#2016-070

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Tel: (31) (43) 388 44 00
UNU-MERIT Working Papers
ISSN 1871-9872

Maastricht Economic and social Research Institute on Innovation and Technology
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Offshoring Medium-Skill Tasks, Low-Skill Unemployment and the Skill-Wage Structure*

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December 14, 2016

Abstract

This paper studies the direct and indirect channels through which offshoring affects the domestic skill-wage structure and employment opportunities. To identify these channels, we develop a task-based model with unemployment that accounts for skill heterogeneity and endogenous allocation of domestic tasks to skill groups and abroad. A decline in offshoring costs of medium skill-intensive tasks induces i) a specialization effect towards low and high skill-intensive tasks, explaining one source of wage polarization, ii) an internal skill-task reallocation effect, and iii) a productivity effect due to production cost reductions. The key determinants of these channels are the elasticity of substitution between domestic and offshore tasks and the elasticity of task productivity schedules between domestic skill groups and between domestic and offshore workers across tasks.

Keywords Skill-Task Assignment · Offshoring · Productivity Effect · Equilibrium Unemployment · Skill-Wage Structure

JEL F16 · F66 · J21 · J24 · J64

*The authors are grateful for valuable comments and discussions to Hartmut Egger, Ingo Geishecker, Maarten Goos, Hans-Jörg Schmerer, Ignat Stepanok and to participants at the 2nd International IAB/RCEA/ZEW Workshop in Nuremberg, 2014, at the 3rd Joint Workshop of Aarhus University and IAB in Nuremberg, 2014, at ESPE 2014 in Braga, and at ASSET 2015 in Granada.
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1 Introduction

One key feature of the recent globalization trend is the growing phenomenon of international reorganization of production and work processes, resulting in offshoring of jobs. This trend has heightened concerns regarding job and wage cuts in many advanced countries (cf. Bhagwati et al., 2004; Snower et al., 2009).\footnote{Blinder (2009a) estimates that 30 million to 40 million jobs in the USA are potentially offshorable, while job tasks that require face-to-face contact as well as abstract and cognitive skills are protected. See also the studies by Jensen and Kletzer (2010) and Moncarz et al. (2008) regarding offshorability of service occupations. For example, Moncarz et al. (2008) identify the offshorability of 160 service occupations, where the range of occupations includes scientists, mathematicians, radiologists and editors at the high end of the market as well as those of telephone operators, clerks and typists at the low end.}

When looking at the causes, earlier studies have highlighted the labor market impact of international fragmentation of the value added chain, captured by the increasing penetration of intermediate goods (Feenstra and Hanson, 1996, 1999; Jones and Kierzkowski, 1990, 2001; Kohler, 2004a,b). More recent observations accentuate the important role of job characteristics and task content of occupations in global competition (cf. Blinder, 2009a,b). To put it in the words of Blinder (2009b, p.54), “...this time it’s not the British who are coming, but the Indians...neither by land nor by sea, but electronically”.

The rationale behind this new trend can be found in various factors: on the one hand, the integration process of national markets into a global market has been accelerated by advances in information and communication technology (ICT) as well as by declines in trade transaction and transportation costs of goods and services. On the other hand, rapid economic growth in major emerging countries, such as Brazil, Russia, India, and China (BRIC), has been characterized by high accumulation of human capital and advanced technologies as well as by improvements in the economic and business infrastructure. As a consequence the emerging countries have become highly competitive in areas such as information technology services in which the advanced countries have been dominant (Bhagwati et al., 2004; Snower et al., 2009; Spence, 2011).

These developments have reduced the locational viability of some occupations. In particular jobs with a high content of routine, non-interactive, and non-cognitive tasks can be easily codified, enabling firms in many advanced countries to reorganize production and work processes. This reorganization implies that the various stages of production are geographically decomposed into clusters of tasks and each task cluster is located in the country where it is most profitable (Snower et al., 2009). Therefore the comparative advantage of performing specific tasks in occupations has become important.

The empirical evidence has highlighted how global competition led to offshoring of routine-intensive tasks and identified offshoring as one of the key sources of recent polarizing developments in employment and wages observed in many advanced countries.\footnote{For recent empirical evidence regarding the polarization effect in the US labor market see Autor et al. (2003); Autor and Dorn (2009, 2013); Autor et al. (2006, 2008); Firpo et al. (2011); Michaels et al. (2014); and in the European labor markets Baumgarten et al. (2013); Dustmann et al. (2009); Goos and Manning (2007); Goos et al. (2009, 2014); Spitz-Oener (2006).} However, the link between offshoring-induced changes in task structure, on the one hand, and skill-wage structure and unemployment, on the other hand, is rather implicit in most of the literature. In our perception a fruitful approach is to make this link more explicit.
Figure 1: Predicted distribution of offshorability of occupations in the U.S., by skill intensity

Notes: The figure plots the predicted fit along with the 95% confidence interval of the mean from the fractional-polynomial estimation of the adjusted offshorability index of 290 occupations in the US. For a detailed description of data, see Appendix A.

by identifying skills as a unique characteristic of workers. Skills then can be directly related to wages and unemployment as is often done in the empirical literature (cf. Acemoglu and Autor, 2011).

We illustrate this point by presenting an important stylized fact regarding the nature of offshoring occupations in Figure 1. Using data for the U.S., we plot the predicted distribution of 290 occupations by the degree of offshorability and the skill intensity. The resulting relation highlights that occupations with lowest and highest skill-intensity are currently less prone to offshoring, while occupations in the middle range of the skill-intensity reflect a substantial degree of offshorability. For instance, medium skill-intensive occupations are bookkeeping, accounting, billing and posting clerks and machine operators with an average share of medium-skill workers of about 82 percent. Low skill-intensive occupations are such as textile winding, machine operators and tenders and high skill-intensive occupations are, for example, economists, lawyers, medical and physical scientist.

The empirical literature has adequately addressed the direct wage and employment implications of offshoring for the domestic workforce, emphasizing that despite a displacement effect due to job reallocation abroad, offshoring may induce a potential countervailing productivity effect due to cost savings on offshored inputs (tasks). However, we are still lacking an understanding of the underlying general equilibrium mechanisms behind the offshoring-induced trends in the labor market. More specifically, the existing studies have ignored determinants of underlying channels of offshoring-induced internal skill-task reallocation effects for skill groups who are not immediately affected by offshoring. Recent empirical evidence shows that
offshoring may induce an occupational mobility by displaced workers, usually from routine-intensive occupations to occupations with high intensity in manual and cognitive tasks (cf. Cortes et al., 2016).

Therefore, the objective of this paper is to improve our understanding regarding the underlying driving forces behind these indirect channels. We develop a theoretical model that identifies various mechanisms through which offshoring affects the labor market conditions of different skill groups in the home country. Our model includes four types of workers, consisting of low-, medium-, and high-skill workers in the home country and offshore workers abroad. Each type of workers performs a range of tasks that are combined by a CES-aggregate to produce a final consumption good. Workers are heterogeneous with respect to their comparative advantage to perform tasks, while offshoring is additionally subject to variable transaction costs. In line with the evidence discussed above, offshoring activities are by assumption limited to medium skill-intensive tasks. We also allow for equilibrium unemployment that can be explained in two alternative ways. A first explanation of equilibrium unemployment is that the low-skill labor market segment is characterized by a minimum wage scheme above the market clearing wage rate. As an alternative explanation we consider a more general case of labor market friction where low-skill labor market is now characterized by an elastic wage curve. The latter explanation enables us to account for adjustments of both demand and supply sides of the labor market.

The results of the analysis show that easier offshoring affects the skill-wage structure in the home country through three channels. First, easier offshoring of medium skill-intensive tasks leads to an increase in the range of offshored tasks and reduces the range of tasks produced by medium-skill workers at home. This is the direct displacement effect of offshoring at the extensive margin. However, a potential countervailing impact is that easier offshoring reduces the overall marginal cost of factor labor at home as a result of lower transaction costs. This is the productivity effect of offshoring at the intensive margin. The third effect is an internal skill-task reallocation effect of offshoring-induced displaced medium-skill workers to low and high skill-intensive tasks. Finally, our analysis shows that a reduction in offshoring costs of medium skill-intensive tasks leads to a specialization of the domestic economy in low and high skill-intensive tasks in a Walrasian labor market. However, with equilibrium unemployment in the low-skill labor market segment, characterized by a wage-setting curve, the specialization effect becomes ambiguous and depends on the elasticity of the wage curve.

We show that the relative magnitude between the direct displacement effect and the productivity effect depends on the degree of the internal skill-task reallocation and the external relocation of tasks abroad. The net effect depends on the elasticity of task productivity schedules, i.e. the extent of the comparative advantage, of workers at the extensive task margins, indicating how easily different type of workers can be replaced across tasks. Allowing for unemployment in the low-skill labor market segment, the internal skill-task reallocation effect emphasizes again the role of the elasticity of task productivity schedules between low-
skill and medium-skill workers across tasks. For a sufficiently high elasticity of task productivity schedules between low-skill and medium-skill workers lower offshoring costs induce a decline in the unemployment rate of low-skill workers.

Moreover, our results suggest that the direction of the productivity effect depends on the elasticity of substitution between tasks. Whenever there is a sufficient degree of complementarity between tasks, easier offshoring generates a positive impact on wages and employment for the workforce at home through the productivity effect. Hence, our results highlight that the impact of offshoring will depend importantly on the elasticity of task productivity schedules of different type of workers, as well as on the elasticity of substitution between the tasks, indicating the complementarity between offshored and domestic tasks. These key determinants provide new insights regarding the underlying mechanism behind the direct and indirect effects of offshoring.

In summary, our key contribution is to identify several important channels and their underlying determinants through which offshoring affects the domestic labor market. In particular, it identifies four channels which are crucial in determining the immediate and indirect effects of offshoring on employment and wages: On the one hand, the elasticity of task productivity schedules (indicating the relative comparative advantage) between medium-skill and low-skill worker, between offshore and medium-skill workers, and between high-skill and medium-skill workers. These elasticities capture the notion of how different type of workers are substitutable across the range of tasks. On the other hand, the elasticity of substitution between domestic and offshored tasks, which accounts for importance of production technology. These parameters are crucial in determining the immediate and indirect effects of offshoring on employment and wages. Moreover, these new insights can guide the empirical research by providing rationales why, for instance, the magnitude and the incidence of labor market polarization have been different between the advanced countries over the past recent decades.

The paper is organized as follows. The following section briefly reviews the related studies. In section 3 we introduce our theoretical model, while in sections 4 and 5 we discuss our main results regarding the impact of offshoring and internal skill-task reallocation on the domestic skill-wages structure and low-skill unemployment, respectively. Finally, section 6 offers concluding remarks.

## 2 Literature Review

Our theoretical approach is related to the workhorse trade-in-task models of Acemoglu and Autor (2011) and Grossman and Rossi-Hansberg (2008). While Acemoglu and Autor (2011) highlight the importance of skill heterogeneity to account for recent wage polarizing trends in advanced countries, Grossman and Rossi-Hansberg (2008) show that offshoring-induced displacement effects may be mitigated by a productivity ef-
fect due to production cost savings. However, by assuming a Cobb-Douglas or Leontief production technology (Acemoglu and Autor, 2011; Grossman and Rossi-Hansberg, 2008, respectively) both approaches ignore the important role of the elasticity of substitution between tasks. For that reason, we merge and augment these models by developing a framework that accounts for endogenous offshoring and skill heterogeneity combined in a CES production function with continuum of tasks. We show how the elasticity of substitution between offshored and domestic tasks and the elasticity of task productivity schedules between domestic skill groups across tasks has an important impact on the labor market outcomes of offshoring. Moreover, the potential productivity effect is now characterized by the interaction between an endogenous allocation of domestic skill groups across tasks (internal skill-task reallocation), and offshorability of domestic tasks (external task relocation). We show that the magnitude of this interaction crucially depends on the elasticity of task productivity schedules between domestic and offshore workers across tasks. In addition, our model can be extended to include equilibrium unemployment. These features are absent in Acemoglu and Autor (2011) and Grossman and Rossi-Hansberg (2008).

Two related recent papers by Egger et al. (2015) and Groizard et al. (2014) study the implications of offshoring in a model with firm heterogeneity à la Meltiz (2003). Egger et al. (2015) focus mostly on the implications of offshoring on income inequality, particularly between entrepreneurs and production workers. The key finding of their analysis highlights the non-monotonic relationship between offshoring costs and a distributional effect, where high offshoring costs induce more firms into less productive sectors. This, in turn, redirects the production workers into these low-productivity firms, leading to higher inequality between production workers and entrepreneurs, and vice versa.

Groizard et al. (2014) focus instead on the impact of offshoring on unemployment. The results of their analysis highlight the importance of the elasticity of substitution between inputs and its interaction with the elasticity of substitution between intermediate goods and the elasticity of demand in determining the impact of offshoring on intrafirm and intrasectoral employment. Similar to the offshoring implication in our model, they show that higher degree of complementarity between offshore inputs and domestic jobs induces a net job creation due to the productivity effect. However, none of these models account for skill heterogeneity and thus ignore the implications of offshoring on the domestic skill-wage structure, next to unemployment effects. Our model highlights another important channel: the extent of comparative advantage of workers regarding task performance.

There is a growing number of empirical studies providing evidence on the nature of offshoring domestic jobs, such as the task-content of occupations, and its labor market implication for the domestic workforce, suggesting a negative effect for workers in occupations with high content of repetitive, routine tasks (Becker

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3A third channel, as put forward in Grossman and Rossi-Hansberg (2008), is via the terms-of-trade effect that may wipe out the productivity effect. However, see Bhagwati et al. (2004) for a discussion regarding the empirical insignificance of terms-of-trade effects of offshoring.
et al., 2013; Baumgarten et al., 2013; Ebenstein et al., 2014; Hummels et al., 2014; Olney, 2012; Ottaviano et al., 2013; Wright, 2014). Related to our paper, two recent studies have tested empirically the consequences of offshoring-induced occupational mobility, suggesting that switching occupations is a costly action for offshoring-displaced workers. Using matched worker-firm data from Denmark, Hummels et al. (2014) find that offshoring increases the skill premium within firms, i.e. the relative wage of skilled workers, and that the downward wage pressure is more pronounced in occupations that involve routine tasks. However, by allowing for labor mobility across occupations, they find that the cohort-average wage loss (i.e. of workers who leave the firm, and those who stay) is exacerbated for both low- and high-skill workers. The authors relate the latter outcome to losses in specific human capital and search costs that considerably hinder the reattachment to the labor market for the offshoring-induced displaced workers. However, Hummels et al. (2014) only distinguish between low-skill and high-skill workers and therefore do not observe polarization.

Ebenstein et al. (2014) investigate the impact of trade and offshoring on wages for the USA. Their empirical findings show that import penetration and offshoring induce a downward pressure for workers performing routine intensive occupations, while export activities have a positive impact. Moreover, the empirical evidence emphasizes that the negative wage effect becomes substantial once occupation-sector mobility of workers is taken into account, suggesting the important role of occupation-specific human capital. Our theoretical framework contributes also to the empirical literature by providing a structural guidance regarding the underlying mechanisms behind the occupational mobility of displaced workers. We show that the elasticity of task productivity schedules between different skill groups is the critical parameter that accounts for the magnitude of internal skill-task reallocation. Moreover, our analysis also provides new insight on how this internal skill-task reallocation effects shape the labor market outcomes for other skill groups, especially low-skill workers, who are not directly affected by offshoring.

