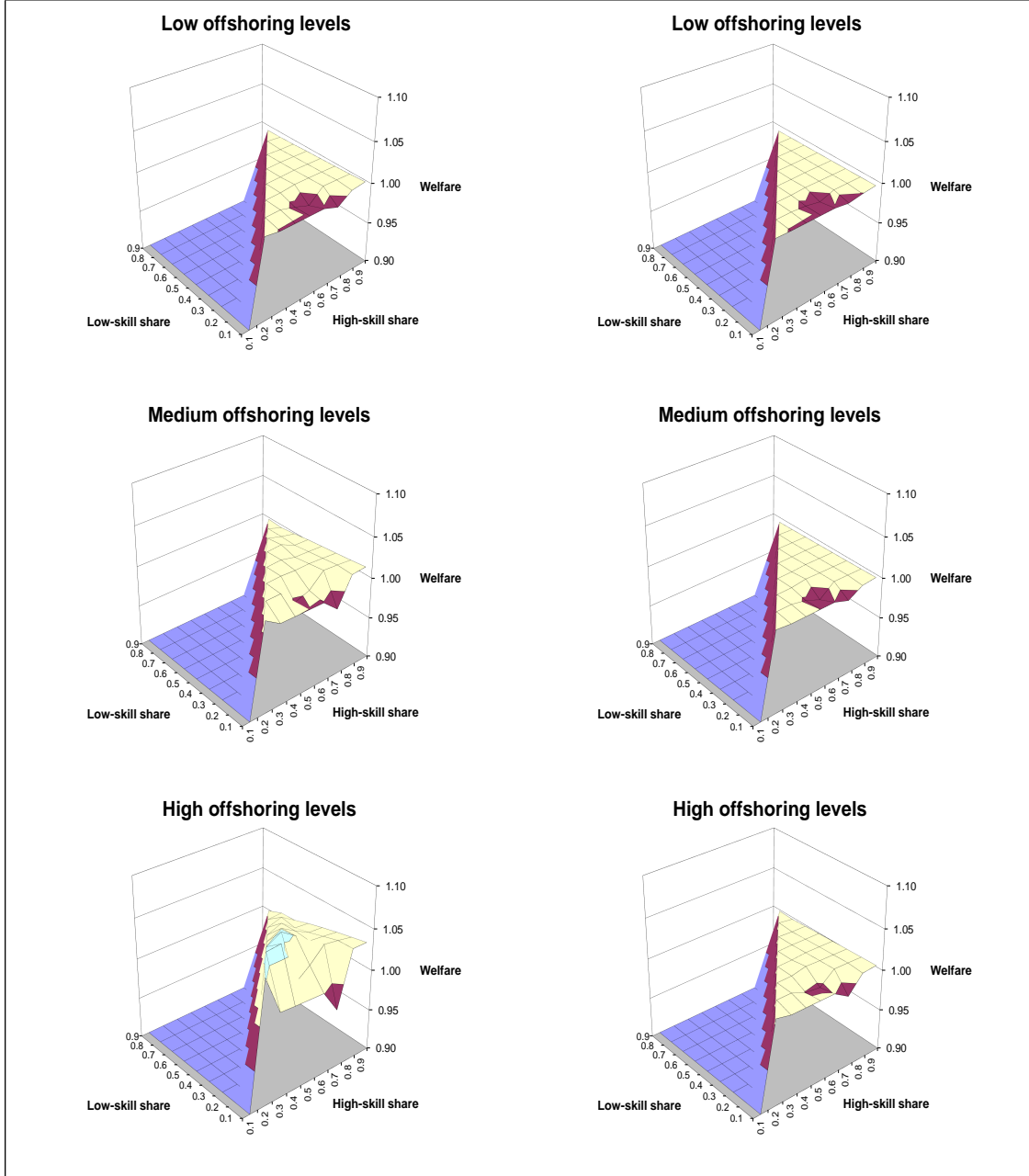
Notes: Left column has more sensitive offshoring cost parameters ($OC1$: $t_1 = 1$, $t_2 = 1$, $t_3 = 1$) and right column less sensitive parameters ($OC2$: $t_1 = 1$, $t_2 = 4$, $t_3 = 1$). Common parameters in all graphs: $\sigma = 1.44$, $\alpha_x = 0.3$ and $\alpha_y = 0.6$. In the low offshoring cases β is reduced 10% with respect to β_0, in the medium and high offshoring cases the reduction is 20% and 30%, respectively.

Figure 10: GRH two-country model, terms-of-trade (TOT) changes with respect to no-offshoring scenario, with linear offshoring cost schedules (one per column), at three different offshoring levels.

Notes: Left column has more sensitive offshoring cost parameters ($OC1$: $t_1 = 1$, $t_2 = 1$, $t_3 = 1$) and right column less sensitive parameters ($OC2$: $t_1 = 1$, $t_2 = 4$, $t_3 = 1$). Common parameters in all graphs: $\sigma = 1.44$, $\alpha_x = 0.3$ and $\alpha_y = 0.6$. In the low offshoring cases β is reduced 10% with respect to β_0, in the medium and high offshoring cases the reduction is 20% and 30%, respectively.

Figure 11: GRH two-country model, changes in relative wages with respect to no-offshoring scenario, with non-linear offshoring cost schedules (one per column), at three different offshoring levels.

Notes: Left column has more sensitive offshoring cost parameters ($OC3$: $t_1 = 1$, $t_2 = 7$, $t_3 = 1.5$) and right column less sensitive parameters ($OC4$: $t_1 = 1$, $t_2 = 7$, $t_3 = 2.5$). Common parameters in all graphs: $\sigma = 1$, $\alpha_x = 0.2$ and $\alpha_y = 0.7$. In the low offshoring cases β is reduced 10% with respect to β_0, in the medium and high offshoring cases the reduction is 20% and 30%, respectively.

