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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

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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).[1] 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".

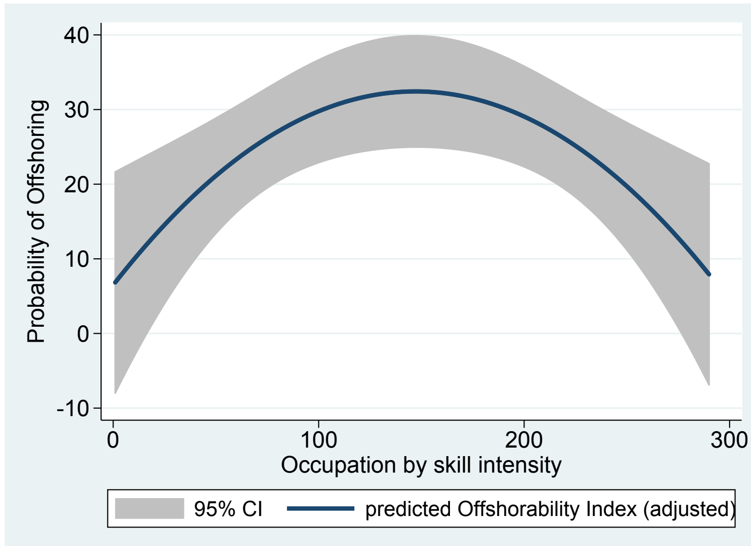
The rationale behind this new trend can be found in various factors: on the one hand, the integration process of national markets into a global market has been accelerated by advances in information and communication technology (ICT) as well as by declines in trade transaction and transportation costs 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.[2] 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

[1] 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.

[2] 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).

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 effect due to production cost savings.[3] 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 á 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

[3]A 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]

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

where B is a positive parameter[5], α 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

$$E = P_E^{-\frac{1}{\alpha}}\mathcal{B}, \tag{2}$$

where $\mathcal{B} = ((1-\alpha)B)^{1/\alpha}$ 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]

$$E = \left[\int_0^1 t(i)^{\frac{\sigma-1}{\sigma}} \mathrm{d}i\right]^{\sigma/(\sigma-1)}, \tag{3}$$

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, $\mathcal{I}_j$ where $\mathcal{I}_j \in (0,1)$, for $j = \{L, M, H\}$.

Let w_j denote the effective marginal cost of hiring workers of skill type j to produce any task $i \in \mathcal{I}_j$. 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

$$w_M = \frac{w_L}{\varphi_L(I_L)}, \tag{4}$$
$$w_M = \frac{w_H}{\varphi_H(I_H)}. \tag{5}$$

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, ε_L and ε_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.[9] 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 $\check{I}$ such that for all $i \in [0, \check{I})$, $\zeta(i)$ is (strict) monotonically decreasing, and for all $i \in (\check{I}, 1]$, $\zeta(i)$ 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.[10] 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 dichotomous 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).[11]

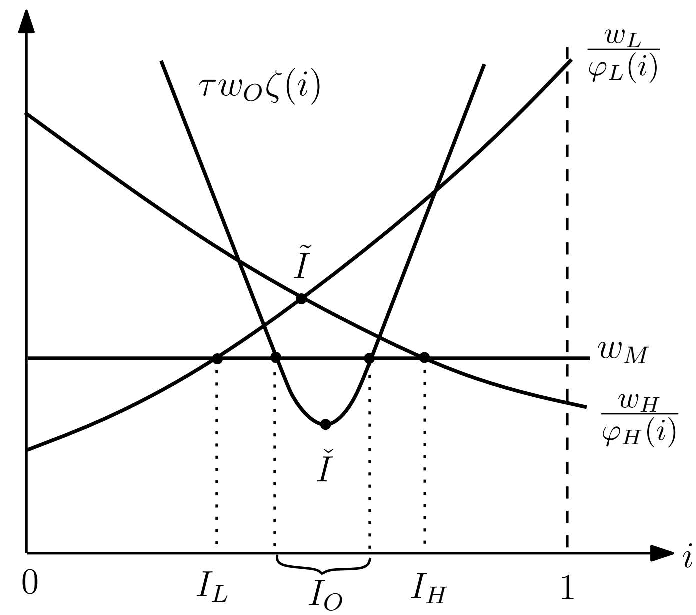
If a firm decides to offshore, it must pay a hiring cost for a unit of offshore workers, w_O, and an additional

[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 immigrants 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.