To sum up, the set-up of our model is rich enough to highlight various important adjustment mechanisms through which the domestic labor market absorbs the offshoring shock. We therefore augment the existing literature by providing new insights regarding the determinants of direct and indirect channels of offshoring affecting the domestic skill-wage structure and employment opportunities.

3 Model

We consider a small open economy consisting of an aggregate output that is produced under diminishing returns to scale and perfect competition using a task composite input. The task composite, in turn, consists of a continuum of tasks that are performed by different types of workers, domestic workers, and offshore workers. The domestic workers can be distinguished in low-, medium-, and high-skill groups, while offshore workers are homogeneous regarding their skills. However, in line with the stylized facts discussed earlier, we
assume that offshore workers compete on tasks concentrated in the middle range of the task distribution. These are tasks that are performed mainly by domestic medium-skill workers. Below, we outline the framework and discuss the equilibrium conditions, while all formal proofs are relegated to the Supplementary Mathematical Appendix B.

3.1 Production technology

Aggregate output, $Y$, is produced according to the following Cobb-Douglas technology function:\(^4\)

$$Y = BE^{1-\alpha}, \quad \alpha \in (0, 1), \quad (1)$$

where $B$ is a positive parameter\(^5\), $\alpha$ denotes the standard share of physical capital, and $E$ is the task composite. Furthermore, $Y$ is considered as the numeraire, i.e. $P_Y = 1$, so that returns to labor are in real terms.

Assuming profit maximization, the optimal demand for task composite is given by

$$E = P_E^{-\frac{1}{\alpha}}B, \quad (2)$$

where $B = ((1 - \alpha)B)^{1/\alpha}$ and $P_E$ denotes the price index of the task composite, which will be defined below.

3.2 Task allocation

The task composite input is, in turn, produced using a continuum of differentiated tasks, $t(i)$, defined over a unit interval, $i \in [0, 1]$. Tasks are combined according to the following CES function:\(^6\)

$$E = \left[\int_0^1 t(i)^{-\frac{\sigma-1}{\sigma}} \, di\right]^\frac{\sigma}{(\sigma-1)}, \quad (3)$$

where $\sigma \geq 0$ denotes the elasticity of substitution or complementarity between the tasks. Over the unit interval tasks are ordered such that higher indexed tasks have higher content of complexity and skill requirement. Also, as in models with heterogeneous task productivity (cf. Acemoglu and Autor, 2011; Grossman and Rossi-Hansberg, 2008), workers differ in terms of their comparative advantage performing tasks. Our aim is to analyze the labor market implication of offshoring for medium-skill workers and its general equilibrium effects for other skill groups. Therefore, we define the task productivity schedules of each type of labor in terms in terms of the medium-skill workers.\(^7\) In this section we first discuss the allocation of tasks between

\(^4\)Notice that when $B = 1$ and $\alpha = 0$, equation (1) reduces to the one used by Acemoglu and Autor (2011).

\(^5\)This may be a function of exogenous variables such as total factor productivity (TFP) and physical capital.

\(^6\)Grossman and Rossi-Hansberg (2008) assume perfect complementarity, i.e. a Leontief production function, $\sigma = 0$. Acemoglu and Autor (2011) consider a Cobb-Douglas production function, i.e. $\sigma = 1$. Ottaviano et al. (2013); Groizard et al. (2014) use a CES production technology.

\(^7\)Since skill-task allocation is in the spirit of Recardian comparative advantage, the terms “relative task productivity” and “comparative advantage” are used interchangeably.
domestic skill groups and next the optimal task allocation to offshore workers.

### 3.2.1 Domestic task allocation

Let \( \varphi_L(i) \) and \( \varphi_H(i) \) denote the relative task productivity of low-skill and high-skill workers compared to medium-skill workers, respectively.\(^8\) Since tasks are ordered in terms of skill intensity over the unit interval, it follows \( \varphi_L(i) < 0 < \varphi'_H(i) \). To produce some unit of task \( i \), a firm will either employ \( l_M(i) \) effective unit of medium-skill workers, or \( \varphi_L(i)l_L(i) \) effective units of low-skill workers, or \( \varphi_H(i)l_H(i) \) effective units of high-skill workers. That is, \( t(i) = \varphi_L(i)l_L(i) \), or \( t(i) = l_M(i) \), or \( t(i) = \varphi_H(i)l_H(i) \), where \( l_j(i) \) denotes units of labor per task \( i \). If a firm allocates tasks to low-, medium-, and high-skill workers, then each skill group will produce a subset of tasks, \( I_j \) where \( I_j \in (0, 1) \), for \( j = \{L, M, H\} \).

Let \( w_j \) denote the effective marginal cost of hiring workers of skill type \( j \) to produce any task \( i \in I_j \). Then, by the law of one price, the optimal labor demand condition implies that the marginal cost within each skill group (i.e. across each subrange of tasks) is constant. Moreover, notice that the unit cost of producing a unit of task \( i \) is \( w_L/\varphi_L(i) \) using low-skill workers, \( w_H/\varphi_H(i) \) for high-skill workers, and \( w_M \) for medium-skill workers. Hence, given the functional properties of the relative task productivity schedules, \( \varphi_L(i) \) and \( \varphi_H(i) \), the optimal domestic skill-task allocation must satisfy conditions at which the unit cost using different skill groups to produce task \( i \) is equalized. These optimality conditions are presented in Lemma 1.

**Lemma 1 (Domestic task allocation).** Allocation of tasks between domestic skill groups is defined as follows:

i) A firm will employ low-skill workers to produce tasks up to threshold \( I_L \) and high-skill workers from threshold \( I_H \), where

\[
\begin{align*}
w_M &= \frac{w_L}{\varphi_L(I_L)}, \tag{4} \\
w_M &= \frac{w_H}{\varphi_H(I_H)}. \tag{5}
\end{align*}
\]

ii) The elasticity of task productivity schedules between domestic skill groups across the tasks is given by \( \varepsilon_L \equiv -\frac{\partial \ln \varphi_L(I_L)}{\partial I_L} > 0 \) and \( \varepsilon_H \equiv \frac{\partial \ln \varphi_H(I_H)}{\partial I_H} > 0 \).

iii) For \( w_L/\varphi_L(\tilde{I}) = w_H/\varphi_H(\tilde{I}) > w_M = \max\{w_L/\varphi_L(0), w_H/\varphi_H(1)\} \), it follows that \( 0 < I_L < \tilde{I} < I_H < 1 \).

Lemma 1 i) defines the domestic skill-task allocation, characterized by two endogenous thresholds, \( I_L \) and \( I_H \). These thresholds denote the extensive domestic task margins. Lemma 1 ii) defines the magnitude of changes at these extensive task margins, indicating the relative comparative advantage of medium-skill workers compared to low-skill and high-skill workers across tasks. We capture this by the terms, \( \varepsilon_L \) and \( \varepsilon_H \), accounting for the magnitude of changes in the neighborhood of \( I_L \) and \( I_H \), respectively.

Lemma 1 iii) then establishes the necessary and sufficient conditions permitting the employment of all three skill groups in equilibrium. The lower boundary indicates that low-skill workers are the most cost

\(^8\) Readers familiar with Acemoglu and Autor (2011) will notice that the schedule of comparative advantage may be defined as \( \varphi_L(i) \equiv \frac{a_L(i)}{a_M(i)} \) and \( \varphi_H(i) \equiv \frac{a_H(i)}{a_M(i)} \), where \( a_j(i) \) denotes the task productivity schedule of skill type \( j = \{L, M, H\} \).
efficient ones at the least skill-intensive task $i = 0$ and high-skill workers are the most cost efficient ones at
the most skill-intensive task $i = 1$. In addition, the upper boundary ensures that medium-skill workers have
comparative advantage in the middle range of the task distribution. For example, if $w_L / \varphi_L(\tilde{I}) = w_H / \varphi_H(\tilde{I}) \leq w_M$, then medium-skill workers have no comparative advantage in performing any task relative to low- and
high-skill workers, until $w_M$ falls far enough. The labor market would then employ only low- and high-skill
workers.

To sum up, Lemma 1 shows that the domestic labor force is allocated over the unit interval as follows:
low-skill workers are employed in the interval $i \in [0, I_L]$, medium-skill workers in $i \in (I_L, I_H)$, and high-skill
workers in $i \in [I_H, 1]$. Figure 2 gives a graphical illustration of equilibrium task allocations.

3.2.2 Offshoring task allocation

As depicted in Figure 1, occupations concentrated in the middle range of the skill distribution are most
likely offshorable. The intuition behind this is that these occupations exhibit a high content of routine,
non-interactive and non-complex tasks, making them easily codifiable and reducing their "face-to-face" or
"physical presence" requirement Blinder (2009b).

To account for this stylized fact, we assume that the comparative advantage of offshore workers compared
to medium-skill workers has a non-monotonic feature. More precisely, let $\zeta(i)$ denote the task productivity
schedule of offshore workers relative to medium-skill workers, where its functional form is described by the
following assumption.

Assumption 1. There exists a threshold $\tilde{I}$ such that for all $i \in [0, \tilde{I})$, $\zeta(i)$ is (strict) monotonically decreasing,
and for all $i \in (\tilde{I}, 1]$, $\zeta(i)$ is (strict) monotonically increasing.

Hence, by Assumption 1 the relative task productivity schedule of offshore workers has a U-shaped form,
capturing the notion of the inverted U-shaped offshorability index in Figure 1. Tasks both at the lower and
upper end of the unit interval require a strong geographic proximity, e.g. due to high intensity in manual and
complex activities, respectively. This is in stark contrast to the standard approach in the literature, where
offshorability of domestic intermediate inputs (tasks) has a monotonic property and occurs in a dichoto-

mous form. That is, over the unit interval the offshoring decision is usually characterized by reallocation
of tasks from homogeneous domestic labor, performing a set of tasks on the upper (right-bounded) part
of the interval, to offshore labor, performing a set of tasks on the lower (left-bounded) part of the interval
(Grossman and Rossi-Hansberg, 2008).

If a firm decides to offshore, it must pay a hiring cost for a unit of offshore workers, $w_O$, and an additional

\[9\] Notice that at strict equality the potential employer is indifferent between all three skill groups at task margin $\tilde{I}$.

\[10\] Intuitively, these tasks require face-to-face contact and physical presence (Blinder, 2009a).

\[11\] One exception is the study by Ottaviano et al. (2013), in which offshoring is a reallocation of tasks performed previously by immi-
grants and natives. However, they do not account for skill heterogeneity and thus disregard to address the non-monotonicity property
of offshoring and the consequences of the internal skill-task reallocation effect.
transportation cost, \( \tau \), for each task \( i \), such that the unit cost of producing task \( i \) abroad is \( \tau w_O \zeta(i) \). We summarize the inverse offshoring costs by \( \omega \equiv \frac{1}{\tau w_O} \), where higher values of \( \omega \) indicate easier offshoring. The unit cost of producing task \( i \) abroad then are \( \zeta(i)/\omega \), which should be compared to the unit costs \( w_M \) of producing it domestically with medium-skill workers. The conditions under which a profit maximizing firm decides to offshore tasks and the optimal amount of offshore workers to employ in the task composite is summarized in Lemma 2.

**Lemma 2 (Offshoring task allocation).** Let \( I_O \in (I_L, I_H) \) denote the Lebesgue measure of offshored tasks, then

i) the equilibrium value of a subset of offshored tasks is

\[
 w_M = \frac{\varphi_O(I_O)}{\omega},
\]

where \( \varphi_O(I_O) = \exp[\mu I_O] \) is a positive monotonic transformation of \( \zeta(\cdot) \), \( \mu > 0 \) denotes the elasticity of task productivity schedules between offshore and medium-skill workers across tasks, and \( \varphi'_O(I_O) > 0 \).

ii) For all \( \omega \) in the interval \( \frac{\varphi_O(0)}{w_M} < \omega < \frac{\varphi_O(I')}{w_M} \), \( \forall i \in I' \leftrightarrow i \in I_M = I_H - I_L \) and \( I_L < \tilde{I} |_{\text{lm} \zeta(\cdot) = 0} < I_H \), it follows that \( I_O > 0 \) and \( I_O \in (I_L, I_H) \).

Several properties of these conditions are worth mentioning. First, in Lemma 2 i) equation (6) indicates that at the extensive offshoring margin, \( I_O \), the marginal cost of offshoring must equal the marginal costs of producing tasks using domestic medium-skill worker. Thus, a firm will assign tasks to offshore workers if \( w_M > \varphi_O(i)/\omega, \forall i : i \in I_O, i \notin (I_L, I_H), I_O \in (I_L, I_H) \). Part ii) denotes the necessary and sufficient conditions that ensure the existence of offshoring and hence avoid corner solutions in equilibrium. Figure 2 depicts
the equilibrium allocation of tasks between medium-skill workers and offshore, and between domestic skill groups.

### 3.3 Labor demand

Having decided to allocate tasks among the domestic skill groups and between offshore and medium-skill workers, a profit-maximizing firm decides on the amount of workers to hire. Let $N_j$ denote the total (exogeneously given) mass of workers of skill type $j = \{L, M, H\}$ and $n_o$ be the (endogenously given) mass of offshore workers employed by a firm. Then Lemma 3 establishes the equilibrium values of inverse labor demand and the task composite.

**Lemma 3 (Labor demand).** Given the task margins $I_L$, $I_H$, and $I_O$, and given the price index of task composite $P_E$, we obtain the inverse demand for

1. **domestic workers**

   \[
   w_L = P_E \left( \frac{E}{N_L} \right)^{\frac{1}{\sigma}} \gamma_L(I_L)^{\frac{1}{\sigma}},
   \]

   \[
   w_M = P_E \left( \frac{E}{N_M} \right)^{\frac{1}{\sigma}} (I_H - I_L - I_O)^{\frac{1}{\sigma}},
   \]

   \[
   w_H = P_E \left( \frac{E}{N_L} \right)^{\frac{1}{\sigma}} \gamma_H(I_H)^{\frac{1}{\sigma}},
   \]

2. **offshore workers**

   \[
   w_O = P_E \left( \frac{E}{n_O} \right)^{\frac{1}{\sigma}} \tau^{\frac{1}{\sigma}} \gamma_O(I_O)^{\frac{1}{\sigma}},
   \]

where $\gamma_L(I_L) = \int_0^{I_L} \varphi_L(i)^{\sigma-1} \, di$, $\gamma_O(I_O) = \int_{I_O}^{1} \varphi_O(i)^{1-\sigma} \, di$, and $\gamma_H(I_H) = \int_{I_H}^{1} \varphi_H(i)^{\sigma-1} \, di$.

3. **The equilibrium value of task composite** is given by

   \[
   E = \left[ \gamma_L(I_L)^{\frac{1}{\sigma}} N_L^{\frac{\sigma-1}{\sigma}} + (I_H - I_L - I_O)^{\frac{1}{\sigma}} N_M^{\frac{\sigma-1}{\sigma}} + \gamma_O(I_O)^{\frac{1}{\sigma}} n_O^{\frac{\sigma-1}{\sigma}} + \gamma_H(I_H)^{\frac{1}{\sigma}} N_H^{\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\sigma}}.
   \]

From Eqs. (7)–(10) it is evident that inverse labor demand is an increasing function of the respective task margins, i.e. $\frac{\partial w_L}{\partial I_L} > 0$, $\frac{\partial w_M}{\partial I_H} > 0$, and $\frac{\partial w_O}{\partial I_O} > 0$.