Figure 12: GRH two-country model, changes in relative wages with respect to no-offshoring scenario, with extreme production shares, offshoring cost schedule $OC3$, at three different offshoring levels.
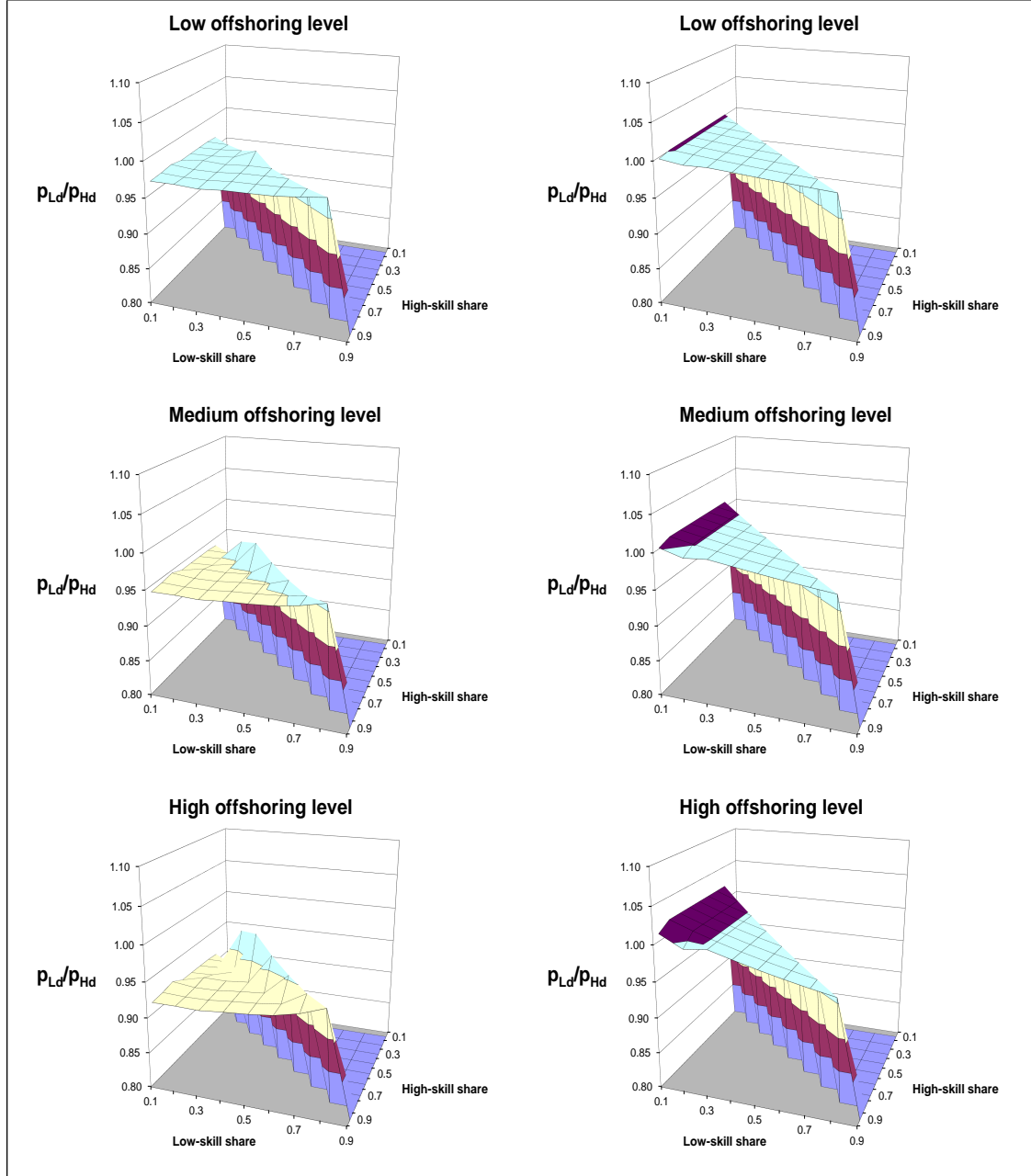
Notes: Left column has production shares: $\alpha_x = 0.4$ and $\alpha_y = 0.5$. Right column has $\alpha_x = 0.1$ and $\alpha_y = 0.9$. Common parameters in all graphs: $\sigma = 1.44$, offshoring cost schedule $OC3$: $t_1 = 1$, $t_2 = 7$, $t_3 = 1.5$. In the low offshoring cases β is reduced 10% with respect to β_0, in the medium and high offshoring cases the reduction is 20% and 30%, respectively.