Figure 2: Equilibrium task allocation



transportation cost, τ, 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 ω 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

$$w_M = \frac{\varphi_O(I_O)}{\omega}, \tag{6}$$

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 ω in the interval $\frac{\varphi_O(0)}{w_M} < \omega < \frac{\varphi_O(I')}{w_M}$, $\forall i \{i \in I' \leftrightarrow i \in I_M = I_H - I_L\}$ and $I_L < \breve{I}|_{\frac{\partial \ln \zeta(\cdot)}{\partial i}=0} < I_H$, 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 (exogenously 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*

i) domestic workers

$$w_L = P_E \left(\frac{E}{N_L}\right)^{\frac{1}{\sigma}} \gamma_L(I_L)^{\frac{1}{\sigma}}, \tag{7}$$

$$w_M = P_E \left(\frac{E}{N_M}\right)^{\frac{1}{\sigma}} (I_H - I_L - I_O)^{\frac{1}{\sigma}}, \tag{8}$$

$$w_H = P_E \left(\frac{E}{N_L}\right)^{\frac{1}{\sigma}} \gamma_H(I_H)^{\frac{1}{\sigma}}, \tag{9}$$

ii) offshore workers

$$w_O = P_E \left(\frac{E}{n_O}\right)^{\frac{1}{\sigma}} \tau^{\frac{1-\sigma}{\sigma}} \gamma_O(I_O)^{\frac{1}{\sigma}}, \tag{10}$$

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

iii) The equilibrium value of task composite is given by

$$E = \left[\gamma_L(I_L)^{\frac{1}{\sigma}} N_L^{\frac{\sigma-1}{\sigma}} + (I_H - I_L - I_O)^{\frac{1}{\sigma}} N_M^{\frac{\sigma-1}{\sigma}} + \gamma_O(I_O)^{\frac{1}{\sigma}} n_O^{\frac{\sigma-1}{\sigma}} + \gamma_H(I_H)^{\frac{1}{\sigma}} N_H^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}. \tag{11}$$

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

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*

$$\Omega(I_L, I_H, I_O) = \left[\gamma_L(I_L)\varphi_L(I_L)^{1-\sigma} - I_L + \gamma_O(I_O)\varphi_O(I_O)^{\sigma-1} - I_O + \gamma_H(I_H)\varphi_H(I_H)^{1-\sigma} + I_H\right]^{\frac{1}{1-\sigma}}. \tag{12}$$

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

$$P_E = C_E. \tag{13}$$

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 ω), e.g. due to lower hiring costs ($\mathrm{d}w_O < 0$) or lower trade costs ($\mathrm{d}\tau < 0$), 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 *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*

$$\frac{N_L}{N_M} = \frac{\gamma_L(I_L)}{(I_H - I_L - I_O)\varphi_L(I_L)^\sigma}, \tag{14a}$$

$$\left(\frac{\mathcal{B}}{N_M}\right)^\alpha \omega = \frac{\varphi_O(I_O)\Omega(\cdot)^{1-\sigma\alpha}}{(I_H - I_L - I_O)^\alpha}, \tag{14b}$$

$$\frac{N_M}{N_H} = \frac{(I_H - I_L - I_O)\varphi_H(I_H)^\sigma}{\gamma_H(I_H)}. \tag{14c}$$

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 $\mathrm{d}\omega > 0$ induced either by i) $\mathrm{d}w_O < 0$, e.g. due to accumulation of human capital abroad, or by ii) $\mathrm{d}\tau < 0$, 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

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

where $\mathcal{K}_j \equiv \ln(N_j\mathcal{B})^{-\alpha}$ 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

$$\frac{\mathrm{d}\ln w_L}{\mathrm{d}\omega} = \left(\frac{\alpha}{s_L} - (1-\alpha\sigma)\varepsilon_L\right)\frac{\mathrm{d}I_L}{\mathrm{d}\omega} - (1-\alpha\sigma)\frac{\mathrm{d}\ln\Omega}{\mathrm{d}\omega} \tag{15}$$

$$\frac{\mathrm{d}\ln w_M}{\mathrm{d}\omega} = -\frac{\alpha}{I_H - I_L - I_O}\left[\frac{\mathrm{d}I_O}{\mathrm{d}\omega} - \left(\frac{\mathrm{d}I_H}{\mathrm{d}\omega} - \frac{\mathrm{d}I_L}{\mathrm{d}\omega}\right)\right] - (1-\alpha\sigma)\frac{\mathrm{d}\ln\Omega}{\mathrm{d}\omega} \tag{16}$$

$$\frac{\mathrm{d}\ln w_H}{\mathrm{d}\omega} = -\left(\frac{\alpha}{s_H} - (1-\alpha\sigma)\varepsilon_H\right)\frac{\mathrm{d}I_H}{\mathrm{d}\omega} - (1-\alpha\sigma)\frac{\mathrm{d}\ln\Omega}{\mathrm{d}\omega}, \tag{17}$$