To obtain the marginal cost of the task composite, note that the optimization problem of a firm is characterized by means of the minimization of production costs of a task composite unit. From equilibrium conditions (4) and (5) in Lemma 1, condition (6) in Lemma 2 together with the equilibrium results in Lemma 3, Lemma 4 shows the value of overall marginal cost of task production in equilibrium.

**Lemma 4 (Marginal cost).** The marginal cost of the task composite is given by $C_E = \Omega(I_L, I_H, I_O)w_M$, where

\[
\Omega(I_L, I_H, I_O) = \left[ \gamma_L(I_L)\varphi_L(I_L)^{1-\sigma} - I_L + \gamma_O(I_O)\varphi_O(I_O)^{\sigma-1} - I_O + \gamma_H(I_H)\varphi_H(I_H)^{1-\sigma} + I_H \right]^{\frac{1}{\sigma}}.
\]

For $0 < \{I_L, I_O, I_H\} < 1$, $\frac{\partial \Omega}{\partial I_L} < 0$, $\frac{\partial \Omega}{\partial I_H} < 0$, $\frac{\partial \Omega}{\partial I_O} > 0$. Moreover, the perfect competition nature of the market for task performance implies

\[
P_E = C_E.
\]
Equation (13) shows that, in any perfect competition equilibrium, the price index must equal the marginal cost. Equation (12) denotes the equilibrium value of the marginal cost – capturing both the internal skill-task allocation, i.e. among the domestic skill groups, and the external task relocation, i.e. between domestic medium-skill and offshore workers. The implied endogenous adjustment to external shocks highlights the novel feature of the task-assignment approach. For instance, from Lemma 2 we know that easier offshoring (i.e. higher values of \( \omega \)), e.g. due to lower hiring costs (\( d\omega_O < 0 \)) or lower trade costs (\( d\tau < 0 \)), lead to an increase at the extensive offshoring task margin \( I_O \), implying relocation of additional tasks abroad. The partial derivative of \( I_O \) in equation (12) then shows that easier offshoring will decrease the overall marginal costs of task production. The intuition behind this effect is that a decline in offshoring costs has also an impact on the cost structure at the intensive task margin, referring to cost savings on all tasks that has been already produced abroad. This effect is referred to as the \textit{productivity effect}.

However, the Walrasian nature of the labor market requires the re-employment of offshoring-induced displaced medium-skilled workers. This implies that the marginal cost of hiring medium-skill workers must decline, increasing their competitiveness performing tasks in the neighborhood of task margins \( I_L \) and \( I_H \). As elaborated below, this endogenous internal task reallocation from low-skill and high-skill to medium-skill workers will mitigate the productivity effect. This is a novel feature of our model which stands in stark contrast to the standard approach in the literature. Our theoretical model highlights the importance of skill heterogeneity because it allows to capture important indirect adjustment mechanisms, which are critical to address the impact of offshoring on skill-wage inequality.

### 3.4 Equilibrium solution

The general equilibrium closed form solution to the equilibrium task margins (\( I_L \), \( I_O \), and \( I_H \)) is characterized by the equilibrium demand condition for task composite, Eq. (2), the optimal task allocation conditions, Eqs. (4) and (5) in Lemma 1, and Eq. (6) in Lemma 2, as well as the optimal labor demand conditions, (7)–(10). From these conditions, we obtain a system of three equations determining simultaneously the implicit solution to the task margins, shown by Lemma 5.

**Lemma 5 (Implicit solution to task margins).** Given Lemmas 1–4, the implicit equilibrium solution to the task margins is

\[
\begin{align*}
\frac{N_L}{N_M} & = \frac{\gamma_L(I_L)}{(I_H - I_L - I_O)\varphi_L(I_L)^\sigma}, \quad \text{(14a)} \\
\left( \frac{B}{N_M} \right)^\alpha & = \frac{\varphi_O(I_O)\Omega^{1-\sigma\alpha}}{(I_H - I_L - I_O)^\alpha}, \quad \text{(14b)} \\
\frac{N_M}{N_H} & = \frac{(I_H - I_L - I_O)\varphi_H(I_H)^\sigma}{\gamma_H(I_H)}. \quad \text{(14c)}
\end{align*}
\]
Note that the left hand side of Eqs. (14a)–(14c) is denoted by exogenous parameters and variables of the model, i.e. the skill endowment and offshoring costs, while the right hand side is a function of all three task margins. We summarize the equilibrium characteristics in the following proposition.

**Proposition 1 (Unique equilibrium).** Given Lemma 1 and 2, the system of equations (14a)–(14c) determines the unique equilibrium values for all endogenous task margins \(\{I_L, I_H, I_O\}\) as a function of the exogenous variables and parameters.

Having solved implicitly for the equilibrium values of task margins, the convenient block-recursive structure of the model allows to solve for other endogenous variables \((w_L, w_M, w_H, n_O, P_E, E)\) by using the results in Lemma 3 and 4.

4 Easier Offshoring: Task Reallocation, Productivity and Real Wages

In this section we analyze the implications of the model for the effect of a marginal decline in offshoring costs on the task reallocation and real domestic wages. Note that easier offshoring is associated with \(d\omega > 0\) induced either by i) \(d\omega_O < 0\), e.g. due to accumulation of human capital abroad, or by ii) \(d\tau < 0\), e.g. because of abolition of transportation barriers.

To derive the effects of easier offshoring on domestic real wages, recall from Lemma 3 the optimal domestic labor demand functions, (7), (8) and (9). Utilizing equation (2) and the results derived in Lemma 1 and 4, yields

\[
\begin{align*}
    w_L &= \left( \frac{\Omega(\cdot)}{\varphi_L(I_L)} \right)^{-(1-\alpha\sigma)} \gamma_L(I_L)^\alpha \mathcal{K}_L, \\
    w_M &= \Omega(\cdot)^{-(1-\alpha\sigma)}(I_H - I_L - I_O)^\alpha \mathcal{K}_M, \\
    w_H &= \left( \frac{\Omega(\cdot)}{\varphi_H(I_H)} \right)^{-(1-\alpha\sigma)} \gamma_H(I_H)^\alpha \mathcal{K}_H,
\end{align*}
\]

where \(\mathcal{K}_j \equiv \ln (N_jB)^{-\alpha}\) is a constant. Now taking logs in the previously derived equations, we can compute the impact of a marginal decrease in offshoring costs on real wages, which is given by

\[
\begin{align*}
    \frac{d \ln w_L}{d \omega} &= \left( \frac{\alpha}{s_L} - (1 - \alpha\sigma)\varepsilon_L \right) \frac{dI_L}{d\omega} - (1 - \alpha\sigma) \frac{d \ln \Omega}{d \omega}, \\
    \frac{d \ln w_M}{d \omega} &= -\frac{\alpha}{I_H - I_L - I_O} \left[ \frac{dI_O}{d\omega} - \left( \frac{dI_H}{d\omega} - \frac{dI_L}{d\omega} \right) \right] - (1 - \alpha\sigma) \frac{d \ln \Omega}{d \omega}, \\
    \frac{d \ln w_H}{d \omega} &= -\left( \frac{\alpha}{s_H} - (1 - \alpha\sigma)\varepsilon_H \right) \frac{dI_H}{d\omega} - (1 - \alpha\sigma) \frac{d \ln \Omega}{d \omega},
\end{align*}
\]
where \( s_j = \frac{\gamma_j(I_j)}{\varphi_j(I_j)} \) denotes the average range of tasks performed by skill type \( j \in \{ L, H \} \).

In order to assess the signs of equations 15–17, we need to know the signs of \( \frac{dL}{dw} \), \( \frac{dO}{dw} \), and \( \frac{dH}{dw} \), which will be discussed in the section 4.1 (i.e. Lemma 2), and the signs of \( \frac{d\Omega}{d\omega} \) (i.e. Lemma 6, which will be discussed in section 4.2. The overall effect on real wages is then discussed in section 4.3 (i.e. Proposition 3).

### 4.1 Easier offshoring and task reallocation

Utilizing the system (14a)–(14c) derived in Lemma 5, we first discuss how a decline in offshoring costs affects the task allocation both among domestic skill groups as well as between domestic and offshore workers. Taking logs in the equations derived in the system (14) and rearranging, we obtain

\[
-\ln \left( \frac{N_L}{N_M} \right) - \ln \left( I_H - I_L - I_O \right) - \sigma \ln \varphi_L(I_L) + \ln \gamma_L(I_L) = 0
\]

\[
-\alpha \ln \left( \frac{B}{N_M} \right) - \alpha \ln \left( I_H - I_L - I_O \right) + \ln \varphi_O(I_O) + (1 - \sigma \alpha) \ln \Omega(\cdot) = \ln \omega
\]

\[
-\ln \left( \frac{N_M}{N_H} \right) + \ln \left( I_H - I_L - I_O \right) + \sigma \ln \varphi_H(I_H) - \ln \gamma_H(I_H) = 0.
\]

Now we can compute the impact of easier offshoring on the task margins. We summarize the main results in Proposition 2.

**Proposition 2** (Easier offshoring of medium-skill tasks and changes in task margins). The extent and the impact of easier offshoring \((d\omega > 0)\) on task allocation is characterized by:

1. An expansion of the offshorable range of tasks and a contraction of low- and high-skill-intensive tasks ranges

\[
\frac{dL}{d\omega} < 0, \quad \frac{dO}{d\omega} > 0, \quad \frac{dH}{d\omega} > 0, \quad \text{and} \quad \left| \frac{dO}{d\omega} \right| > \left| \frac{dH}{d\omega} \right| + \left| \frac{dL}{d\omega} \right|.
\]

2. An asymmetric impact on the domestic skill-task reallocation

\[
\left| \frac{dL}{d\omega} \right| \ll \left| \frac{dH}{d\omega} \right|, \quad \Leftrightarrow \quad \left( \frac{1}{s_L} + \sigma \varepsilon_L \right) \ll \left( \frac{1}{s_H} + \sigma \varepsilon_H \right).
\]

The intuition can be explained in the following way. Easier offshoring, e.g. due to lower transportation cost \((d\tau < 0)\), or a decline in foreign wage costs \((d\omega_O < 0)\), increases the cost advantage for a firm to reallocate domestic tasks abroad. This effect displaces medium-skill workers performing tasks in the neighborhood of \( I_O \). The law-of-one price and the perfectly competitive labor market imply a downward wage adjustment for medium-skill workers. The no-arbitrage conditions (4) and (5) in Lemma 1 then indicate a reallocation of displaced medium-skill workers to low skill-intensive (i.e. lower \( I_L \)) and high skill-intensive (i.e. higher \( I_H \)) tasks.
Thus, Proposition 2 highlights what Costinot and Vogel (2010) call a \textit{task upgrading} at the high-skill extensive margin, i.e. more medium-skill workers produce former high-skill tasks, and a \textit{task downgrading} at the low-skill extensive margin, i.e. more medium-skill workers produce former low-skill tasks.\textsuperscript{12} The key determinants behind the magnitude of the skill down- and upgrading are $\varepsilon_L$ and $\varepsilon_H$, indicating the elasticity of task productivity schedules of medium-skill workers relative to low-skill and high-skill workers at the equilibrium task margins $I_L$ and $I_H$, respectively. A relatively high comparative advantage at the high skill-intensive tasks (higher values of $\varepsilon_H$) implies that medium-skill workers are disproportionately allocated into low-skill-intensive job tasks. The empirical literature has highlighted a gradual growth of low-paid service jobs (cf. Autor and Dorn, 2013) and skill downgrading, in particular of medium-skill workers (cf. Brynin and Longhi, 2009) in many advanced countries.

4.2 Easier offshoring and productivity

We now turn to the determinants of the offshoring-induced productivity effect. As highlighted earlier, this effect reduces the overall marginal cost of task production, which in turn may lead to beneficial outcomes for the domestic skill groups. However, the magnitude of this effect depends on the interaction between the external task relocation and the internal task-skill reallocation. Therefore, the labor market implication of offshoring differs crucially from Grossman and Rossi-Hansberg (2008), where by construction the internal skill-task allocation is omitted. It also differs from the approach by Acemoglu and Autor (2011), where offshoring is exogenously introduced in terms of a fixed range and the cost index of task composite ($PE$) is held constant.

From Proposition 2 we know the sign of changes in the task margins ($dI_H / d\omega$, $dI_L / d\omega$, $dI_O / d\omega$). The only term which is not defined yet is the last term in Eqs. (15)–(17), $d \ln \Omega / d\omega$, capturing the impact of offshoring costs on the overall marginal cost of task composite. This last term is the source of the productivity effect. The following lemma summarizes the conditions defining the sign of changes in the overall marginal costs.

**Lemma 6** (Offshoring and overall marginal costs). \textit{Given the results in Proposition 2, changes in overall marginal costs due to lower offshoring costs can be decomposed into an internal task-skill reallocation ($D$) and an external task relocation ($F$), i.e.}

\[
\frac{d \ln \Omega(\cdot)}{d\omega} = \left( \lambda_H \varepsilon_H \frac{d I_H}{d\omega} - \lambda_L \varepsilon_L \frac{d I_L}{d\omega} \right)_{\mathcal{D} > 0} + \left( \lambda_O \mu \frac{d I_O}{d\omega} \right)_{\mathcal{F} > 0} < 0 \quad \Leftrightarrow \quad \mu > \max \left\{ \frac{\lambda_L}{\lambda_O} \varepsilon_L, \frac{\lambda_H}{\lambda_O} \varepsilon_H \right\}, \quad (19)
\]

\textit{where $\lambda_j$ denote the cost share of labor type $j \in \{L, H, O\}$}.

\textsuperscript{12}Notice, however, that (easier) offshoring in our framework differs from Costinot and Vogel (2010, section VI.B.). Their results affirm a pervasive rise in wages of more skilled workers, i.e. an increase in inequality, induced by an implicit increase in the size of the relatively skill scarce foreign economy. In contrast, we follow up on the recent empirical findings on the offshoring-induced changes in the skill-wage structure (e.g. polarization effect) and highlight the key channels behind its impact on real wages and employment.
Equation (19) highlights two novel features. First, a reduction in the overall marginal costs of task production due to a reduction in offshoring costs \( \mathcal{F} \) is mitigated by an endogenous internal adjustment of the domestic labor market \( D \). Second, the magnitude of the offshoring-induced productivity effect depends on the relative productivity of task production between medium-skill and offshore workers. Contrary to the standard approach in the literature, offshoring is not simply limited to relocation of inputs abroad, but more importantly it induces also an internal, domestic reallocation of inputs across the domestic workforce. Therefore, offshoring-induced displaced medium-skill workers will compete on tasks which are produced by low- and high-skill workers. This endogenous response generates an ambiguous relationship between offshoring and the productivity effect. Intuitively, easier offshoring leads to a contraction of medium-skill-intensive tasks and to a specialization of the home country in performing low and high skill-intensive tasks \( (dI_L/d\omega < 0, dI_H/d\omega > 0) \). This specialization pattern raises the return to low-skills and high-skills and thus mitigates the direct cost-savings effect from offshoring.