Figure 13: GRH two-country model, changes in relative wages with respect to no-offshoring scenario, with $\sigma = 3$, two different offshoring cost schedules ($OC2$ and $OC3$), at three different offshoring levels.
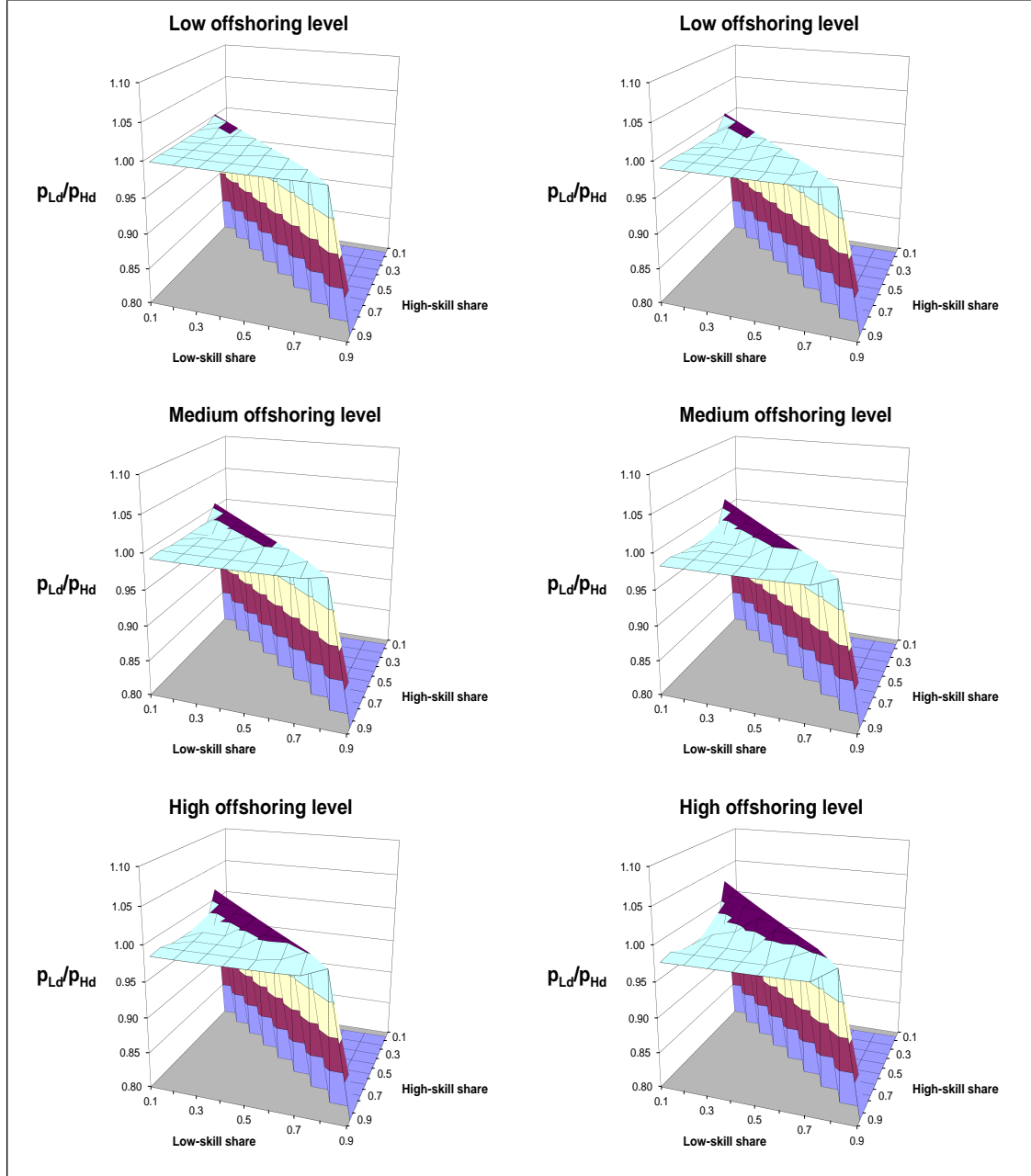
Notes: Left column has offshoring cost $OC2$ ($t_1 = 1$, $t_2 = 4$, $t_3 = 1$) and right column has $OC3$ ($t_1 = 1$, $t_2 = 7$, $t_3 = 1.5$). Common parameters in all graphs: $\sigma = 3$, $\alpha_x = 0.3$ and $\alpha_y = 0.6$. In the low offshoring cases β is reduced 10% with respect to β_0, in the medium and high offshoring cases the reduction is 20% and 30%, respectively.

Figure 14: United Kingdom, offshorability index for 27 industry division, with industries ranked by average education levels, average values from 1997, 2000 and 2006 data[a]

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

Here we allow for both L-task and H-task offshoring. In particular, we run simulation when 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 three stages of γ decreases, that are related to the low, medium and high L-task offshoring levels used until now. For the low offshoring level γ is not changing (and there is no H-task offshoring), but in the medium and high offshoring levels γ is decreased by 2% and 5%, respectively. 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 15 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 robust to different offshoring cost schedules, different α values and our three main σ values (1, 1.44 and 2).

Figure 15: GRH two-country model, changes in relative wages with respect to no-offshoring scenario, with both L-task and H-task offshoring at three different off-shoring levels.
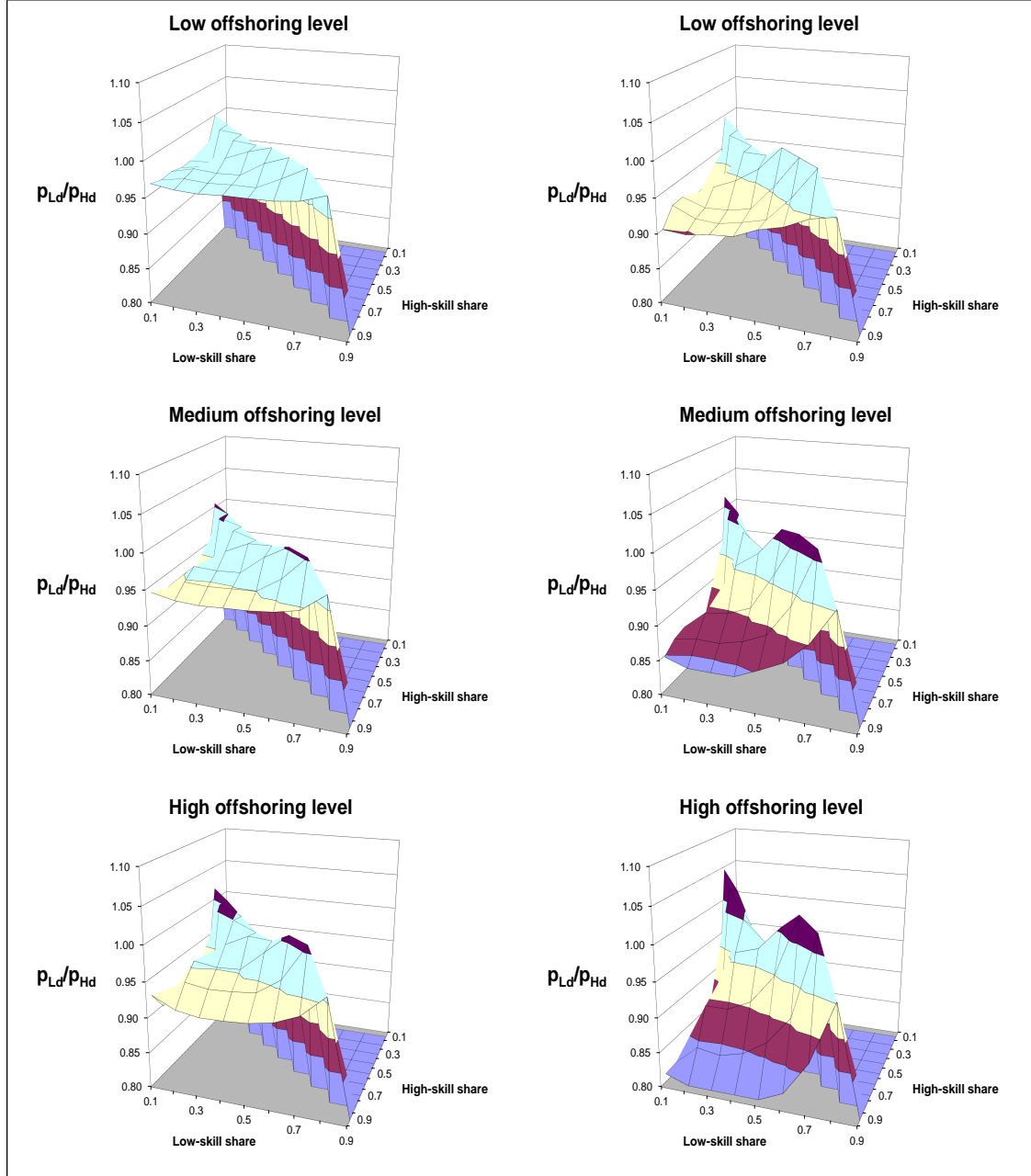
Notes: Left column has offshoring cost $OC3$ ($t_1 = 1$, $t_2 = 7$, $t_3 = 1.5$) and right column has $OC4$ ($t_1 = 1$, $t_2 = 7$, $t_3 = 2.5$). Common parameters in all graphs: $\sigma = 1$, $\alpha_x = 0.3$ and $\alpha_y = 0.6$. In the low offshoring cases β is reduced 10% with respect to β_0, while γ is not changed. In the medium and high offshoring cases β is reduced is 20% and 30%, respectively; while γ is reduced by 2% and 5%, respectively.