where $s_j = \frac{\gamma_j(I_j)}{\varphi_j(I_j)^{1-\sigma}}$ 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 $\frac{\mathrm{d}I_L}{\mathrm{d}\omega}$, $\frac{\mathrm{d}I_O}{\mathrm{d}\omega}$, and $\frac{\mathrm{d}I_H}{\mathrm{d}\omega}$, which will be discussed in the section 4.1 (i.e. Lemma 2), and the signs of $\frac{\mathrm{d}\Omega}{\mathrm{d}\omega}$ (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

$$-\ln\left(\frac{N_L}{N_M}\right) - \ln\left(I_H - I_L - I_O\right) - \sigma \ln \varphi_L(I_L) + \ln \gamma_L(I_L) = 0 \tag{18a}$$

$$-\alpha \ln\left(\frac{\mathcal{B}}{N_M}\right) - \alpha \ln\left(I_H - I_L - I_O\right) + \ln \varphi_O(I_O) + (1-\sigma\alpha)\ln \Omega(\cdot) = \ln \omega \tag{18b}$$

$$-\ln\left(\frac{N_M}{N_H}\right) + \ln\left(I_H - I_L - I_O\right) + \sigma \ln \varphi_H(I_H) - \ln \gamma_H(I_H) = 0. \tag{18c}$$

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 ($\mathrm{d}\omega > 0$) on task allocation is characterized by:*

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

$$\frac{\mathrm{d}I_L}{\mathrm{d}\omega} < 0, \quad \frac{\mathrm{d}I_O}{\mathrm{d}\omega} > 0, \quad \frac{\mathrm{d}I_H}{\mathrm{d}\omega} > 0, \qquad \textit{and} \qquad \left|\frac{\mathrm{d}I_O}{\mathrm{d}\omega}\right| > \left|\frac{\mathrm{d}I_H}{\mathrm{d}\omega}\right| + \left|\frac{\mathrm{d}I_L}{\mathrm{d}\omega}\right|.$$

ii) An asymmetric impact on the domestic skill-task reallocation

$$\left|\frac{\mathrm{d}I_L}{\mathrm{d}\omega}\right| \lesseqgtr \left|\frac{\mathrm{d}I_H}{\mathrm{d}\omega}\right|, \;\Leftrightarrow \left(\frac{1}{s_L} + \sigma\varepsilon_L\right) \lesseqgtr \left(\frac{1}{s_H} + \sigma\varepsilon_H\right).$$

The intuition can be explained in the following way. Easier offshoring, e.g. due to lower transportation cost ($\mathrm{d}\tau < 0$), or a decline in foreign wage costs ($\mathrm{d}w_O < 0$), 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 *task upgrading* at the high-skill extensive margin, i.e. more medium-skill workers produce former high-skill tasks, and a *task downgrading* at the low-skill extensive margin, i.e. more medium-skill workers produce former low-skill tasks.[12] The key determinants behind the magnitude of the skill down- and upgrading are ε_L and ε_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 ε_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 (P_E) is held constant.

From Proposition 2 we know the sign of changes in the task margins $\left(\frac{\mathrm{d}I_H}{\mathrm{d}\omega}, \frac{\mathrm{d}I_L}{\mathrm{d}\omega}, \frac{\mathrm{d}I_O}{\mathrm{d}\omega}\right)$. The only term which is not defined yet is the last term in Eqs. (15)–(17), $\frac{\mathrm{d}\ln\Omega}{\mathrm{d}\omega}$, 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)**.** *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 ($\mathcal{D}$) and an external task relocation ($\mathcal{F}$), i.e.*

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

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

[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 ($\mathcal{D}$). 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 ($\mathrm{d}I_L/\mathrm{d}\omega < 0$, $\mathrm{d}I_H/\mathrm{d}\omega > 0$). 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 μ) 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 $-(1-\alpha\sigma)\frac{\mathrm{d}\ln\Omega}{\mathrm{d}\omega}$. Whether a decline in offshoring costs is translated into higher real wages for the domestic workforce, therefore depends next to the sign of $\frac{\mathrm{d}\ln\Omega}{\mathrm{d}\omega}$ also on the magnitude of another key parameter. A greater elasticity of substitution between tasks (i.e. a higher value of σ) 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 μ 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 $\left(\frac{\alpha}{s_L} - (1-\alpha\sigma)\varepsilon_L\right)\frac{\mathrm{d}I_L}{\mathrm{d}\omega}$. Whether the labor demand per task for low-skill workers declines depends on the value of ε_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 $-\left(\frac{\alpha}{s_H} - (1-\alpha\sigma)\varepsilon_H\right)\frac{\mathrm{d}I_H}{\mathrm{d}\omega}$ and depends on ε_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 ε_L and ε_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. $\mathrm{d}I_L/\mathrm{d}\omega < 0$ and $\mathrm{d}I_H/\mathrm{d}\omega > 0$, 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. $\frac{\alpha}{(1-\alpha\sigma)s_L} < \varepsilon_L < \frac{\alpha}{1-\alpha\sigma}\frac{1}{\lambda_L(I_H-I_L-I_O)}$,