Moreover, Equation (19) shows the key determinant dispelling this ambiguity. Whenever the comparative advantage of medium-skill workers relative to offshore workers is sufficiently high in the neighborhood of \( I_O \) (indicating high values of \( \mu \)) the external (foreign) task allocation will become a dominating factor. The intuition is that a firm will save more on production costs at the intensive offshoring task margin due to a decline in offshoring costs than it shifts domestic jobs abroad. Thus, accounting for internal task reallocations between domestic skill groups is critical to capture potential adjustment mechanisms of the domestic labor market in result of easier offshoring.

### 4.3 Easier offshoring and real wages

In equations (15)–(17) the overall sign of the productivity effect is defined by \( -(1 - \alpha \sigma) \frac{d \ln \Omega}{d\omega} \). Whether a decline in offshoring costs is translated into higher real wages for the domestic workforce, therefore depends next to the sign of \( \frac{d \ln \Omega}{d\omega} \) also on the magnitude of another key parameter. A greater elasticity of substitution between tasks (i.e. a higher value of \( \sigma \)) implies that tasks produced at home can be easily replaced by cheaper offshore workers and relocated abroad. The empirical evidence suggests a substantial degree of complementarity between tasks, cf. Autor et al. (2003); Peri and Sparber (2009). For example, using US data Peri and Sparber (2009) show that estimated values for the elasticity of substitution between manual and communication tasks range between 0.63 and 1.43. Overall, the productivity effect will lead to an increase in real domestic wages if and only if \( \sigma < 1/\alpha \) and \( \mu \) is sufficiently large.

The impact of offshoring on real wages is also characterized by task demand effect for each skill group due to changes at the extensive task margins. This is denoted by the first term on the right hand side of Eqs. (15)–(17). Given the results in Proposition 2, medium-skill workers experience a decline in labor demand per task. This is the job displacement effect due to increasing direct competition with offshore workers.
The task demand effect for low-skill and high-skill workers is ambiguous and depends on their comparative advantage at $I_L$ and $I_H$, respectively. From equation (15) changes in task demand for low-skill workers is given by $\left(\frac{\alpha}{\sigma} - (1 - \alpha\sigma)\varepsilon_L\right) \frac{dI_L}{d\omega}$. Whether the labor demand per task for low-skill workers declines depends on the value of $\varepsilon_L$, capturing the extent of changes in the neighborhood of $I_L$. Similarly, in equation (17) changes in labor demand per task for high-skill workers is given by $-\left(\frac{\alpha}{\sigma} - (1 - \alpha\sigma)\varepsilon_H\right) \frac{dI_H}{d\omega}$ and depends on $\varepsilon_H$, capturing the extent of changes in the neighborhood of $I_H$.

Hence, the extent of internal skill-task allocation is crucially determined by the elasticity of task productivity schedules between low-skill and high-skill workers relative to medium-skill workers in the neighborhood of $I_L$ and $I_H$, respectively. Moreover, for sufficient high values of $\varepsilon_L$ and $\varepsilon_H$, there will be, respectively, a favorable task demand shift for low-skill and high-skill workers at the intensive task margin, increasing their real wages. The intuition behind this lies in the specialization effect induced by easier offshoring: the home country becomes more specialized in the range of low and high skill-intensive tasks, i.e. $dI_L/d\omega < 0$ and $dI_H/d\omega > 0$, respectively. This specialization pattern gives the rationale behind recent wage polarization trends in many advanced countries.

In Proposition 3, we summarize the main conditions under which easier offshoring leads to a productivity effect raising real wages of all skill groups.

**Proposition 3 (Offshoring and real wages).** Assuming a sufficient degree of complementarity across tasks, $\sigma < 1/\alpha$, a marginal decline in offshoring costs induces a positive real wage effect for all skill groups in the home country if and only if

1. $\frac{\alpha}{(1-\alpha\sigma)\lambda_L} < \varepsilon_L < \frac{\alpha}{1-\alpha\sigma} \lambda_L(I_H-I_L-I_O)$,

2. $\frac{\alpha}{(1-\alpha\sigma)\lambda_H} < \varepsilon_H < \frac{\alpha}{1-\alpha\sigma} \lambda_H(I_H-I_L-I_O)$,

3. $\frac{\alpha}{1-\alpha\sigma} \lambda_O(I_H-I_L-I_O) < \mu$.

The boundaries of the elasticities can be straightforwardly derived as follows. From Eqs. (16) and (19) we obtain the lower boundary in part 3 and the upper limits in parts 1 and 2. The lower limits in parts 1 and 2 are derived from (15) and (17), respectively.

These jointly sufficient conditions in Proposition 3 highlight the key parameters determining the direction and magnitude of various channels through which offshoring affects the domestic skill-wage structure. On the one hand, wage gains for the domestic workforce resulting from offshoring-induced productivity effects depend on the elasticity of substitution between the tasks. On the other hand, the elasticity of task productivity schedules between domestic skill groups across tasks as well as between medium-skill and offshore workers play a critical role in determining the magnitude of internal skill-task allocation and the productivity effect. These are novel features of our model. It is worth noticing that easier offshoring unambiguously
induces the specialization effect, i.e. \( \frac{dI_L}{d\omega} < 0 \) and \( \frac{dI_H}{d\omega} > 0 \). However, as we discuss below, with equilibrium unemployment, characterized by an endogenous wage-setting curve, the specialization becomes ambiguous.

## 5 Equilibrium unemployment

So far we have considered a Walrasian labor market. However, another important concern raised in the public debate on offshoring is the displacement effect of least-skilled workers, leading to unemployment. In the this section, we discuss the internal skill-task reallocation effects of offshoring when there are labor market frictions. Particularly, we extend the framework by allowing for equilibrium unemployment. In doing so, we assume that only low-skill workers face the risk of unemployment. Intuitively and in line with our discussion in the introduction, easier offshoring may indirectly displace low-skill workers from the labor market due to increasing competition with medium-skill workers who have been displaced by offshoring. This potential displacement effect is referred to as the crowding-out effect (cf. Muysken et al., 2015).

We assume two potential sources of labor market frictions, without altering considerably the structure of the model. One potential source of frictions might be a minimum wage regime, which is set above the market equilibrium wage rate. Consequently, a proportion of low-skill workers ends up unemployed. Alternatively, frictions can arise when we allow for endogenous supply of low-skill labor services. In this case, we assume that the low-skill wage rate is set as a mark-up over the unemployment benefits, where the mark-up depends negatively on unemployment rate. While the former is the mirror image of the full-employment case, characterized by a perfect inelastic labor supply curve, the latter allows for an elastic labor supply curve and thus accounts for a more general scenario of labor market frictions.

### 5.1 Minimum wage regime

Let the institutional minimum wage be \( \bar{w} \). We assume that the minimum wage is set sufficiently low such that it is still attractive for a firm to employ low-skill workers, but is sufficiently high such that a proportion of low-skill workers ends up unemployed. Let \( u_L \) denote the low-skill unemployment rate. Formally, we impose the following assumption on the minimum wage scheme.

**Assumption 2 (Minimum wage scheme).**

\[
\frac{w_L}{\varphi_L(0)} < \bar{w}/\varphi_L(0) < w_M,
\]

where \( w_L \) and \( w_M \) are the equilibrium values resulting from the model analyzed in the previous section.

In addition, compared to the full-employment case, only a fraction of low-skill workers can be hired, i.e.
\[ n_L = (1 - u_L)N_L, \]  
and the resource constraint is now given by \[ \int_0^{I_L} l_{iL}(i)di = n_L. \]

Hence, the labor market adjustment for low-skill workers is now through employment. The next lemma summarizes the adjusted equilibrium conditions.

**Lemma 7 (Minimum wage and adjusted equilibrium conditions).** If the low-skill labor market is characterized by a minimum wage scheme, then by Assumption 2 a firm sets the optimal task margin for low-skill workers such that the no-arbitrage condition holds, i.e.

\[ w_M = \frac{\bar{W}}{\varphi_L(I_L)}, \]  

and decides on the optimal amount of low-skill workers by means of cost minimization

\[ \bar{W} = P_E \left( \frac{E}{n_L} \right)^{\frac{1}{\gamma}} \gamma_L(I_L)^{\frac{1}{\sigma}}. \]

The adjusted implicit equilibrium solution to task margin \( I_L \) is given by

\[ \left( \frac{E}{N_M} \right)^{\alpha} \bar{W}^{-1} = \frac{\Omega^{1-\alpha \sigma}}{\varphi_L(I_L)(I_H - I_L - I_O)^{\alpha}}. \]

It is readily seen that equation (22) is the counterpart of equation (14a) in the Walrasian labor market discussed above. Thus, from equation (22) together with the implicit solutions (14b) and (14c) derived in Lemma 5, we obtain a 3 × 3 system of equations characterizing the implicit solution to the task margins under the minimum wage scheme.

To grasp an idea about consequences of a minimum wage scheme above the market clearing wage rate for low-skill workers, we analyze the consequences of a marginal increase in the minimum wage scheme on the task allocation. Intuitively, given the level of the minimum wage, the representative firm will reallocate the tasks from low-skill to medium-skill workers up to the task margin such that equation (20) holds again, implying a lower equilibrium value of task margin \( I_L \). Moreover, from the general equilibrium perspective, it follows that task margins \( I_O \) and \( I_H \) will readjust also increase. This is because the minimum wage raises the relative demand for medium-skill workers, and thus their wages too. By the law of one price, the comparative advantage of medium-skill workers relative to high-skill and offshore workers in the neighborhood of \( I_H \) and \( I_O \), respectively, decreases. Consequently, the range of tasks performed by high-skill \((1 - I_H)\) and offshore workers \(I_O\) must increase in order to fulfill Eqs. (5) and (6).

Recalling the 3 × 3 system of equations characterized by Eqs. (14b), (14c), and (22), taking logs and rear-
ranging slightly, we obtain

\[ -\alpha \ln \left( \frac{B}{N_M} \right) - \alpha \ln (I_H - I_L - I_O) - \ln \varphi_L(I_L) + (1 - \alpha\sigma) \ln \Omega(\cdot) + \ln \bar{W} = 0 \quad (23a) \]

\[ -\alpha \ln \left( \frac{B}{N_M} \right) - \alpha \ln (I_H - I_L - I_O) + \ln \varphi_O(I_O) + (1 - \alpha\sigma) \ln \Omega(\cdot) - \ln \omega = 0 \quad (23b) \]

\[ -\ln \left( \frac{N_M}{N_H} \right) + \ln (I_H - I_L - I_O) + \sigma \ln \varphi_H(I_H) - \ln \gamma_H(I_H) = 0. \quad (23c) \]

To compute the impact of the minimum wage on the task margins, we differentiate the system in (23) with respect to \( \bar{W} \). The following proposition summarizes the main results of the impact of a marginal increase in minimum wage scheme as well as of a marginal decline of offshoring costs on task margins.

**Proposition 4 (Minimum wage, offshoring, and task reallocation).** Given a minimum wage scheme in the low-skill labor market segment and offshoring of medium skill-intensive tasks, a rise in the minimum wage scheme will lead to a contraction of low skill-intensive tasks, i.e. \( \frac{dI_L}{d\bar{W}} < 0 \), and to an expansion of high skill-intensive and offshorable tasks, i.e. \( \frac{dI_H}{d\bar{W}} < 0 \) and \( \frac{dI_O}{d\bar{W}} > 0 \), respectively. Moreover, easier offshoring generates similar task reallocation effects as in Proposition 2.

In order to assess the impact of easier offshoring on the low-skill unemployment rate we utilize equation (2) and the equilibrium conditions derived in Lemma 1 and 4 in the adjusted low-skill labor demand condition (21). Then, taking logs and rearranging slightly, we obtain

\[ \ln n_L = \ln \gamma_L(I_L) + \left( \frac{1}{\alpha} - \sigma \right) \ln \varphi_L(I_L) - \left( \frac{1}{\alpha} - \sigma \right) \ln \Omega(\cdot) - \frac{1}{\alpha} \ln \bar{W} + \sigma \ln B. \]

Now total differentiating with respect to offshoring friction (\( \omega \)) yields

\[ \frac{d\ln n_L}{d\omega} = \frac{1}{\alpha} \left( \frac{\alpha}{s_L} - (1 - \alpha\sigma)\varepsilon_L \right) \frac{dI_L}{d\omega} - \frac{1}{\alpha} (1 - \alpha\sigma) \frac{d\ln \Omega}{d\omega}. \quad (24) \]

From Eq. (24) it is readily seen that under a minimum wage scheme the impact of offshoring on low-skill (un)employment is characterized by similar channels as in the Walrasian case, derived in equation (15). We summarize the main result in the following proposition.

**Proposition 5 (Minimum wage, offshoring, and low-skill unemployment).** If a fraction of low-skill workers is unemployed due to a minimum wage scheme, then a marginal decline in offshoring costs will lead to a decline in the low-skill unemployment rate if and only if Proposition 3 holds.

As the low-skill wage is fixed by the minimum wage scheme, employment has to adjust. Consequently, the same determinants as in the Walrasian scenario will affect changes in low-skill employment.
5.2 Endogenous low-skill labor supply

A more general approach addressing labor market frictions is to allow low-skill workers to supply endogenously labor services, implying an elastic labor supply curve. We follow the standard approach in the literature and assume that the low-skill wage is a mark-up on unemployment benefits that depends negatively on the unemployment rate. This mark-up can be explained in many ways, such as the standard individual leisure–work choice, wage bargaining (Layard et al., 2005), search and matching theory à la Pissarides (2000) and efficiency wages à la Shapiro and Stiglitz (1984). Imposing such a negative relationship between the mark-up and unemployment induces an elastic labor supply curve. As discussed below, this approach has important implications for labor market outcomes, providing new insights regarding the interaction between supply and demand sides of the labor market. This way, we provide a more general analysis of the indirect consequences due to the internal skill-task reallocation of offshoring on low-skill labor market compared to the minimum wage case.14

More precisely, we make the following assumption on the structure of the low-skill labor market segment

**Assumption 3 (Endogenous low-skill wage curve).** *Let the endogenous low-skill wage curve be characterized by*

\[ w_L = f(u_L)b_L, \]  

*where* \( f(u_L) \) *denotes the mark-up over unemployment benefits,* \( b_L \), *and has the following properties: \( f(u_L) > 1 \) and \( \frac{\partial f(u_L)}{\partial u_L} < 0 \). Moreover, we define the elasticity of the wage curve with respect to \( u_L \) as \( \delta \equiv -\frac{\partial \ln f(u_L)}{\partial u_L} > 0 \).*  

Hence, in contrast to the full employment and minimum wage cases, Assumption 3 indicates that both the low-skill wage and employment will react to exogenous shocks. The next lemma summarizes the adjusted equilibrium conditions regarding the low-skill labor demand and task margin \( I_L \).