## 8.5 Alternative trade-in-tasks models

8.5.1 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 16. 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 16, 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 16: GRH-Markusen model, relative wage changes with respect to no-offshoring scenario, at three different offshoring levels.
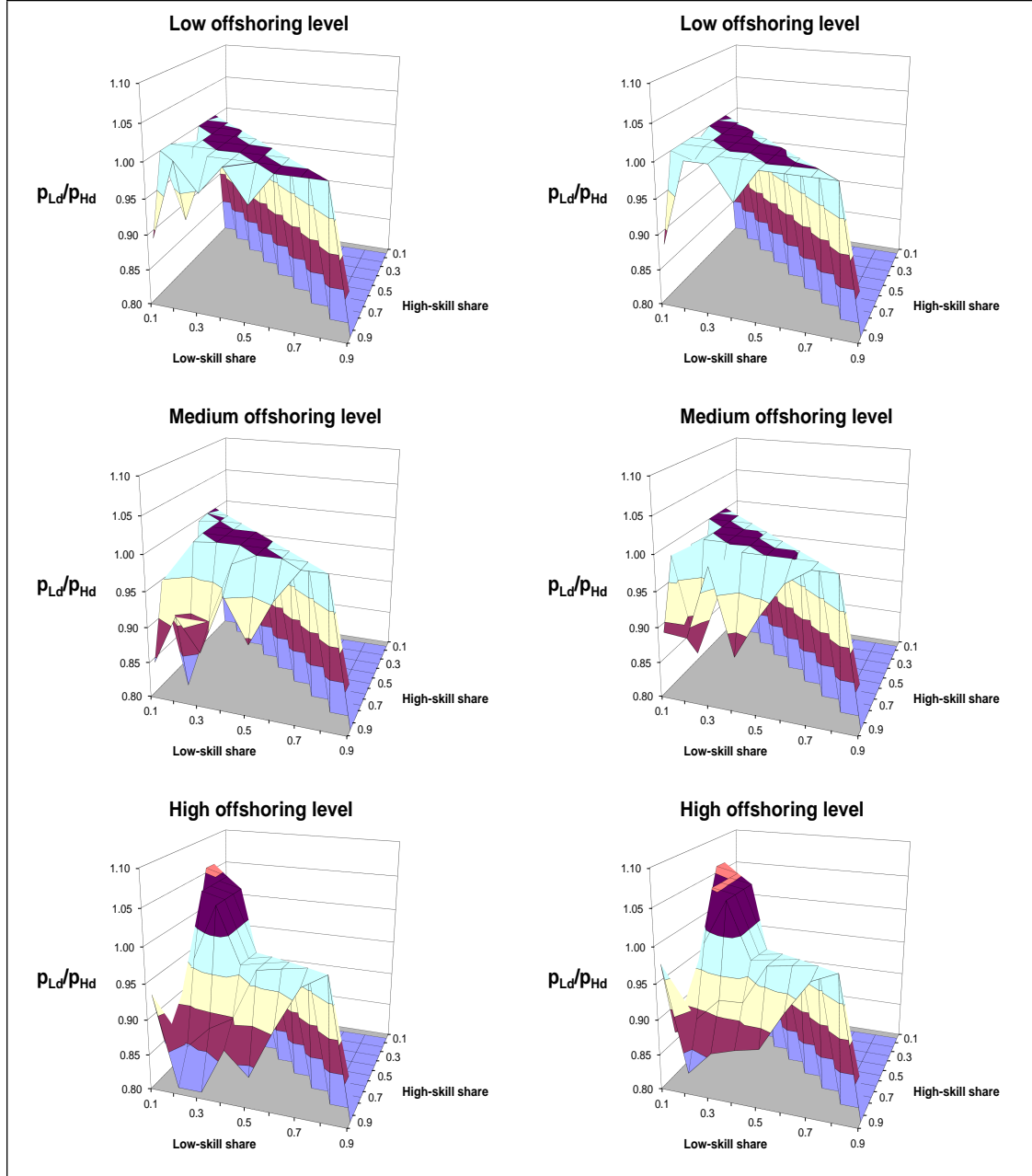
Notes: Left column has $\sigma = 1$ and right column has $\sigma = 1.44$. Common parameters in all graphs: $\alpha_x = 0.2$ and $\alpha_y = 0.7$. In the low offshoring cases trade costs are reduced by 10%. In the medium and high offshoring cases the trade cost reduction is 20% and 30%, respectively.