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

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

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. $\mathrm{d}I_L/\mathrm{d}\omega < 0$ and $\mathrm{d}I_H/\mathrm{d}\omega > 0$. 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)**.**

$$w_L/\varphi_L(0) < \bar{W}/\varphi_L(0) < w_M,$$

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 $\int_0^{I_L} l_L(i)\mathrm{d}i = n_L$.[13] 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.*

$$w_M = \frac{\bar{W}}{\varphi_L(I_L)}, \tag{20}$$

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

$$\bar{W} = P_E \left(\frac{E}{n_L}\right)^{\frac{1}{\sigma}} \gamma_L(I_L)^{\frac{1}{\sigma}}. \tag{21}$$

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

$$\left(\frac{\mathcal{B}}{N_M}\right)^{\alpha} \bar{W}^{-1} = \frac{\Omega(\cdot)^{1-\alpha\sigma}}{\varphi_L(I_L)(I_H - I_L - I_O)^{\alpha}}. \tag{22}$$

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-

[13] For the sake of simplicity, we keep the same notation of equilibrium variables as in the frictionless labor market scenario and highlight differences where necessary.

ranging slightly, we obtain

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

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

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

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.* $\frac{\mathrm{d}I_L}{\mathrm{d}\bar{W}} < 0$*, and to an expansion of high skill-intensive and offshorable tasks, i.e.* $\frac{\mathrm{d}I_H}{\mathrm{d}\bar{W}} < 0$ *and* $\frac{\mathrm{d}I_O}{\mathrm{d}\bar{W}} > 0$*, 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

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

Now total differentiating with respect to offshoring friction (ω) yields

$$\frac{\mathrm{d}\ln n_L}{\mathrm{d}\omega} = \frac{1}{\alpha}\left(\frac{\alpha}{s_L} - (1-\alpha\sigma)\varepsilon_L\right)\frac{\mathrm{d}I_L}{\mathrm{d}\omega} - \frac{1}{\alpha}(1-\alpha\sigma)\frac{\mathrm{d}\ln\Omega}{\mathrm{d}\omega}. \tag{24}$$

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*

$$w_L = f(u_L)b_L, \tag{25}$$

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*

$$w_L = \left(\frac{\gamma_L(I_L)}{(1-u_L)N_L}\right)^{\alpha} \Omega(\cdot)^{-(1-\alpha\sigma)} \varphi_L(I_L)^{(1-\alpha\sigma)} \mathcal{B}^{\alpha}, \tag{26}$$

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

[14] It 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

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

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

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

From the adjusted equilibrium conditions (27) and (28) together with the implicit solutions (14b) and (14c) in Lemma 5, we obtain a 4×4 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

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

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

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

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

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 ω. 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 ($\mathrm{d}I_O/\mathrm{d}\omega > 0$) and the extensive high-skill task margin ($\mathrm{d}I_H/\mathrm{d}\omega > 0$). 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. high value of δ) easier offshoring leads unambiguously to a decline in the extensive low-skill task margin ($\mathrm{d}I_L/\mathrm{d}\omega < 0$) 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-sill 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

Acemoglu, D. and Autor, D. (2011). Chapter 12 - Skills, Tasks and Technologies: Implications for Employment and Earnings. In Ashenfelter, O. and Card, D., editors, *Handbook of Labor Economics*, volume 4, Part B, pages 1043–1171. Elsevier.

Autor, D. H. and Dorn, D. (2009). This jobs are getting old: Measuring changes in job opportunities using occupation age structure. *American Economic Review: Papers & Proceedings*, 99(2):45–51.

Autor, D. H. and Dorn, D. (2013). The growth of low skill service jobs and the polarization of the U.S. labor market. *American Economic Review*, 103(5):1553–1597.

Autor, D. H., Katz, L. F., and Kearney, M. S. (2006). The Polarization of the U.S. Labor Market. *American Economic Review*, 96(2):189–194.