**Lemma 8 (Endogenous labor supply and adjusted equilibrium conditions).** *If the low-skill labor market is characterized by an endogenous wage curve described in Assumption 3, then adjusted general equilibrium demand for low-skill workers is given by*

\[ w_L = \left( \frac{\gamma_L(I_L)}{(1 - u_L)n_L} \right)^\alpha \Omega(\cdot)^{-\sigma} \varphi_L(I_L)^{(1-\alpha\sigma)} B^\alpha, \]  

*where* \( n_L = (1 - u_L)N_L \) *has been utilized. The adjusted optimality condition characterizing the implicit*

---

14It is worth mentioning the important implications of applying different equilibrium unemployment paradigms regarding the adjustment mechanism of the labor market to exogenous shocks. However, our objective is not to explain the efficiency of various adjustment mechanisms, and thus we deliberately leave this to future research. For an application of search-matching and efficiency wage theories to the original task-based approach of Grossman and Rossi-Hansberg (2008), see Kohler and Wrona (2011).
equilibrium solution to task margin \( I_L \) is given by

\[
\frac{N_L}{N_M} = \frac{1}{1 - u_L} \frac{\gamma_L(I_L) \varphi_L(I_L)^{-\sigma}}{I_H - I_L - I_O}.
\] (27)

Finally, the market-clearing condition for low-skill workers requires

\[
f(u_L) b_L = \left( \frac{\gamma_L(I_L)}{(1 - u_L) N_L} \right)^{\alpha} \Omega(\cdot)^{-(1 - \alpha \sigma)} \varphi_L(I_L)^{(1 - \alpha \sigma)} B^\alpha.
\] (28)

From the adjusted equilibrium conditions (27) and (28) together with the implicit solutions (14b) and (14c) in Lemma 5, we obtain a \( 4 \times 4 \) implicit system of equations characterizing the general equilibrium solution to the four endogenous variables \( I_L, I_H, I_O \) and \( u_L \). Taking logs in these equations and rearranging, we get

\[
-\alpha \ln \left( \frac{B}{N_L} \right) + \ln b_L + \ln f(u_L) + \alpha \ln(1 - u_L) + (1 - \alpha \sigma) \left( \ln \Omega(\cdot) - \ln \varphi_L(I_L) \right) - \alpha \ln \gamma_L(I_L) = 0.
\] (29a)

\[
- \ln \left( \frac{N_L}{N_M} \right) - \ln(1 - u_L) - \ln(I_H - I_L - I_O) - \sigma \ln \varphi_L(I_L) + \ln \gamma_L(I_L) = 0
\] (29b)

\[
-\alpha \ln \left( \frac{B}{N_M} \right) - \alpha \ln(I_H - I_L - I_O) + \ln \varphi_O(I_O) + (1 - \alpha \sigma) \ln \Omega(\cdot) - \ln \omega = 0
\] (29c)

\[
- \ln \left( \frac{N_M}{N_H} \right) + \ln(I_H - I_L - I_O) + \sigma \ln \varphi_H(I_H) - \ln \gamma_H(I_H) = 0
\] (29d)

Now the marginal impact of offshoring on task margins and the low-skill unemployment rate can be computed by straightforward differentiation of the system in (29) with respect to \( \omega \). We summarize the main results in the following proposition.

**Proposition 6** (Offshoring, endogenous labor supply, and low-skill unemployment). Let the low-skill labor market be characterized by an endogenous wage curve, where a fraction \( u_L \) of low-skill workers is unemployed. Offshoring of medium-skill tasks leads unambiguously to an expansion of the range of offshored tasks \((dI_O/d\omega > 0)\) and the extensive high-skill task margin \((dI_H/d\omega > 0)\). Moreover, easier offshoring reduces unambiguously the low-skill unemployment rate and raises real wages of medium-skill and high-skill workers if the sufficient conditions in Proposition 3 hold. The impact of a decline in offshoring costs on the extensive low-skill task margin and low-skill wages is ambiguous. For a sufficiently inelastic low-skill wage curve \( (i.e. \text{high value of } \delta) \) easier offshoring leads unambiguously to a decline in the extensive low-skill task margin \((dI_L/d\omega < 0)\) and an increase in low-skill wages.

Next to the importance of comparative advantage between skill groups in performing tasks, Proposition 6 highlights in addition the role of endogenous labor supply. This latter channel determines critically changes in the extensive low-skill task margin, affecting importantly the specialization pattern in low skill-intensive
tasks and the real wage of low-skill workers. Intuitively, the adjustment of the low-skill labor market segment to the offshoring-induced internal skill-task reallocation is now characterized by higher unemployment and lower wages due to a downward adjustment of the wage curve. However, the extent of this adverse adjustment depends crucially on the elasticity of the low-skill wage curve. Whenever the sufficient conditions in Proposition 3 hold, the productivity effect induces an increase in labor demand for low-skill workers along the wage curve, leading to an unambiguous decline in low-skill unemployment. If the wage curve is sufficiently inelastic (indicating a steeper slope), then this favorable shift in labor for low-skill workers will also raise their real wages. The intuition behind the real wage effects for medium-skill and high-skill workers is equivalent to the one discussed in Proposition 3.

6 Conclusion

In this paper, we have analyzed the general equilibrium implications of offshoring for the domestic skill-wage structure and for the low-skill unemployment rate. We develop a task-based model that accounts for skill heterogeneity, endogenous task allocation between domestic skill groups as well as between domestic and offshore workers, and equilibrium unemployment. We contribute to the existing literature by identifying three important channels through which the domestic labor market responds to offshoring shocks. We show that a marginal decline in offshoring costs of domestic medium skill-intensive tasks influences the domestic labor market through: i) a productivity effect, due to cost-saving effects at extensive and intensive margins, ii) an internal skill-task reallocation of tasks between domestic skill groups, and iii) a relative specialization of the domestic economy in low and high skill-intensive tasks.

The magnitude and the direction of the productivity effect depend crucially on two key parameters. The elasticity of task productivity schedules between medium-skill and offshore workers across tasks at the extensive task margin and the elasticity of substitution between domestic and offshore tasks. The results highlight that for a sufficient high degree of task-specific comparative advantage of medium-skill workers relative to offshore workers the magnitude of the productivity effect increases due to overall cost reductions of task production, both at extensive and intensive margins. This follows from the low degree of substitution of medium-skill workers by offshore workers in the neighborhood of extensive offshoring margins. However, the direction of the productivity effect depends on the elasticity of substitution between tasks, performed by domestic skill groups and offshore workers. Whenever there is a sufficient degree of complementarity between these tasks, easier offshoring induces a positive labor market effect.

The magnitude of internal skill-task allocation is determined by two key factors. On the one hand, it depends on the elasticity of task productivity schedules between low-skill and medium-skill workers in the neighborhood of the extensive low-skill task margin. On the other hand, it depends on the elasticity of task
productivity schedules between high-skill and medium-skill workers in the neighborhood of the extensive high-skill task margin. The comparative static analysis indicate that for a sufficiently high elasticity of task productivity schedules of low-skill and high-skill workers compared to medium-skill workers and complementarity between tasks, a marginal decline in offshoring costs will raise the wage rates of all domestic skill groups. In addition, our results also indicate that easier offshoring leads to a stronger increase in real wages of low-skill and high-skill workers relative to medium-skill workers, due to the specialization of the home economy in the production of low and high skill-intensive tasks. This provides the rationale behind the recent empirical evidence on wage polarization, observed in many advanced countries.

Finally, we extend the model with respect to equilibrium unemployment. We analyze the impact of offshoring under two alternative labor market frictions. First, we introduce a minimum wage scheme, which forces a fraction low-skill workers in unemployment. Second, we account for a more general scenario of labor market frictions in which low-skill labor market is characterized by an elastic wage curve. While in both cases the main results of our model still hold, in the latter changes at the extensive low-skill task margin become ambiguous. Whenever the wage curve is sufficiently inelastic, easier offshoring leads to a specialization in low skill-intensive tasks next to high skill-intensive tasks.

To sum up, our contribution is to disentangle important adjustment mechanisms and the underlying determinants of labor market effects of offshoring. These new insights provide also useful rationalization for the empirical literature.
References


Appendix

A Data

In order to understand how offshoring affects the workforce in advanced countries, Blinder (2009a) provides a new index of offshorability of 291 US occupations, which gives an idea about the potential impact of offshoring on the structure of occupation and thus the consequences for workers in the US. However, our concern is regarding the effects of offshoring for domestic skill groups. We augment Blinder’s offshorability index in the following way, while for details regarding the estimation of the offshorability index we refer the reader to Blinder (2009a). First, we extend the Appendix Table in Blinder (2009a) by collecting data from the U.S. Bureau of Labor Statistics on the skill distribution in each occupation. More specifically, we use data from the Employment Projections Program, which contains information on education and training measurements for workers 25 years and older by detailed occupations in 2008. We summarize the educational attainments into three broad skill groups. Low-skill denotes educational attainment “Less than high school diploma”; Medium-skill is the sum of the following educational attainments: “high school diploma or equivalent”, “some college, no degree”, and “Associate’s degree”; High-skill is defined by the following educational attainments: “Bachelor’s degrees”, “Master’s degrees”, and “Doctoral or professional degree”. We then adjust the offshorability index by the employment share of each occupation to account for the potential magnitude of the job-destruction impact of offshoring for the domestic workforce. These results are presented in Table A.1 below. In the second step, we order the 290 occupations by the high skill-intensity and estimate the fractional-polynomial prediction of the adjusted offshorability index. Figure 1 in the main text depicts the predicted fit of the adjusted offshorability index.

### Table A.1: Characteristics of 290 occupations by offshorability and skill intensity, for the U.S. in 2008

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<th>Occupation</th>
<th>SOC code</th>
<th>Offshorability index</th>
<th>Adjusted offshorability index</th>
<th>Employment</th>
<th>Educational attainment percent distribution</th>
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<td>Petroleum pump system operators, refinery operators and gaugers</td>
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<td>Plant and system operators, all other</td>
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<td>Separating, filtering, clarifying, precipitating, and still machine setters, operators, and tenders</td>
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<td>Grinding and polishing workers, hand</td>
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Table A.1: (continued)

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<tr>
<th>Occupation</th>
<th>SOC Code</th>
<th>Offshorability index</th>
<th>Employment</th>
<th>Educational attainment percent distribution</th>
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<tr>
<td>Extruding, forming, pressing, and compacting machine setters, operators and tenders</td>
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<td>Inspectors, testers, sorters, samplers, and weighers</td>
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<td>Cleaning, washing, and metal pickling equipment operators and tenders</td>
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<td>Cooling and freezing equipment operators and tenders</td>
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Table A.1: (continued)

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<th>Occupation</th>
<th>SOC Code</th>
<th>Offshorability index</th>
<th>Employment</th>
<th>Educational attainment percent distribution</th>
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<td>Etchers and engravers</td>
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<td>Moulders, shapers, and casters, except metal and plastic</td>
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<td>Ship engineers</td>
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Notes: The adjusted offshoring index is defined by multiplying the offshoring index reported in (Blinder, 2009a, Appendix Table) by the employment shares. Employment shares denote the percentage in total employment over the 290 occupations. Moreover, due to data availability we have combined the occupational categories "Computer support specialists A" and "Computer support specialists B" reported in (Blinder, 2009a, Appendix Table) into one item "Computer support specialist" (SOC code: 151041) and computed the offshorability index as the arithmetic average.
B Supplementary Mathematical Appendix

In this section we elaborate the formal steps of equilibrium conditions and main results of the comparative static analysis.

B.1 Firm optimization problem

The optimization problem of a firm can be solved in two steps. For given task margins, a firm minimizes the unit costs of task production by hiring the optimal amount of each domestic skill group and offshore workers. It then chooses the optimal task margins, which we discuss in the next section. The Lagrangian to the cost minimization problem is defined as follows:

\[
\begin{align*}
\min_{I_j(i), \xi} L &= w_L \int_0^{I_L} I_L(i) di + w_M \int_{I_M} I_M(i) di + w_O \int_{I_O} I_O(i) di + w_H \int_H^1 I_H(i) di \\
&+ \xi \left( E - \int_0^{I_L} (\varphi_L(i) I_L(i)) \frac{\sigma - 1}{\sigma} di + \int_{I_M} I_M(i) \frac{\sigma - 1}{\sigma} di + \int_{I_O} I_O(i) \left( \frac{\sigma - 1}{\sigma} \right) di + \int_H^1 (\varphi_H(i) I_H(i)) \frac{\sigma - 1}{\sigma} di \right) \frac{\sigma}{\sigma - 1}.
\end{align*}
\]

where \( \xi \) is the Lagrangian multiplier and \( I_j \) denote the subset of tasks produced by labor type \( j \in \{M, O\} \). The first-order conditions w.r.t. \( I_j(i) \) for \( j \in \{M, H, O\} \) and inserting the results into condition (B.6), we get

\[
\xi = \left[ \int_0^{I_L} \varphi_L(i) \frac{1}{\sigma - 1} diw_{1-\sigma}^L + (I_H - I_L - I_O)w_{1-\sigma}^M + \int_{I_O} \zeta(i) \frac{1}{\sigma - 1} diw_{1-\sigma}^O + \int_H^1 \varphi_H(i) \frac{1}{\sigma - 1} diw_{1-\sigma}^H \right] \frac{1}{\sigma - 1},
\]

where we use \( I_M = I_H - I_L - I_O \).

By the envelope theorem, the marginal cost of task composite is denoted by the shadow price, i.e. \( \frac{\partial L}{\partial E} = \xi \). Thus, under perfect competition, the marginal cost must equal the price index of task composite, i.e. \( P_E = \xi \).

B.2 Proofs of Lemmas and Propositions

Proof of Lemma 1.

Recall the marginal cost of the task composite (i.e. unit costs of task production) Eq. (B.7). Now the optimal choice of domestic task margins, \( I_L \) and \( I_H \), is obtained by minimizing \( \xi \) with respect to \( I_L \) and \( I_H \), respectively:

\[
\begin{align*}
\frac{d\xi}{dI_L} &= \frac{1}{1 - \sigma} \xi^\sigma \left[ \varphi_L(I_L)^{\sigma - 1} w_{1-\sigma}^L - w_{1-\sigma}^M \right],
\frac{d\xi}{dI_H} &= \frac{1}{1 - \sigma} \xi^\sigma \left[ w_{1-\sigma}^M - \varphi_H(I_H)^{\sigma - 1} w_{1-\sigma}^H \right].
\end{align*}
\]

We then get that \( \frac{d\xi}{dI_L} = 0 \) and \( \frac{d\xi}{dI_H} = 0 \) if and only if conditions (4) and (5) in Lemma 1 hold, respectively.
Proof of Lemma 2.

The proof of Lemma 2 can be shown in two steps. First, we define the set and the extensive margins of offshoring tasks. Second, by means of a positive monotonic transformation we derive the no-arbitrage conditions of offshoring task allocation in terms of the length of offshoring interval.