8.5.2 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 17 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 17: Markusen-Venables (2007) model, relative wage changes with respect to no-offshoring scenario, at three different offshoring levels.
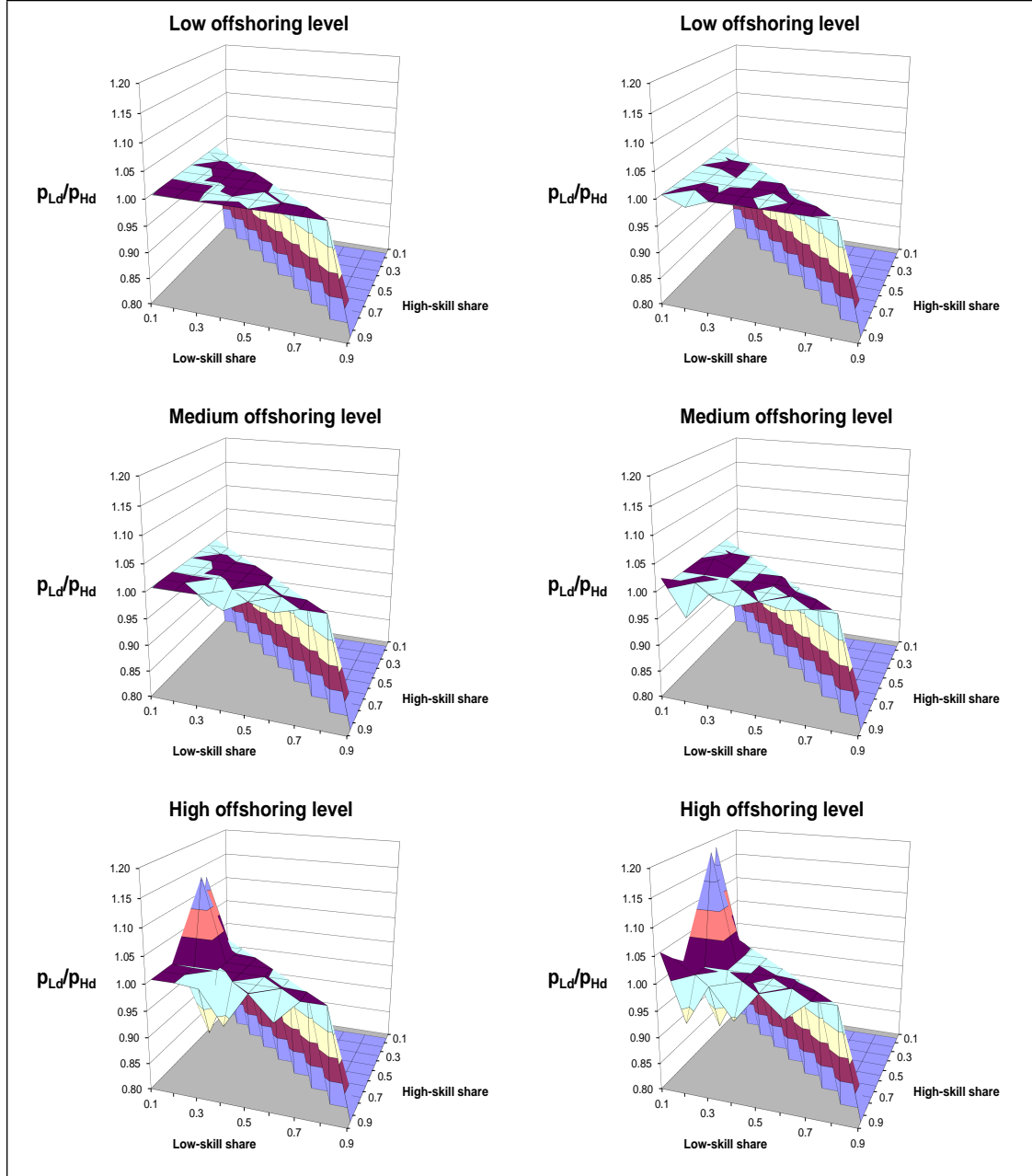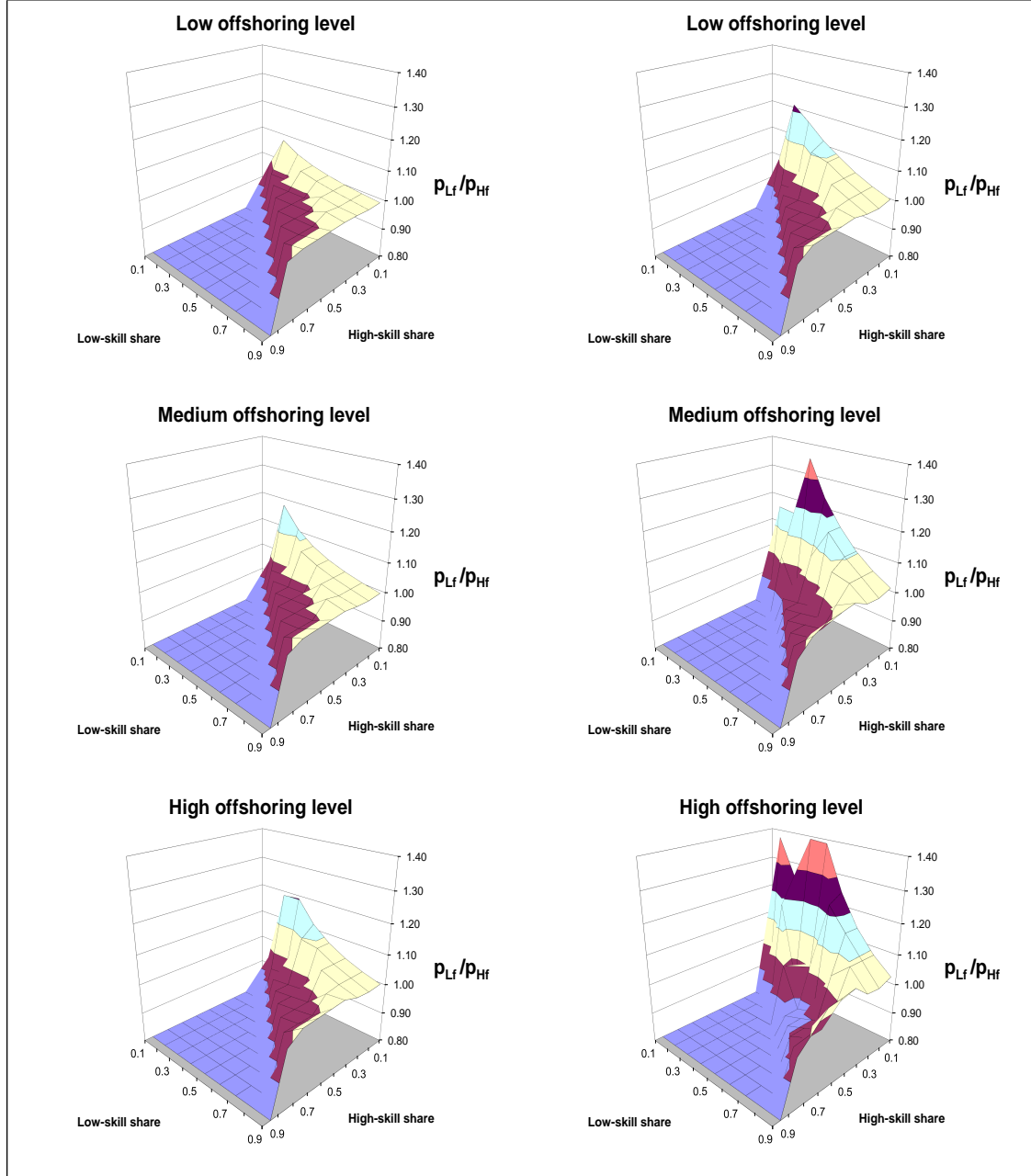
Notes: Left column has $\sigma = 1$ and right column has $\sigma = 1.44$. In the low offshoring cases trade costs are reduced by 10%. In the medium and high offshoring cases the trade cost reduction is 20% and 30%, respectively.