Autor, D. H., Katz, L. F., and Kearney, M. S. (2008). Trend in U.S. wage inequality: Revising the revisionists. *Review of Economics and Statistics*, 90:300–323.

Autor, D. H., Levy, F., and Murnane, R. J. (2003). The Skill Content of Recent Technological Change: An Empirical Investigation. *The Quarterly Journal of Economics*, 118:1279–1333.

Baumgarten, D., Geishecker, I., and Görg, H. (2013). Offshoring, tasks, and the skill-wage pattern. *European Economic Review*, 61:132–52.

Becker, S. O., Ekholm, K., and Muendler, M.-A. (2013). Offshoring and the onshore composition of tasks and skills. *Journal of International Economics*, 90:91–106.

Bhagwati, J., Panagariya, A., and Srinivasan, T. (2004). The muddles over outsourcing. *Journal of Economic Perspectives*, 18:93–114.

Blinder, A. S. (2009a). How Many U.S. Jobs Might Be Offshorable? *World Economics*, 10(2):41–78.

Blinder, A. S. (2009b). Offshoring: Big deal, or business as usual? In Friedman, B. M., editor, *Offshoring of Amercian Jobs. What Response from U.S. Economic Policy?*, pages 19–60. MIT Press, Cambridge, Mass.

Brynin, M. and Longhi, S. (2009). Overqualification: Major or minor mismatch? *Economics of Education Review*, 28:114–121.

Cortes, G. M. et al. (2016). Where have the middle-wage workers gone? a study of polarization using panel data. *Journal of Labor Economics*, 34(1):63–105.

Costinot, A. and Vogel, J. (2010). Matching and Inequality in the World Economy. *Journal of Political Economy*, 118(4):747–786.

Dustmann, C., Ludsteck, J., and Schönberg, U. (2009). Revisiting the German Wage Structure. *Quarterly Journal of Economics*, 124(2):843–881.

Ebenstein, A., Harrison, A., McMillan, M., and Phillips, S. (2014). Estimating the Impact of Trade and Offshoring on American Workers Using the Current Population Surveys. *The Review of Economics and Statistics*, 96(4):581–595.

Egger, H., Kreickemeier, U., and Wrona, J. (2015). Offshoring domestic jobs. *Journal of International Economics*, 97(1):112–25.

Feenstra, R. C. and Hanson, G. H. (1996). Globalization, outsourcing, and wage inequality. *The American Economic Review*, 86(2):240–245.

Feenstra, R. C. and Hanson, G. H. (1999). The impact of outsourcing and high-technology capital on wages: Estimates for the united states, 1979–1990. *The Quarterly Journal of Economics*, 86(2):240–245.

Firpo, S., Fortin, N. M., and Lemieux, T. (2011). Occupational tasks and changes in the wage structure. IZA, Discussion Paper No. 5542.

Goos, M. and Manning, A. (2007). Lousy and Lovely Jobs: The Rising Polarization of Work in Britain. *Review of Economic Studies*, 89:118–133.

Goos, M., Manning, A., and Salomons, A. (2009). Job polarization in Europe. *American Economic Review: Papers & Proceedings*, 99:58–63.

Goos, M., Manning, A., and Salomons, A. (2014). Explaining job polarization: Routine-biased technological change and offshoring. *American Economic Review*, 104:2509–2526.

Groizard, J. L., Ranjan, P., and Rodriguez-Lopez, A. (2014). Offshoring and jobs: The myriad channels of influence. *European Economic Review*, 72:221–239.

Grossman, G. M. and Rossi-Hansberg, E. (2008). Trading Task: A Simple Theory of Offshoring. *American Economic Review*, 98:1978–1997.

Hummels, D., Jørgensen, R., Munch, J., and Xiang, C. (2014). The Wage Effects of Offshoring: Evidence from Danish Matched Worker-Firm Data. *American Economic Review*, 104(6):1597–1629.

Jensen, J. B. and Kletzer, L. G. (2010). *Measuring Tradable Services and the Task Content of Offshorable Services Jobs*, pages 309–335. University of Chicago Press.

Jones, R. W. and Kierzkowski, H. (1990). The role of services in production and international trade: A theoretical framework. In Jones, R. W. and Krueger, A. O., editors, *The Political Economy of International Trade*, pages 31–48. Basil Blackwell, Oxford.

Jones, R. W. and Kierzkowski, H. (2001). A framework for fragmentation. In Arndt, S. and Kierzkowski, H., editors, *Fragmentation: New Production Patterns in the World Economy*, pages 17–45. Oxford University Press, New York.