Notice that by Assumption 1 the U-shaped functional form of the comparative advantage schedule, \( \zeta(i) \), requires that the subset of offshore task \( I_O \) is defined by a closed set. Let \( I_1 \) and \( I_2 \) denote the boundaries of the offshore set such that \( I_1 < I_2, I_O = \{ I_1, I_2 \} \), and \( I_M = I_H - I_L = (I_2 - I_1) \). Then, the optimal choice of offshoring task margins, \( I_1 \) and \( I_2 \), is obtained by minimizing \( \lambda \) with respect to \( I_1 \) and \( I_2 \), respectively:

\[
\frac{d\xi}{dI_1} = \frac{1}{1-\sigma} \epsilon^\sigma \left[ \zeta(I_1)^{1-\sigma} (\tau w_O)^{1-\sigma} - w_M^{1-\sigma} \right], \tag{B.10}
\]

\[
\frac{d\xi}{dI_2} = \frac{1}{1-\sigma} \epsilon^\sigma \left[ w_M^{1-\sigma} - \zeta(I_2)^{1-\sigma} (\tau w_O)^{1-\sigma} \right]. \tag{B.11}
\]

Recalling \( \omega = 1/(\tau w_O) \), it then follows that \( \frac{d\xi}{dI_1} = 0 \) and \( \frac{d\xi}{dI_2} = 0 \) if and only if

\[
w_M = \frac{\zeta(I_1)}{\omega}, \tag{B.12}
\]

\[
w_M = \frac{\zeta(I_2)}{\omega}. \tag{B.13}
\]

However, it is useful to look at changes in the length of offshoring interval, i.e. \( I_O = I_2 - I_1 \), indicating implicitly changes in the extensive offshoring margins, \( I_1 \) and \( I_2 \). In fact, all we need to show is how offshoring-induced changes in the interval \( I_O \) affects the domestic skill-task margins, \( I_L \) and \( I_H \). Let \( \tilde{w} \equiv w_M \omega \) and let the semi-elasticities at the extensive offshoring margins \( I_1 \) and \( I_2 \) be given by \( \epsilon_1 = \frac{\partial \ln \zeta(I_1)}{\partial I_1} > 0 \) and \( \epsilon_2 = \frac{\partial \ln \zeta(I_2)}{\partial I_2} > 0 \), respectively. Next, taking logs in equations (B.12) and (B.13) and differentiating totally these two equations together with \( I_O = I_2 - I_1 \), we obtain

\[
d \ln \tilde{w} = -\epsilon_1 d I_1,
\]

\[
d \ln \tilde{w} = \epsilon_2 d I_2,
\]

\[
d I_O = d I_2 - d I_1.
\]

Utilizing then the first two equations in the last one, yields

\[
d I_O = d \ln \tilde{w} \left( \frac{1}{\epsilon_2} + \frac{1}{\epsilon_1} \right).
\]

It is convenient to define \( \mu = \frac{\epsilon_2}{\epsilon_2 + \epsilon_1} > 0 \), which is increasing in both arguments. Then, after further manipulation, we obtain \( d \ln \tilde{w} = \mu d I_O \). This is a simple first-order linear homogeneous ordinary differential equation. Thus, by integration

\[
\int d \ln \tilde{w} di = \int \mu d I_O di,
\]

we obtain a unique solution

\[
w_M = \frac{\varphi_O(I_O)}{\omega}, \tag{B.14}
\]

where \( \varphi_O(I_O) = \exp[\mu I_O] \). Equation (B.14) also implies that the unit offshore labor hired to produce a task \( i \) can be written as \( t_O(i) = \frac{I_O(i)}{\tau \varphi_O(i)} \), such that the first order condition (B.5) becomes

\[
\frac{\partial C}{\partial t_O(i)} = w_O - \xi \left( \frac{E}{t_O(i)} \right)^{1/\sigma} (\tau \varphi_O(i))^{\frac{1-\sigma}{\sigma}} = 0, \text{ for } i \in I_O. \tag{B.15}
\]
Proof of Lemma 3.

Let $N_j$ denote the endowment of each skill group $j \in \{L, M, H\}$ in the home country. Then, the resource constraints must satisfy

$$\begin{align*}
N_L &= \int_0^{I_L} l_L(i) di, \\
N_M &= \int_{i \in I_M} l_M(i) di, \\
N_H &= \int_{I_H} l_H(i) di, \\
n_O &= \int_{i \in O} l_O(i) di.
\end{align*}$$

From the optimality conditions (B.2)–(B.4), a firm will allocate each skill group across the different range of tasks that satisfies

$$\begin{align*}
I_L(i) &= I_L(i') \left( \frac{\varphi_L(i)}{\varphi_L(i')} \right)^{\sigma - 1}, \quad \forall i, i' \in [0, I_L], \\
I_M(i) &= I_M(i'), \quad \forall i, i' \in I_M = I_H - I_L - I_O, \\
I_H(i) &= I_H(i') \left( \frac{\varphi_H(i)}{\varphi_H(i')} \right)^{\sigma - 1}, \quad \forall i, i' \in [I_H, 1], \\
I_O(i) &= I_O(i') \left( \frac{\varphi_O(i)}{\varphi_O(i')} \right)^{1 - \sigma}, \quad \forall i, i' \in [I_1, I_2],
\end{align*}$$

where to derive equation (B.23) we made use of equation (B.15).

Thus, for the medium-skill labor it follows from (B.17) and (B.21) that a firm allocates an equal amount of workers across the range of tasks

$$I_M = \frac{N_M}{I_H - I_L - I_O}, \quad \forall i \in I_M.$$  

Note that for low-skill and high-skill workers as well as for offshore workers Eqs. (B.20), (B.22), and (B.23) imply $I_L(i) = I_L(0) \left( \frac{\varphi_L(i)}{\varphi_L(0)} \right)^{\sigma - 1}$ for $i \in [0, I_L]$, $I_H(i) = I_H(1) \left( \frac{\varphi_H(i)}{\varphi_H(1)} \right)^{\sigma - 1}$ for $i \in [I_H, 1]$, and $I_O(i) = I_O(I_O) \left( \frac{\varphi_O(i)}{\varphi_O(I_O)} \right)^{1 - \sigma}$ for $i \in I_O$, respectively. Utilizing these expressions, respectively, into Eqs. (B.20), (B.22), and (B.23), manipulating and substituting back into the expressions for $I_L(i)$, $I_H(i)$, and $I_O(i)$, we obtain

$$\begin{align*}
I_L(i) &= \frac{\varphi_L(i)^{\sigma - 1}}{\gamma_L(I_L)} N_L, \\
I_H(i) &= \frac{\varphi_H(i)^{\sigma - 1}}{\gamma_H(I_H)} N_H, \\
I_O(i) &= \frac{\varphi_O(i)^{1 - \sigma}}{\gamma_O(I_O)} n_O,
\end{align*}$$

where $\gamma_L(I_L) = \int_0^{I_L} \varphi_L(i)^{\sigma - 1} di$, $\gamma_H(I_H) = \int_{I_H} \varphi_H(i)^{\sigma - 1} di$, and $\gamma_O(I_O) = \int_{I_O} \varphi_O(i)^{1 - \sigma} di$.

First, utilize equations (B.24)–(B.27), respectively, into the first order conditions (B.3), (B.2), (B.4), and (B.15). In addition, to obtain the equilibrium values of the inverse labor demand conditions. Second, substituting these results into the condition (B.6) we obtain the equilibrium values of task composite derived in Lemma 3.

\[ \blacksquare \]

Proof of Lemma 4.

The marginal costs of task composite is given by $C_E = \lambda$. Substituting the no-arbitrage conditions (4) and (5) from Lemma 1 for $w_L$ and $w_H$, respectively, and (6) from Lemma 2 for $\omega$ in (B.7) and manipulating slightly, we obtain the equilibrium value of marginal costs of task composite, Eq. (12).  

\[ \blacksquare \]
Proof of Lemma 5.

To obtain the implicit equilibrium solution to the task margins, take first the ratio between inverse medium-skill labor demand and inverse labor demand of other types of workers from Eqs. (7)–(10) in Lemma 3

\[
\frac{w_L}{w_M} = \left( \frac{N_L}{N_M} \right)^{-\frac{\lambda}{\gamma}} \left( \frac{\gamma_L(I_L)}{I_H - I_L - I_O} \right)^{\frac{1}{\alpha}}, \quad (B.28)
\]

\[
\frac{w_O}{w_M} = \left( \frac{n_O}{N_M} \right)^{-\frac{\lambda}{\gamma}} \left( \frac{\gamma_O(I_O)}{I_H - I_L - I_O} \right)^{\frac{1}{\alpha}}, \quad (B.29)
\]

\[
\frac{w_M}{w_H} = \left( \frac{N_M}{N_H} \right)^{-\frac{\lambda}{\gamma}} \left( \frac{I_H - I_L - I_O}{\gamma_H(I_H)} \right)^{\frac{1}{\alpha}}. \quad (B.30)
\]

Notice that \(n_O\) is endogenously chosen by the firm. Thus, to account for employment adjustments, recall equation (10) to get the labor demand for offshoring workers:

\[
n_O = w_O^{-\sigma} r^{1-\sigma} \gamma_O(I_O) P_{OE}. \]

Utilizing the demand for task production (2) and the equilibrium conditions from Lemmas 2 and 4 into the previously derived equation, we obtain

\[
n_O = w_O^{-\sigma} r^{1-\sigma} \gamma_O(I_O) \rho^{1/\alpha} B
\]

\[
= w_O^{-\sigma} r^{1-\sigma} \gamma_O(I_O) (\Omega(I)w_M)^{\sigma-1/\alpha} B
\]

\[
= \tau \gamma_O(I_O)(\Omega(\varphi_O(I_O))^{\sigma-1/\alpha} (w_{OT})^{-\frac{\lambda}{\gamma}} B \quad (B.31)
\]

Substituting (B.31) back into equation (B.29) and rearranging, we obtain

\[
\frac{1}{w_M} = (\Omega(\varphi_O(I_O))^\frac{1}{\sigma} (w_{OT})^{-\frac{1}{\alpha} B} \left( \frac{N_M}{I_H - I_L - I_O} \right)^{-\frac{1}{\alpha}}. \quad (B.29')
\]

Now, combining the equations (B.28) and (B.30) with the optimal domestic task allocation conditions (4) and (5) in Lemma 1, respectively, and equation (B.29') with the optimal offshoring condition (6) in Lemma 2 and rearranging slightly, we obtain the implicit equilibrium solution (14) derived in Lemma 5.

Proof of Proposition 1.

By Lemma 1 iii) and Lemma 2 ii), we assume that the values of \(w_L\), \(w_M\), and \(w_H\) and the offshoring cost, \(\omega\), are sufficiently positive, respectively, such that an interior solution for all task margins exists in equilibrium. For the uniqueness of the equilibrium task margins, we evaluate the Jacobian of the implicit equilibrium solution (14). The comparative static analysis regarding changes in the task margins implies total differentiation of (14) w.r.t. \(I_L\), \(I_O\), and \(I_O\), which can be written as

\[
J = \begin{pmatrix}
\left( \frac{\sigma_L(I_L)^{\sigma-1}}{\gamma_L(I_L)} + \frac{1}{I_H - I_L - I_O} + \sigma \varepsilon \right) \\
\left( \frac{1}{1 - \sigma} \right) \frac{\Omega_L(\cdot)}{\Omega(\cdot)} + \frac{\sigma \varepsilon}{1 - \sigma} \\
- \frac{1}{I_H - I_L - I_O}
\end{pmatrix}
\begin{pmatrix}
\frac{1}{I_H - I_L - I_O} \\
\mu + \frac{\sigma \varepsilon}{1 - \sigma} \\
\left( \frac{1 - \sigma \varepsilon \mu}{\gamma_H(I_H)} \right)
\end{pmatrix}
\begin{pmatrix}
\left( \frac{\sigma_L(I_L)^{\sigma-1} - \sigma \varepsilon \mu \Omega_L(\cdot)}{\gamma_L(I_L)} + \frac{\sigma \varepsilon}{1 - \sigma} \right) \\
\left[ \frac{\sigma \varepsilon}{1 - \sigma} \right] \frac{\Omega_H(\cdot)}{\Omega(\cdot)} + \frac{\sigma \varepsilon \mu}{1 - \sigma} \\
\left( \frac{\sigma_L(I_L)^{\sigma-1} - \sigma \varepsilon \mu \Omega_L(\cdot)}{\gamma_L(I_L)} + \frac{\sigma \varepsilon}{1 - \sigma} \right)
\end{pmatrix}
\begin{pmatrix}
\left( \frac{\sigma_L(I_L)^{\sigma-1}}{\gamma_L(I_L)} + \frac{\sigma \varepsilon}{1 - \sigma} \right) \\
\left( \frac{\sigma \varepsilon}{1 - \sigma} \right) + \frac{\sigma \varepsilon \mu}{1 - \sigma} \\
\left( \frac{\sigma_L(I_L)^{\sigma-1}}{\gamma_L(I_L)} + \frac{\sigma \varepsilon}{1 - \sigma} \right)
\end{pmatrix}
\]

where \(\Omega_L(\cdot)/\Omega(\cdot) = \frac{\partial \Omega_L}{\partial \Omega} / \Omega(\cdot) = -\lambda_L \varepsilon < 0, \Omega_O(\cdot)/\Omega(\cdot) = \frac{\partial \Omega_O}{\partial \Omega} / \Omega(\cdot) = -\lambda_O \varepsilon < 0, \Omega_H(\cdot)/\Omega(\cdot) = \frac{\partial \Omega_H}{\partial \Omega} / \Omega(\cdot) = \lambda_H \varepsilon > 0,\) and \(\lambda_L = \gamma_L(I_L)^{-\sigma} \varphi_L(I_L)^{-1-\sigma}, \lambda_H = \gamma_L(I_L)^{-\sigma} \varphi_L(I_L)^{-1-\sigma},\) and \(\lambda_L = \gamma_L(I_L)^{-\sigma} \varphi_L(I_L)^{-1-\sigma}\) denote the cost shares. Next for a sufficient degree of complementarity between tasks, i.e. \(\sigma < 1/\alpha\), and a low offshoring cost shares, \(\lambda_O < 1/(1-\sigma)\), the diagonal elements of the Jacobian, (B.32), are always positive.