Figure 18: GRH two-country model, changes in low-skill real wages with respect to no-offshoring scenario, with non-linear offshoring cost schedules (one per column), at three different offshoring levels.

Notes: Left column has more sensitive offshoring cost parameters ($OC3$: $t_1 = 1$, $t_2 = 7$, $t_3 = 1.5$) and right column less sensitive parameters ($OC4$: $t_1 = 1$, $t_2 = 7$, $t_3 = 2.5$). Common parameters in all graphs: $\sigma = 1.44$, $\alpha_x = 0.3$ and $\alpha_y = 0.7$. In the low offshoring cases β is reduced 10% with respect to β_0, in the medium and high offshoring cases the reduction is 20% and 30%, respectively.

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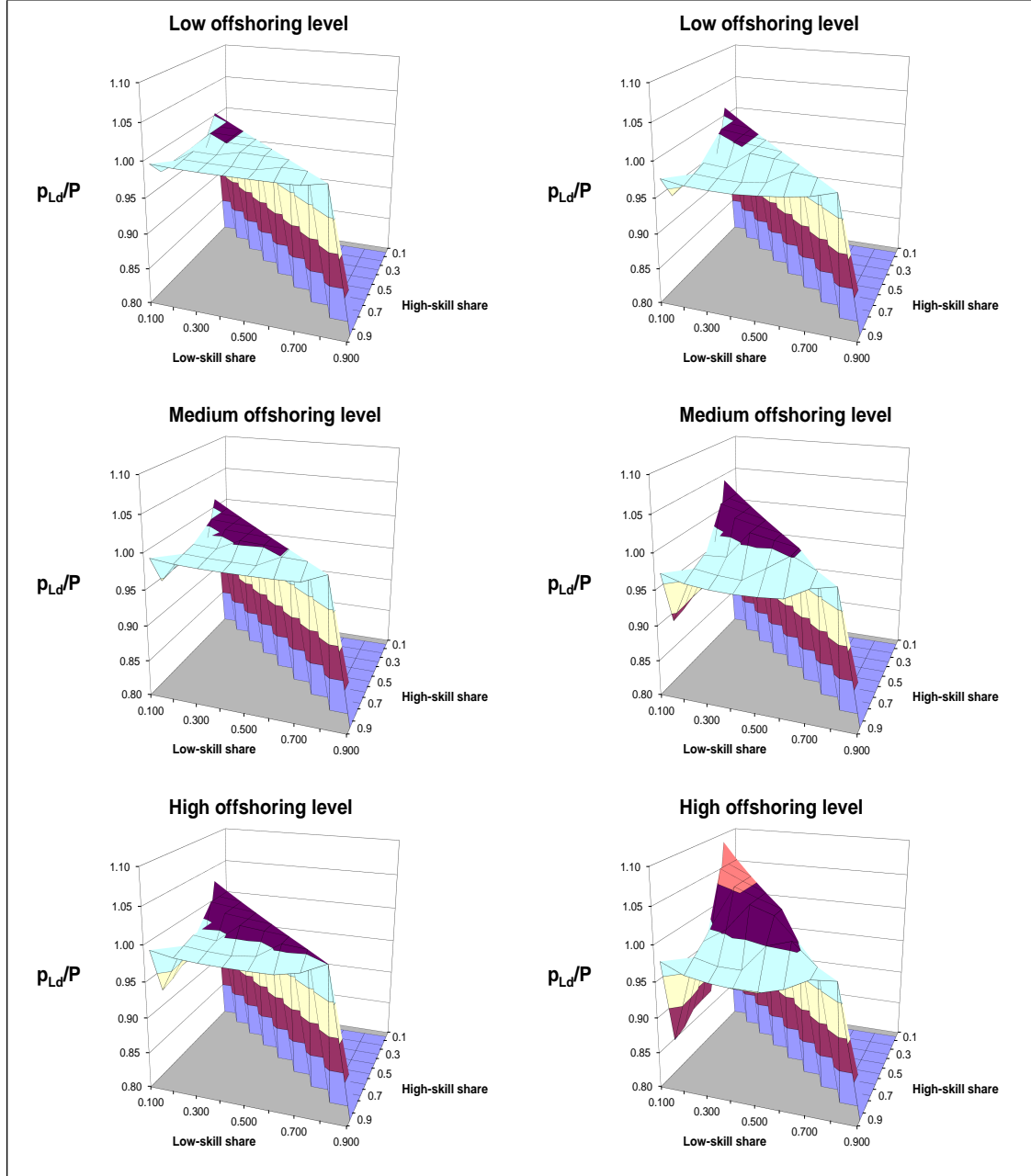
Figure 19: GRH two-country model, L-abundant country, changes in relative wages with respect to no-offshoring scenario, with linear offshoring cost schedules (one per column), at three different offshoring levels.