Kohler, W. (2004a). Aspects of international fragmentation. *Review of International Economics*, 12:793–816.

Kohler, W. (2004b). International outsourcing and factor prices with multistage production. *Economic Journal*, 114:166–185.

Kohler, W. and Wrona, J. (2011). Offshoring Tasks, yet Creating Jobs? University of Tübingen, Working Paper No. 12.

Layard, R., Nickell, S., and Jackman, R. (2005). *Unemployment: Macroeconomic Performance and the Labour Market*. Oxford University Press.

Meltiz, M. (2003). The Impact of Trade on Intra-Idustry Reallocations and Aggregate Industry Productivity. *Econometrica*, 71:1695–1725.

Michaels, G., Natraj, A., and Van Reenen, J. (2014). Has ICT Polarized Skill Demand? Evidence from Eleven Countries over Twenty-Five Years. *The Review of Economics and Statistics*, 96(1):60–77.

Moncarz, R. J., Wolf, M. G., and Wright, B. (2008). Service-providing occupations, offshoring, and the labor market. *Monthly Labor Review*, pages 71–86.

Muysken, J., Vallizadeh, E., and Ziesemer, T. (2015). Migration, Unemployment, and Skill Downgrading. *The Scandinavian Journal of Economics*, 117(6):403–51.

Olney, W. W. (2012). Offshoring, immigration, and the native wage distribution. *Canadian Journal of Economics*, 45:830–856.

Ottaviano, G. I. P., Peri, G., and Wright, G. C. (2013). Immigration, Offshoring and American Jobs. *American Economic Review*, 103(5):1925–59.

Peri, G. and Sparber, C. (2009). Task specialization, immigration, and wages. *American Economic Journal: Applied Economics*, 1(3):135–169.

Pissarides, C. A. (2000). *Equilibrium Unemployment Theory*. MIT Press, Cambrdige, MA, 2nd edition.

Shapiro, C. and Stiglitz, J. (1984). Equilibrium unemployment as a worker discipline device. *American Economic Review*, 75:433–444.

Snower, D. J., Brown, A. J. G., and Merkl, C. (2009). Globalization and the welfare state: A review of Hans-Werner Sinn's *Can Germany Be Saved? Journal of Economic Literature*, 47:136–158.

Spence, M. (2011). Globalization and unemployment: The downside of integrating markets. *Foreign Affairs*, 90(4):28–41.

Spitz-Oener, A. (2006). Technical change, job tasks, and rising educational demands: Looking outside the wage structure. *Journal of Labour Economics*, 24:235–270.

Wright, G. C. (2014). Revisiting the employment impact of offshoring. *European Economic Review*, 66:63–83.

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 "Assiciate'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 offshorabiltiy index.

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

Occupation	SOC code	Offshorability index	Adjusted offshorability index	Employment		Educational attainment percent distribution		
				Absolute	Percent	Low	Medium	High
General and operations managers	111021	55	258	1663810	4.7	2.2	49.2	48.6
Advertising and promotions managers	112011	53	6	41710	0.1	1.0	26.1	72.9
Marketing managers	112021	53	25	166470	0.5	1.0	33.3	65.7
Sales managers	112022	26	23	317970	0.9	1.0	33.3	65.7
Administrative services managers	113011	49	33	239410	0.7	2.2	60.0	37.8
Computer and information systems managers	113021	55	40	259330	0.7	0.6	29.4	70.0
Financial managers	113031	75	75	353963	1.0	1.0	39.8	59.2
Training and development managers	113042	49	4	28720	0.1	2.3	41.6	56.1
Human resources managers, all other	113049	49	8	57830	0.2	2.3	41.6	56.1
Industrial production managers	113051	55	24	153950	0.4	3.7	54.1	42.1
Purchasing managers	113061	49	10	69300	0.2	1.1	42.7	56.3

Table A.1: (continued)