By \(\Upsilon\), sufficient conditions for global uniqueness require that Jacobian is a \(P\)-Matrix, i.e. its principle minors are positive. Computing
the determinants of principle minors of the Jacobian we obtain

\[ |J_{1 \times 1}| = \left( \frac{\varphi_L(I_L)^{n-1}}{\gamma_L(I_L)} + \frac{1}{I_H - I_L - I_O} + \sigma \varepsilon_L \right) > 0. \quad (B.33) \]

\[ |J_{2 \times 2}| = \left( \frac{\varphi_L(I_L)^{n-1}}{\gamma_L(I_L)} + \frac{1}{I_H - I_L - I_O} + \sigma \varepsilon_L \right) \times \left( \mu + \left[ 1 - \sigma \right] \frac{\Omega_O(\cdot)}{\Omega(\cdot)} + \frac{\alpha}{I_H + I_L - I_O} \right) \]

\[ - \left( \left[ 1 - \sigma \right] \frac{\Omega_L(\cdot)}{\Omega(\cdot)} + \frac{\alpha}{I_H - I_L - I_O} \right) \frac{1}{I_H - I_L - I_O} \]

\[ + \frac{\varphi_L(I_L)^{n-1}}{\gamma_L(I_L)} \times \left( \left[ 1 - \sigma \right] \frac{\varphi_H(I_L)^{n-1}}{\gamma_H(I_L)} + \frac{1}{I_H - I_L - I_O} + \sigma \varepsilon_H \right) \]

\[ + \frac{\varphi_L(I_L)^{n-1}}{\gamma_L(I_L)} \times \left( \left[ 1 - \sigma \right] \frac{\varphi_H(I_L)^{n-1}}{\gamma_H(I_L)} + \frac{1}{I_H - I_L - I_O} + \sigma \varepsilon_H \right) \]

\[ \times \left( \left[ 1 - \sigma \right] \frac{\varphi_H(I_L)^{n-1}}{\gamma_H(I_L)} + \frac{1}{I_H - I_L - I_O} + \sigma \varepsilon_H \right) > 0. \quad (B.34) \]

\[ |J_{3 \times 3}| = \left( \frac{\varphi_L(I_L)^{n-1}}{\gamma_L(I_L)} + \frac{1}{I_H - I_L - I_O} + \sigma \varepsilon_L \right) \times \left( \mu + \left[ 1 - \sigma \right] \frac{\Omega_O(\cdot)}{\Omega(\cdot)} + \frac{\alpha}{I_H + I_L - I_O} \right) \times \left( \frac{\varphi_H(I_L)^{n-1}}{\gamma_H(I_L)} + \frac{1}{I_H - I_L - I_O} + \sigma \varepsilon_H \right) \]

\[ + \frac{\varphi_L(I_L)^{n-1}}{\gamma_L(I_L)} \times \left( \left[ 1 - \sigma \right] \frac{\varphi_H(I_L)^{n-1}}{\gamma_H(I_L)} + \frac{1}{I_H - I_L - I_O} + \sigma \varepsilon_H \right) \]

\[ + \frac{\varphi_L(I_L)^{n-1}}{\gamma_L(I_L)} \times \left( \left[ 1 - \sigma \right] \frac{\varphi_H(I_L)^{n-1}}{\gamma_H(I_L)} + \frac{1}{I_H - I_L - I_O} + \sigma \varepsilon_H \right) \]

\[ + \frac{\varphi_L(I_L)^{n-1}}{\gamma_L(I_L)} \times \left( \left[ 1 - \sigma \right] \frac{\varphi_H(I_L)^{n-1}}{\gamma_H(I_L)} + \frac{1}{I_H - I_L - I_O} + \sigma \varepsilon_H \right) > 0. \quad (B.35) \]

Substituting the expressions for \( \Omega_j(\cdot)/\Omega(\cdot) \) and manipulating further, we obtain

\[ \left( \frac{\varphi_L(I_L)^{n-1}}{\gamma_L(I_L)} + \frac{1}{I_H - I_L - I_O} + \sigma \varepsilon_L \right) \times \left( \left[ 1 - \sigma \right] \frac{\varphi_H(I_L)^{n-1}}{\gamma_H(I_L)} + \frac{1}{I_H - I_L - I_O} + \sigma \varepsilon_H \right) \]

\[ + \frac{\varphi_L(I_L)^{n-1}}{\gamma_L(I_L)} \times \left( \left[ 1 - \sigma \right] \frac{\varphi_H(I_L)^{n-1}}{\gamma_H(I_L)} + \frac{1}{I_H - I_L - I_O} + \sigma \varepsilon_H \right) \]

\[ + \frac{\varphi_L(I_L)^{n-1}}{\gamma_L(I_L)} \times \left( \left[ 1 - \sigma \right] \frac{\varphi_H(I_L)^{n-1}}{\gamma_H(I_L)} + \frac{1}{I_H - I_L - I_O} + \sigma \varepsilon_H \right) > 0. \quad (B.36) \]

Proof of Proposition 2.

Total differentiation of the system (18) with respect to \( \omega \), yields

\[ J \times I = \omega. \quad (B.36) \]

where \( J \) is given by (B.32), \( I = \{dL, dO, dH\} \) and \( \omega = \{0, d\omega, \omega\} \).

Let \( |J_k| \) denote the replacement of kth column of \( J \) by the vector \( \omega \), and to ease the notation let \( s_j = \frac{\gamma_j(I_j)^{n-1}}{\varphi_j(I_j)^{n-1}} \) denote the task share of skill group \( j \in \{L, H\} \). Then applying Cramer’s Rule, the solution to (B.36) is

\[ \frac{dL}{d\omega} = \frac{|J_1|}{|J|} = \frac{-1}{|J|} \omega \left( \frac{1}{\varphi_H(I_L)} + \frac{1}{I_H - I_L - I_O} \right) \frac{\varphi_H(I_L)^{n-1}}{\gamma_H(I_L)} + \sigma \varepsilon_H \]  \( < 0, \quad (B.37) \]

\[ \frac{dO}{d\omega} = \frac{|J_2|}{|J|} = \frac{1}{|J|} \omega \left( \frac{1}{\gamma_L(I_L)} + \frac{1}{I_H - I_L - I_O} + \sigma \varepsilon_L \right) \left( \frac{1}{\varphi_H(I_L)} + \sigma \varepsilon_H \right) \]

\[ + \frac{1}{\gamma_L(I_L)} \left( \frac{1}{\varphi_H(I_L)} + \sigma \varepsilon_H \right) > 0, \quad (B.38) \]

\[ \frac{dH}{d\omega} = \frac{|J_3|}{|J|} = \frac{1}{|J|} \omega \left( \frac{1}{\gamma_H(I_L)} + \frac{1}{I_H - I_L - I_O} + \sigma \varepsilon_H \right) \left( \frac{1}{\varphi_H(I_L)} + \sigma \varepsilon_H \right) \]  \( > 0. \quad (B.39) \]
Comparing (B.37) and (B.39) with (B.38), it can be readily shown that offshoring induces a contraction of the range of medium skill-intensive tasks, i.e.

\[ \left| \frac{dI_O}{d\omega} \right| > \left| \frac{dI_H}{d\omega} \right| + \left| \frac{dI_L}{d\omega} \right| \]

Next comparing (B.37) with (B.39), we can show that the magnitude of changes in the domestic task margins, \( I_L \) and \( I_H \), is determined by the degree of comparative advantage, i.e.

\[ \frac{I_H}{I_L} \] and \( \frac{I_H}{I_O} \)

\[ \Rightarrow \left( \frac{1}{s_L} + \sigma \varepsilon_L \right) < \left( \frac{1}{s_H} + \sigma \varepsilon_H \right) \] .

\[ \blacksquare \]

**Proof of Lemma 6.**

Total differentiation of \( \Omega(\cdot) \) with respect to offshoring costs \( \omega \) yields

\[
\frac{d \ln \Omega(\cdot)}{d\omega} = \left( \lambda_H \varepsilon_H \frac{dI_H}{d\omega} - \lambda_L \varepsilon_L \frac{dI_L}{d\omega} \right) - \left( \lambda_O \mu \frac{dI_O}{d\omega} \right) .
\] (B.40)

Now substitute the results of the comparative statics (B.37)-(B.39) into the previous equation and rearrange to obtain

\[
\frac{d \ln \Omega(\cdot)}{d\omega} = \frac{1}{|J|} \left( \frac{1}{I_H - I_L - I_O} \left( \frac{1}{s_L} + \sigma \varepsilon_L \right) + \frac{1}{I_H - I_L - I_O} \left( \frac{1}{s_H} + \sigma \varepsilon_H \right) \right) \] 

\[
- \lambda_O \mu \left( \frac{1}{s_L} + \sigma \varepsilon_L \right) \left( \frac{1}{s_H} + \sigma \varepsilon_H \right) + \left( \frac{1}{s_H} + \sigma \varepsilon_L \right) \left( \frac{1}{I_H - I_L - I_O} \right) .
\]

We can derive sufficient conditions under which the sign of \( \frac{d \ln \Omega(\cdot)}{d\omega} \) is unambiguously determined. It follows \( \frac{d \ln \Omega(\cdot)}{d\omega} < 0 \) whenever \( \mu \geq \max \left\{ \frac{\lambda_L \varepsilon_L}{\lambda_O}, \frac{\lambda_H \varepsilon_H}{\lambda_O} \right\} . \]

\[ \blacksquare \]

**Proof of Proposition 3.**

To derive the boundaries for the elasticity of task productivity schedules, recall (15)-(17) and in these equations substitute for \( \frac{d \ln \Omega(\cdot)}{d\omega} \) the result from (B.40) to obtain

\[
\frac{d \ln w_L}{d\omega} = \left( \frac{\alpha}{s_L} - (1 - \alpha)(1 - \lambda_L) \varepsilon_L \right) \frac{dI_L}{d\omega} + (1 - \alpha) \lambda_O \mu \frac{dI_O}{d\omega} - (1 - \alpha) \lambda_H \varepsilon_H \frac{dI_H}{d\omega} .
\] (B.41)

\[
\frac{d \ln w_M}{d\omega} = \left( 1 - \alpha \right) \lambda_L \varepsilon_L \alpha - \left( \frac{\alpha}{I_H - I_L - I_O} \right) \frac{dI_L}{d\omega} + (1 - \alpha) \lambda_O \mu \frac{dI_O}{d\omega} - \frac{\alpha}{I_H - I_L - I_O} \frac{dI_H}{d\omega} .
\] (B.42)

\[
\frac{d \ln w_H}{d\omega} = \left( 1 - \alpha \right) \lambda_L \varepsilon_L \frac{dI_L}{d\omega} + (1 - \alpha) \lambda_O \mu \frac{dI_O}{d\omega} - \left( \frac{\alpha}{s_H} - (1 - \alpha)(1 - \lambda_L) \varepsilon_H \right) \frac{dI_H}{d\omega} .
\] (B.43)

From the first terms in (B.41) and (B.42), we get the lower and upper boundaries for \( \varepsilon_L \), respectively. Similarly, from the third terms in (B.42) and (B.43), we get the upper and lower boundaries for \( \varepsilon_H \), respectively. Finally, from the second in (B.42) we obtain the lower boundary for \( \mu \). Notice also that by the sufficient condition (19) in Lemma 6 the last two terms in (B.41) and the first two terms in (B.43) are positive.

\[ \blacksquare \]

**Proof of Lemma 7.**

The optimization problem of the firm is similar to the perfect competition case discussed above, except that now a fraction of low-skill workers are unemployed due to a sufficiently high minimum wage scheme. The optimization problem implies that a firm chooses the optimal amount of low-skill workers to produce a task \( i \) given the minimum wage scheme. Then, the modified first-order condition yields

\[
\bar{W} \equiv \bar{\xi} \left( \frac{E}{l_L(i)} \right) \phi L(i) \frac{\sigma-1}{\sigma} ,
\]
where \( \xi \) denotes the modified Lagrangian multiplier and is now given by

\[
\xi = \left[ \int_0^{I_L} \varphi_L(i)^{\sigma-1} \, di \varphi^{1-\sigma} + (I_H - I_L - I_O)w_M^{1-\sigma} + \int_{i \in I_O} \xi(i)^{\sigma-1} \, di \varphi(i)^{1-\sigma} + \int_{I_H}^1 \varphi_H(i)^{\sigma-1} \, di \varphi^{1-\sigma} \right]^{-1}. 
\]

(B.45)

For the sake of notation, we use throughout this section the same equilibrium notations of variables as in the perfect competition scenario. Again the firm decides on the optimal task threshold, determining the allocation of tasks between low-skill and medium-skill workers, so that \( \bar{x}i \) is minimized, i.e.

\[
\frac{\partial \bar{x}i}{\partial I_L} = \frac{1}{1-\sigma} \xi \left[ \varphi_L(I_L)^{-1} \bar{w}^{1-\sigma} - w_M^{1-\sigma} \right].
\]

It follows that \( \frac{\partial \bar{x}i}{\partial I_L} = 0 \) if and only if the following condition holds

\[
W_M = \frac{\bar{W}}{\varphi_L(I_L)}.
\]

Next let the low-skill unemployment rate be given by \( u_L = 1 - n_L/N_L \), where \( n_L \) denotes the endogenous amount of low-skill employment, so that the resource constraint must satisfy \( \int_0^{I_L} \varphi(i) \, di = n_L. \) To derive the equilibrium inverse low-skill labor demand, we follow the same steps as in the proof of Lemma 3 and combine the adjusted resource constraint for low-skill labor with (B.44) to obtain

\[
\bar{W} = P_L \frac{E}{n_L} \gamma_L(I_L)^{\frac{1}{\sigma}}.
\]

To derive the adjusted implicit equilibrium solution to task margin \( I_L \), notice that we need to account for the endogenous low-skill employment \( n_L \) as in the offshoring case. Following the same formal steps as in the proof of Lemma 5 we obtain equation (22).

\[\Box\]

**Proof of Proposition 4.**

Take the total differentiation of the adjusted implicit system equations (23) w.r.t. to \( \bar{W} \), and rearrange to obtain

\[
\bar{J} \times \mathbf{1} = \bar{W},
\]

where \( \mathbf{1} = \{dI_L, dI_O, dI_H \} \), \( \bar{W} = \{-d\bar{W}/\bar{W}, 0, 0 \} \), and \( \bar{J} \) is given by

\[
\bar{J} = \begin{pmatrix}
\alpha \left( \frac{\partial \Omega_L}{\partial I_L} - \frac{\partial \Omega_O}{\partial I_O} \right) + (1 - (1 - \sigma)\lambda_L) \varepsilon_L & - (1 - \sigma)\lambda_O \mu - \frac{\partial \Omega_L}{\partial I_L} - (1 - \sigma)\lambda_H \varepsilon_H \\
\frac{\partial \Omega_L}{\partial I_L} - (1 - \sigma)\lambda_O \varepsilon_L & \frac{\partial \Omega_L}{\partial I_L} + (1 - (1 - \sigma)\lambda_O) \mu - (1 - \sigma)\lambda_H \varepsilon_H \\
- \frac{\partial \Omega_H}{\partial I_O} - \sigma \varepsilon_H + \frac{\partial \Omega_H}{\partial I_H} & \frac{1}{\partial I_H} - \frac{\partial \Omega_H}{\partial I_O} - \sigma \varepsilon_H + \frac{\partial \Omega_H}{\partial I_H}
\end{pmatrix}
\]

(B.47)

where we utilized the following expressions: \( \Omega_L(\cdot) / \Omega(\cdot) \equiv \frac{\partial \Omega_L(\cdot)}{\partial \Omega(\cdot)} = -\lambda_L \varepsilon_L < 0, \Omega_O(\cdot) / \Omega(\cdot) \equiv \frac{\partial \Omega_O(\cdot)}{\partial \Omega(\cdot)} = -\lambda_O \mu < 0, \Omega_H(\cdot) \equiv \frac{\partial \Omega_H(\cdot)}{\partial \Omega(\cdot)} = \lambda_H \varepsilon_H > 0 \), and the expressions for the cost shares \( \lambda_L = \frac{\gamma_L(I_L) \alpha(I_L)^{\sigma-1}}{\gamma_L(I_L)^{\sigma-1}}, \lambda_O = \frac{\gamma_O(I_O) \alpha(I_O)^{\sigma-1}}{\gamma_O(I_O)^{\sigma-1}}, \lambda_H = \frac{\gamma_H(I_H) \alpha(I_H)^{\sigma-1}}{\gamma_H(I_H)^{\sigma-1}} \).