Notes: Left column has less sensitive offshoring cost parameters ($OC3$: $t_1 = 1$, $t_2 = 7$, $t_3 = 1.5$) and right column more sensitive parameters ($OC4$: $t_1 = 1$, $t_2 = 7$, $t_3 = 2.5$). Common parameters in all graphs: $\sigma = 1.44$, $\alpha_x = 0.3$ and $\alpha_y = 0.7$. In the low offshoring cases β is reduced 10% with respect to β_0, in the medium and high offshoring cases the reduction is 20% and 30%, respectively.

Figure 20: GRH two-country model, L-abundant country, welfare changes with respect to no-offshoring scenario, with linear offshoring cost schedules (one per column), at three different offshoring levels.
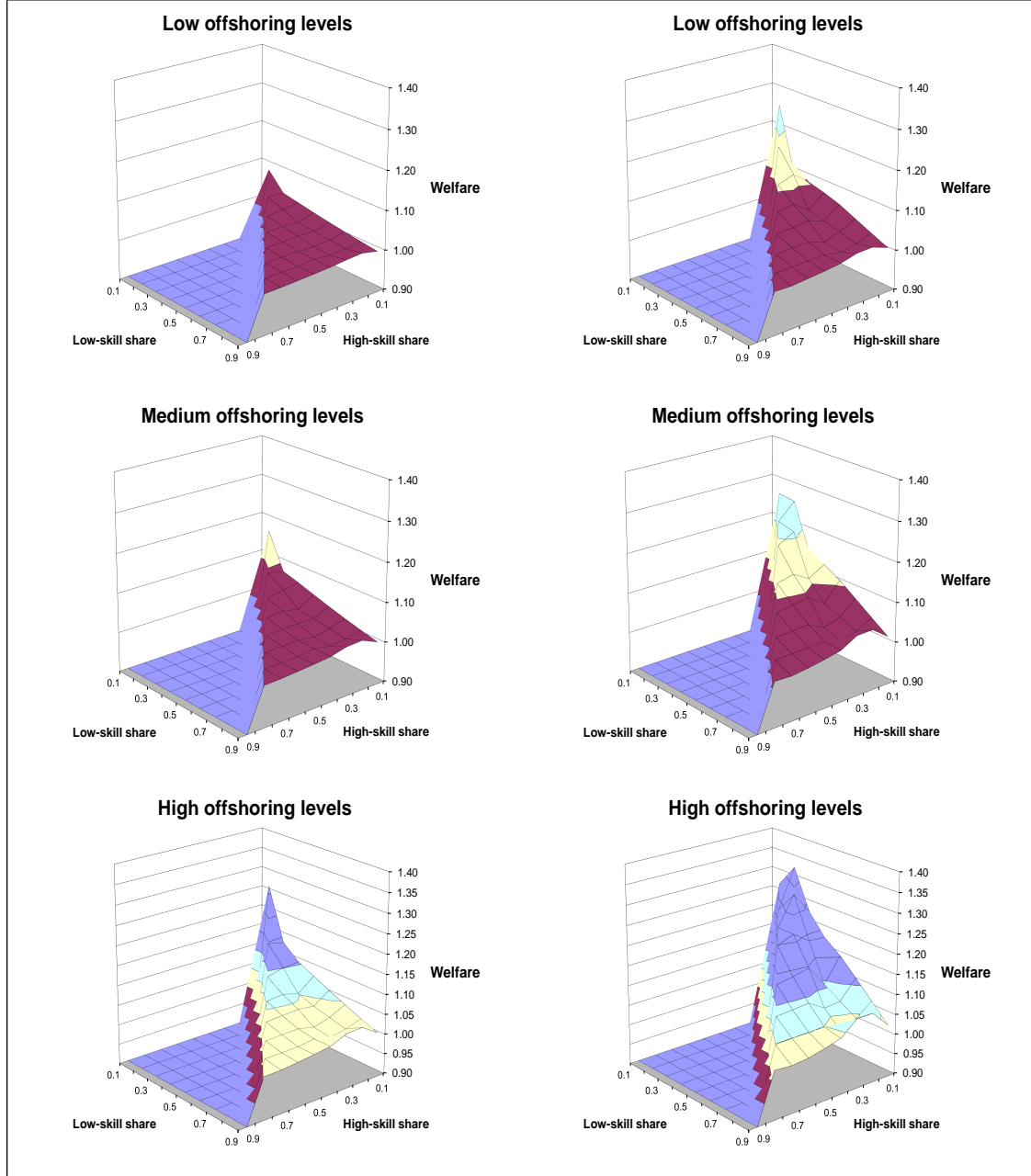
Notes: Left column has less sensitive offshoring cost parameters ($OC3$: $t_1 = 1$, $t_2 = 7$, $t_3 = 1.5$) and right column more sensitive parameters ($OC4$: $t_1 = 1$, $t_2 = 7$, $t_3 = 2.5$). Common parameters in all graphs: $\sigma = 1.44$, $\alpha_x = 0.3$ and $\alpha_y = 0.7$. In the low offshoring cases β is reduced 10% with respect to β_0, in the medium and high offshoring cases the reduction is 20% and 30%, respectively.