Occupation	SOC Code	Offshorability index	Adjusted Offshorability index	Employment		Educational attainment percent distribution		
				Absolute	Percent	Low	Medium	High
Transportation, storage, and distribution managers	113071	49	12	84870	0.2	5.8	68.4	25.8
Engineering managers	119041	54	29	187410	0.5	0.8	17.2	82.0
Natural sciences managers	119121	56	6	40400	0.1	0.6	6.7	92.7
Wholesale and retail buyers, except farm products	131022	55	21	132900	0.4	4.2	62.0	33.8
Purchasing agents, except wholesale, retail, and farm products	131023	55	42	267410	0.8	2.0	59.5	38.6
Cost estimators	131051	50	29	204330	0.6	3.6	66.4	30.0
Compensation, benefits, and job analysis specialists	131072	46	13	97740	0.3	1.6	45.8	52.6
Logisticians	131081	55	8	52220	0.1	2.0	54.7	43.3
Business operations specialists, all other	131199	25	65	916290	2.6	1.9	50.2	47.9
Accountants and auditors	132011	72	160	788415	2.2	0.3	24.7	75.0
Budget analysts	132031	60	9	53510	0.2	0.7	31.0	68.3
Credit analysts	132041	64	11	61500	0.2	1.4	42.4	56.2
Financial analysts	132051	76	39	180910	0.5	0.9	17.3	81.8
Insurance underwriters	132053	85	24	98970	0.3	0.6	49.4	50.0
Tax preparers	132082	68	11	58850	0.2	2.1	49.0	48.9
Financial specialists, all other	132099	50	17	122320	0.3	2.2	46.9	50.9
Computer and information scientists, research	151011	96	7	25890	0.1	0.6	33.9	65.5
Computer programmers	151021	100	110	389090	1.1	0.6	29.4	70.0
Computer software engineers, applications	151031	74	95	455980	1.3	0.3	17.9	81.8
Computer software engineers, systems software	151032	74	67	320720	0.9	0.3	17.9	81.8

Table A.1: (continued)

Occupation	SOC Code	Offshorability index	Adjusted Offshorability index	Employment		Educational attainment percent distribution		
				Absolute	Percent	Low	Medium	High
Computer support specialists *	151041	80	113	499860	1.4	1.0	57.9	41.1
Computer systems analysts	151051	93	129	492120	1.4	0.6	33.9	65.5
Database administrators	151061	75	21	99380	0.3	0.4	30.5	69.1
Network and computer systems administrators	151071	50	38	270330	0.8	0.7	49.1	50.2
Network systems and data communications analysts	151081	92	48	185190	0.5	0.7	43.2	56.1
Computer specialists, all other	151099	90	30	116760	0.3	0.6	33.9	65.5
Actuaries	152011	96	4	15770	0.0	0.1	2.8	97.0
Mathematicians	152021	96	1	2930	0.0	0.4	9.5	90.1
Operations research analysts	152031	82	12	52530	0.1	0.6	32.8	66.6
Statisticians	152041	96	5	17480	0.0	0.4	9.5	90.1
Mathematical technicians	152091	78	0	1430	0.0	0.4	9.5	90.1
Mathematical science occupations, all other	152099	95	2	7320	0.0	0.4	9.5	90.1
Architects, except landscape and naval	171011	25	7	96740	0.3	0.3	11.5	88.1
Cartographers and photogrammetrists	171021	86	3	11260	0.0	0.5	24.5	75.0
Aerospace engineers	172011	37	8	81100	0.2	0.1	16.7	83.2
Biomedical engineers	172031	71	2	11660	0.0	0.0	25.5	74.5
Chemical engineers	172041	72	6	27550	0.1	0.2	9.1	90.7
Computer hardware engineers	172061	73	16	78580	0.2	0.3	28.2	71.5
Electrical engineers	172071	64	26	144920	0.4	0.2	22.2	77.6
Electronics engineers, except computer	172072	70	26	130050	0.4	0.2	22.2	77.6
Health and safety engineers. except mining safety engineers and inspectors	172111	25	2	25330	0.1	0.3	31.8	67.9

Table A.1: (continued)

Occupation	SOC Code	Offshorability index	Adjusted Offshorability index	Employment		Educational attainment percent distribution		
				Absolute	Percent	Low	Medium	High
Industrial engineers	172112	70	38	191640	0.5	0.3	31.8	67.9
Marine engineers and naval architects	172121	69	1	6550	0.0	0.8	28.3	70.9
Materials engineers	172131	71	4	20950	0.1	0.4	29.9	69.7
Mechanical engineers	172141	70	44	220750	0.6	0.3	26.6	73.0
Engineers, all other	172199	72	31	152940	0.4	0.3	19.4	80.4
Architectural and civil drafters	173011	90	26	101040	0.3	1.5	73.8	24.7
Electrical and electronics drafters	173012	98	8	30270	0.1	1.5	73.8	24.7
Mechanical drafters	173013	98	21	74650	0.2	1.5	73.8	24.7
Drafters. all other	173019	90	5	20870	0.1	1.5	73.8	24.7
Electrical and electronic engineering technicians	173023	47	22	165850	0.5	3.7	79.3	17.0
Electro-mechanical technicians	173024	47	2	15130	0.0	3.7	79.3	17.0
Industrial engineering technicians	173026	72	15	73310	0.2	3.7	79.3	17.0
Mechanical engineering technicians	173027	72	9	46580	0.1	3.7	79.3	17.0
Engineering technicians, except drafters, all other	173029	47	10	78300	0.2	3.7	79.3	17.0
Animal scientists	191011	85	1	3000	0.0	0.5	20.5	79.0
Food scientists and technologists	191012	79	2	7570	0.0	0.5	20.5	79.0
Biochemists and biophysicists	191021	83	4	17690	0.0	0.1	6.7	93.1
Microbiologists	191022	83	4	15250	0.0	0.1	6.7	93.1
Biological scientists, all other	191029	83	6	26200	0.1	0.1	6.7	93.1
Medical scientists, except epidemiologists	191042	55	11	73670	0.2	0.2	2.1	97.8
Life scientists, all other	191099	55	2	12790	0.0	0.2	2.1	97.8
Astronomers	192011	30	0	970	0.0	0.0	5.9	94.1