Computing the determinant of the Jacobian (B.47), we show that by sufficient conditions in Proposition 3 and for \( \varepsilon_H > \lambda_L / \lambda_H \varepsilon_L \) the adjusted Jacobian is a \( P \)-Matrix too:

\[
|\bar{J}_{11}| = \left( \frac{\alpha}{I_H - I_L - I_O} + (1 - (1 - \sigma)\lambda_L) \varepsilon_L \right) > 0,
\]

\[
|\bar{J}_{22}| = \left( \frac{\alpha}{I_H - I_L - I_O} + (1 - (1 - \sigma)\lambda_L) \varepsilon_L \right) \times \left( \frac{\alpha}{I_H - I_L - I_O} + (1 - (1 - \sigma)\lambda_O) \mu \right) \times \left( \frac{\sigma \varepsilon_L + \frac{\partial \Omega_H}{\partial I_H}}{\partial I_H} - \frac{\partial \Omega_H}{\partial I_O} - \sigma \varepsilon_H + \frac{\partial \Omega_H}{\partial I_H} \right) > 0,
\]

\[
|\bar{J}_{33}| = \left( \frac{\alpha}{I_H - I_L - I_O} + (1 - (1 - \sigma)\lambda_L) \varepsilon_L \right) \times \left( \frac{\alpha}{I_H - I_L - I_O} + (1 - (1 - \sigma)\lambda_O) \mu \right) \times \left( \frac{\sigma \varepsilon_L + \frac{\partial \Omega_H}{\partial I_H}}{\partial I_H} - \frac{\partial \Omega_H}{\partial I_O} - \sigma \varepsilon_H + \frac{\partial \Omega_H}{\partial I_H} \right) > 0,
\]

\[
|\bar{J}_{31}| = \left( \frac{\alpha}{I_H - I_L - I_O} + (1 - (1 - \sigma)\lambda_L) \varepsilon_L \right) \times \left( \frac{\alpha}{I_H - I_L - I_O} + (1 - (1 - \sigma)\lambda_O) \mu \right) \times \sigma \varepsilon_H > 0.
\]
Inserting in equation (24) the solution from equation (B.40), we obtain

\begin{equation}
\frac{d \ln n_L}{d\omega} = \frac{1}{\alpha} \left( \frac{\alpha}{1 - \alpha \sigma} - (1 - \alpha \sigma) \lambda_L \varepsilon_L \right) \frac{d I_L}{d\omega} - \frac{1}{\alpha} (1 - \alpha \sigma) \lambda_H \varepsilon_H \frac{d I_H}{d\omega} - \left( \lambda_O \mu \frac{d I_O}{d\omega} \right)
\end{equation}

It follows that easier offshoring will reduce the low-skill unemployment rate, i.e. \( \frac{d \ln n_L}{d\omega} > 0 \), if and only if Lemma 6 and Proposition 3 hold.
Proof of Lemma 8.

As in minimum wage scenario, the resource constraint for low-skill labor is given by \( \int_{O}^{L} L(i)di = n_L \). Then, recalling the first-order condition (B.2) and following similar formal steps as in the proof of Lemma 3, we obtain

\[
w_L = P_E \left( \frac{E}{n_L} \right) \frac{1}{E} \gamma_L(I_L) \frac{1}{E}.
\] (B.50)

Next, utilize the demand condition (3) to substitute for \( E \) and combine the equilibrium conditions (4), (12) and (13) to substitute for \( P_E \) in equation (B.50). Rearranging slightly and substituting \( u_L = 1 - n_L/N_L \) for \( n_L \), we obtain equation (26).

To derive the adjusted implicit solution (27), take first the ration between (8) and (B.50) to obtain

\[
\frac{w_L}{w_M} = \left( \frac{N_M}{n_C} \right) \frac{1}{E} \gamma_L(I_L) \frac{1}{E}.
\]

Then, utilizing equilibrium condition (4) and substituting \( u_L = 1 - n_L/N_L \) for \( n_L \), we get (27).

Finally, from equations (25) and (26) we obtain the market-clearing condition (28).

Proof of Proposition 6.

Taking the total differentiation of the system of equations (29) w.r.t. to \( \omega \) and rearranging, yields

\[
\dot{\mathbf{j}} \times \dot{\mathbf{i}} = \dot{\mathbf{\omega}},
\] (B.51)

where \( \dot{\mathbf{i}} = \{dI_L, dI_O, dH, du_L\}, \dot{\mathbf{\omega}} = \{0, 0, d\omega/\omega, 0\} \), and \( \dot{\mathbf{j}} \) is given by

\[
\dot{\mathbf{j}} = \begin{pmatrix}
\left( 1 - \sigma \alpha \right) \left( 1 - \lambda_L \right) \frac{\frac{dI_L}{\dot{\mathbf{i}}} - \frac{\alpha}{s_L}}{\dot{\mathbf{j}}} & -(1 - \sigma \alpha) \lambda_O & (1 - \sigma \alpha) \lambda_H & \left( \frac{\gamma_L(I_L)}{\Omega(I_O)} \right) \\
\left( \frac{1}{I_H - I_L - I_O} + \sigma \alpha \right) \lambda_O & \left( 1 - \sigma \alpha \right) \lambda_O & \left( 1 - \sigma \alpha \right) \lambda_H & \left( \frac{\gamma_L(I_L)}{\Omega(I_O)} \right) \\
\left( \frac{1}{I_H - I_L - I_O} - \sigma \alpha \right) \lambda_L & \frac{1}{I_H - I_L - I_O} & \left( 1 - \sigma \alpha \right) \lambda_H & \left( \frac{\gamma_L(I_L)}{\Omega(I_O)} \right) \\
\left( \frac{1}{I_H - I_L - I_O} - \sigma \alpha \right) \lambda_L & \frac{1}{I_H - I_L - I_O} & \frac{1}{I_H - I_L - I_O} & \left( \frac{\gamma_L(I_L)}{\Omega(I_O)} \right)
\end{pmatrix},
\] (B.52)

where we utilized the following definitions: \( \frac{\partial \Omega(I_O)}{\partial I_O} = -\lambda_O \mu < 0, \frac{\partial \Omega(I_O)}{\partial \lambda_O} = \frac{\partial \Omega(I_O)}{\partial \lambda_L} = -\lambda_O \varepsilon_L < 0, \Omega(I_O) / \Omega(\cdot) \equiv \frac{\partial \Omega(I_O)}{\partial I_O} / \Omega(\cdot) = -\lambda_H \varepsilon_L < 0, \Omega(I_O) / \Omega(\cdot) \equiv \frac{\partial \Omega(I_O)}{\partial \lambda_O} / \Omega(\cdot) = -\lambda_L \varepsilon_L < 0, \lambda_L = \gamma_L(I_L) \varepsilon_L \left( \frac{1}{\Omega(I_O)} \right)^{1-\sigma} \lambda_H = \gamma_L(I_L) \varepsilon_L \left( \frac{1}{\Omega(I_O)} \right)^{1-\sigma}, \lambda_L \). Computing the determinant of the Jacobian (B.52), we show that by sufficient conditions in Proposition 3 the adjusted Jacobian \( \dot{\mathbf{j}} \) is a P-Matrix too:

\[
|J_{1x1}| = \left( 1 - \sigma \alpha \right) \left( 1 - \lambda_L \right) \frac{\varepsilon_L - \frac{\alpha}{s_L}}{s_L} > 0,
\]

\[
|J_{2x2}| = \left( 1 - \sigma \alpha \right) \left( 1 - \lambda_L \right) \frac{\varepsilon_L - \frac{\alpha}{s_L}}{s_L} \times \frac{1}{I_H - I_L - I_O} + \frac{1}{I_H - I_L - I_O} + \left( 1 - \sigma \alpha \right) \lambda_O \mu \left( 1 + \frac{1}{I_H - I_L - I_O} + \sigma \alpha \right) > 0,
\]

\[
|J_{3x3}| = \left( 1 - \sigma \alpha \right) \left( 1 - \lambda_L \right) \frac{\varepsilon_L - \frac{\alpha}{s_L}}{s_L} \times \left( 1 - \sigma \alpha \right) \lambda_L \left( 1 + \frac{1}{I_H - I_L - I_O} + \sigma \alpha \right) \times \left( 1 - \sigma \alpha \right) \lambda_O \mu \left( 1 + \frac{1}{I_H - I_L - I_O} + \frac{\alpha}{I_H - I_L - I_O} \right) + \left( 1 - \sigma \alpha \right) \lambda_O \mu \left( 1 + \frac{1}{I_H - I_L - I_O} + \frac{\alpha}{I_H - I_L - I_O} \right) + \frac{\alpha}{I_H - I_L - I_O} \left( 1 - \sigma \alpha \right) \lambda_O \mu \left( 1 + \frac{1}{I_H - I_L - I_O} + \sigma \alpha \right) \times \left( 1 - \sigma \alpha \right) \lambda_H \left( 1 + \frac{1}{I_H - I_L - I_O} + \frac{\alpha}{I_H - I_L - I_O} \right) + \frac{\alpha}{I_H - I_L - I_O} \left( 1 - \sigma \alpha \right) \lambda_O \mu \left( 1 + \frac{1}{I_H - I_L - I_O} + \sigma \alpha \right) \times \left( 1 - \sigma \alpha \right) \lambda_H \left( 1 + \frac{1}{I_H - I_L - I_O} + \frac{\alpha}{I_H - I_L - I_O} \right) > 0.
\]

To compute the determinant of the Jacobian (B.52), we apply the cofactor expansion along the 1st row, i.e. \( \dot{\mathbf{j}}_{1x4} = \Sigma_{q=1}^{4} a_{1q} \dot{\mathbf{j}}_{1q} \), where \( \dot{\mathbf{j}}_{1q} \) is the
cofactor of the element $a_{14}$. Formally,

$$
\left| J_{1\times 4} \right| = \left[ (1 - \alpha \sigma)(1 - \lambda L)\varepsilon_L - \frac{\alpha}{s_L} \right] J_{11} + (1 - \alpha \sigma)\lambda_O \mu J_{12} + (1 - \alpha \sigma)\lambda_H \varepsilon L J_{13} + \left( \frac{\alpha}{1 - u_L} + \delta \right) J_{14} > 0, \quad (B.53)
$$

where

$$
\begin{align*}
J_{11} &= \frac{1}{1 - u_L}\left( \left( (1 - \alpha \sigma)\lambda_O \mu + \frac{\alpha}{I_H + I_L - I_O} \right) \times \left( \frac{1}{I_H} + \frac{1}{I_H - I_L - I_O} + \sigma s_H \right) + \frac{1}{I_H - I_L - I_O} \left( (1 - \alpha \sigma)\lambda_H \varepsilon L - \frac{\alpha}{I_H - I_L - I_O} \right) \right) > 0, \\
J_{12} &= \frac{1}{1 - u_L}\left( \left( \frac{\alpha}{I_H - I_L - I_O} - (1 - \alpha \sigma)\lambda_L \varepsilon L \right) \times \left( \frac{1}{I_H} + \frac{1}{I_H - I_L - I_O} + \sigma s_H \right) + \frac{1}{I_H - I_L - I_O} \left( (1 - \alpha \sigma)\lambda_H \varepsilon L - \frac{\alpha}{I_H - I_L - I_O} \right) \right) > 0, \\
J_{13} &= \frac{1}{1 - u_L}\left( \frac{1}{I_H - I_L - I_O} \right) \left( \left( (1 - \alpha \sigma)\lambda_H \varepsilon L \right) + \frac{\alpha}{I_H + I_L - I_O} - \left( \frac{\alpha}{I_H - I_L - I_O} - (1 - \alpha \sigma)\lambda_L \varepsilon L \right) \right) > 0.
\end{align*}
$$

and finally from (B.49) it follows $J_{14} > 0$.

Now using Cramer’s Rule we obtain the solution for the four variables.

$$
\frac{dI_L}{d\omega} = -\frac{1}{J} \left[ \frac{(\alpha s_H + (1 + s_H \sigma H))(1 - \lambda L)\varepsilon_L - \alpha \lambda_O (1 - \alpha \sigma) (s_H + (1 - \lambda L) \varepsilon_L) \right] + (1 - \alpha \sigma) s_H \lambda_H \varepsilon L \right] \leq 0,
$$

where

$$
\begin{align*}
\frac{dI_H}{d\omega} &= \frac{1}{J} \left[ \frac{s_L (1 - \alpha \sigma) (1 - \lambda L)\varepsilon_L + \mu \lambda_O + \alpha \sigma s_L \varepsilon L) + (1 - \alpha \sigma) (1 - \lambda L) s_L \varepsilon L - \alpha \lambda_O (1 - \alpha \sigma) (s_H + (1 - \lambda L) \varepsilon_L) \right] + (1 - \alpha \sigma) s_L (1 - s_H \sigma H) (I_H + I_L + I_O) > 0, \\
\frac{du_L}{d\omega} &= \frac{1}{J} \left[ \frac{s_L (1 - \alpha \sigma) (1 - \lambda L)\varepsilon_L + \mu \lambda_O + \alpha \sigma s_L \varepsilon L) + (1 - \alpha \sigma) (1 - \lambda L) s_L \varepsilon L - \alpha \lambda_O (1 - \alpha \sigma) (s_H + (1 - \lambda L) \varepsilon_L) \right] + (1 - \alpha \sigma) s_L \left( 1 + s_H \sigma H \right) \mu \lambda_O (1 - \alpha \sigma) (1 + s_L (I_H - I_L - I_O)) + (1 + (1 - \lambda H) \sigma s_H \varepsilon L) (1 - \lambda L) \varepsilon_L + \sigma s_L \varepsilon L \lambda O \mu \right] < 0.
\end{align*}
$$

The impact of easier offshoring on real wages of medium-skill and high-skill workers can be computed following the steps in the Proof of Proposition 3, while derivation of the impact of offshoring on low-skill real wages requires further steps, which we discuss below.

Recall equations (25) and (26). Taking logs and differentiating totally with respect to $\omega$ we obtain respectively

$$
\frac{d\varepsilon_L}{d\omega} = -\frac{\alpha s_L}{\mu}, \quad \frac{d\varepsilon_L}{d\omega} = -\frac{d\varepsilon_L}{d\omega} - (1 - \alpha \sigma) \frac{d\varepsilon_L}{d\omega} + \frac{\alpha}{1 - u_L} \frac{d\varepsilon_L}{d\omega}, \quad (B.54)
$$

where for convenience $\Delta \equiv (1 - \alpha \sigma)\varepsilon_L - \frac{\alpha}{s_L}$ and by Proposition 3 $\Delta > 0$. Solving equation (B.55) for $\frac{d\varepsilon_L}{d\omega}$ and substituting it in equation (B.54) and rearranging, we get

$$
\frac{d\varepsilon_L}{d\omega} = -\frac{(1 - u_L)\delta}{\alpha + (1 - u_L)\delta} \left( \Delta \frac{d\varepsilon_L}{d\omega} + (1 - \alpha \sigma) \frac{d\varepsilon_L}{d\omega} \right). \quad (B.56)
$$

By Proposition 3 and for $\delta > \mu \lambda_O (1 - \alpha \sigma) s_H + (1 - \lambda L) \varepsilon_L < 0$, it follows $\frac{d\varepsilon_L}{d\omega} < 0$ and $\frac{d\varepsilon_L}{d\omega} < 0$. Thus, from equation (B.56) $\frac{d\varepsilon_L}{d\omega} > 0$. 

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