8.6 Truncated offshoring

This offshoring pattern is characterized by no offshoring of low-skill tasks. We maintain the three stage approach of Section 6 but not allowing for any L-task offshoring. Thus, in stage 1 there is no offshoring activities. In Stage 2 we only reduce μ by 10% to allow M-task offshoring, and in stage 3 μ is reduced by 20% and γ by 10%, so we have $I_M > I_H$.

This particular offshoring sequence is consistent with the view that all the L-tasks that could have been offshored have already been offshored. Thus, the remaining L-tasks performed in the domestic country are tasks that require physical proximity and/or personal face to face contact, and thus, their offshorability is not dependent on international wage differentials. This follows the view of Blinder (2006) that offshorability is directly related to physical proximity.[25]

The simulation results for the truncated offshoring stages are presented in Figure 21. In the first column (stage 2) we only allow for M-task offshoring, and we obtain a wage polarization pattern: medium-skill wages are losing relatively to both low and high-skill wages. For the second column (with both M and H-task offshoring) we observe an overall wage inequality increase, since for most of the endowment combinations, lower skill wages are decreasing to the higher ones. The only exceptions are some endowment combinations where $P_{Md}/P_{Hd} < 1$, i.e. medium-skill wages are decreasing with respect to high-skill wages.

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[25]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. It also fits with the task 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 mostly routine M-tasks are offshorable.

Figure 21: GRH model with three factors, changes in relative wages with a truncated offshoring sequence (no L-task offshoring).
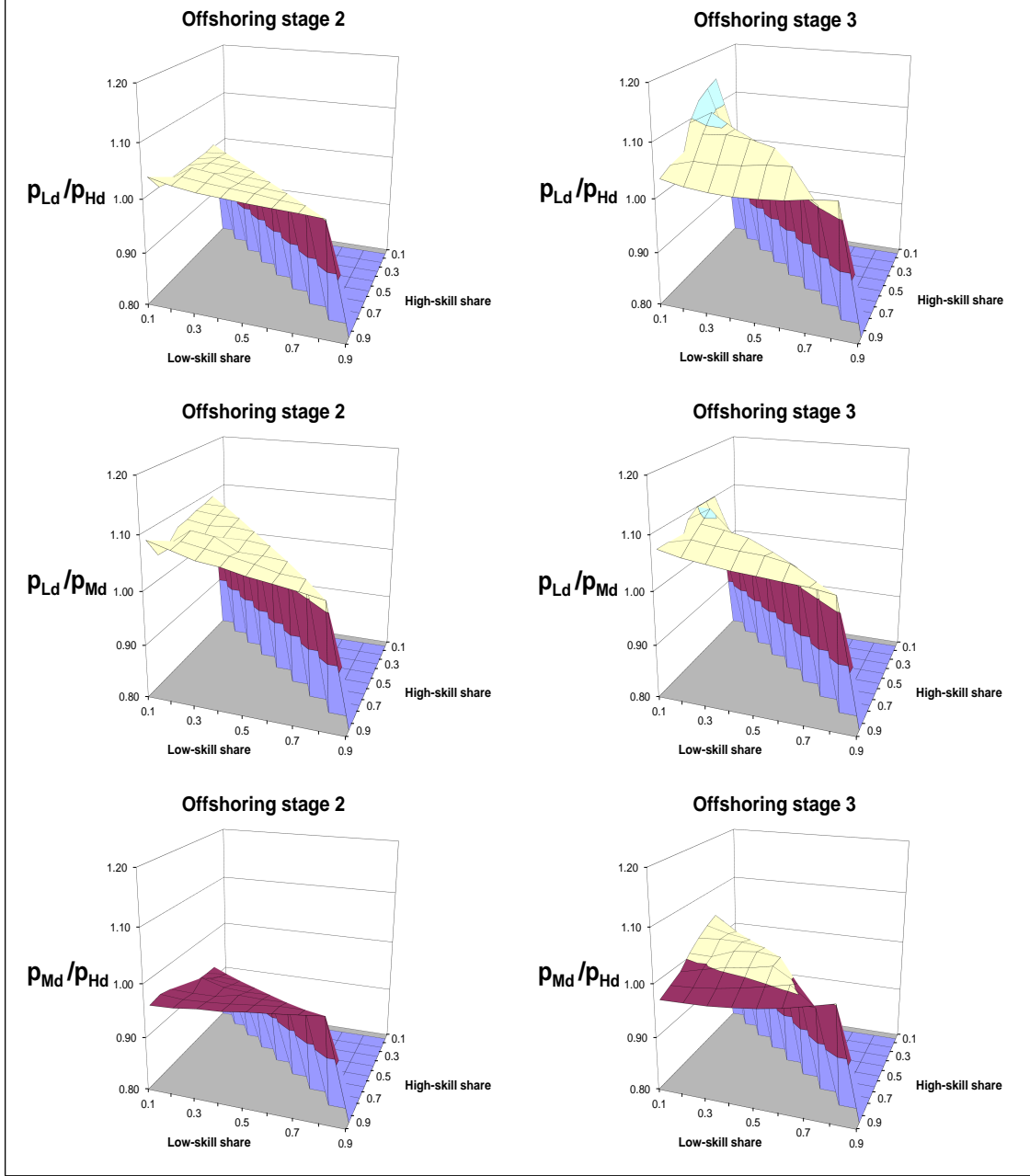
Notes: Left column has truncated stage 2 offshoring: only M-task offshoring and results are compared with no-offshoring case. Right column has truncated stage 3 offshoring: both M and H-task offshoring (with $I_M > I_H$) and results are compared with stage 2. Rows indicate different relative wage combinations. Common parameters in all graphs: Non-linear offshoring schedule $OC4$ ($t_1 = 1$, $t_2 = 7$, $t_3 = 2.5$), $\sigma = 1.44$, $\alpha_x = 0.2$, $\phi_x = 0.3$, $\alpha_y = 0.5$, and $\phi_y = 0.3$.