Table A.1: (continued)

Occupation	SOC Code	Offshorability index	Adjusted Offshorability index	Employment		Educational attainment percent distribution		
				Absolute	Percent	Low	Medium	High
Physicists	192012	67	3	15160	0.0	0.0	5.9	94.1
Atmospheric and space scientists	192021	81	2	7050	0.0	0.0	12.2	87.8
Chemists	192031	66	14	76540	0.2	0.2	7.8	92.0
Materials scientists	192032	66	1	7880	0.0	0.2	7.8	92.0
Physical scientists, all other	192099	66	4	23800	0.1	0.2	2.1	97.7
Economists	193011	89	3	12470	0.0	0.0	1.5	98.5
Survey researchers	193022	90	6	21650	0.1	0.4	21.7	77.9
Agricultural and food science technicians	194011	55	3	19340	0.1	5.5	67.7	26.7
Biological technicians	194021	55	10	67080	0.2	2.9	47.0	50.1
Chemical technicians	194031	55	9	59790	0.2	3.8	64.6	31.6
Geological and petroleum technicians	194041	35	1	11130	0.0	8.4	60.0	31.5
Nuclear technicians	194051	34	1	6050	0.0	2.6	54.1	43.3
Environmental science and protection technicians, including health	194091	33	3	32460	0.1	2.6	54.1	43.3
Life, physical, and social science technicians, all other	194099	39	7	63810	0.2	2.6	54.1	43.3
Lawyers	231011	51	15	105838	0.3	0.1	1.6	98.3
Paralegals and legal assistants	232011	51	31	217700	0.6	0.8	58.9	40.3
Legal support workers. all other	232099	52	4	28424	0.1	2.1	60.1	37.8
Library technicians	254031	33	11	115770	0.3	4.3	61.6	34.0
Art directors	271011	64	5	29350	0.1	3.1	40.7	56.2
Fine artists, including painters, sculptors, and illustrators	271013	89	3	10390	0.0	3.1	40.7	56.2
Multimedia artists and animators	271014	87	6	23790	0.1	3.1	40.7	56.2
Artists and related workers, all other	271019	67	1	5290	0.0	3.1	40.7	56.2

Table A.1: (continued)

Occupation	SOC Code	Offshorability index	Adjusted Offshorability index	Employment		Educational attainment percent distribution		
				Absolute	Percent	Low	Medium	High
Commercial and industrial designers	271021	85	8	31650	0.1	2.7	46.5	50.8
Fashion designers	271022	73	3	12980	0.0	2.7	46.5	50.8
Graphic designers	271024	86	43	178530	0.5	2.7	46.5	50.8
Designers. all other	271029	77	3	12410	0.0	2.7	46.5	50.8
Actors	272011	48	8	59590	0.2	3.3	39.3	57.4
Producers and directors	272012	49	8	59070	0.2	0.8	28.9	70.2
Music directors and composers	272041	25	1	8610	0.0	4.8	41.6	53.6
Radio and television announcers	273011	30	3	41090	0.1	3.8	61.4	34.8
Broadcast news analysts	273021	40	1	6680	0.0	0.2	16.6	83.2
Editors	273041	93	25	96270	0.3	0.7	18.8	80.5
Technical writers	273042	93	12	46250	0.1	0.8	25.1	74.1
Writers and authors	273043	90	11	43020	0.1	0.6	16.3	83.1
Interpreters and translators	273091	93	6	21930	0.1	2.9	48.7	48.5
Media and communication workers, all other	273099	55	4	25660	0.1	2.9	48.7	48.5
Audio and video equipment technicians	274011	36	4	40390	0.1	2.3	63.9	33.8
Broadcast technicians	274012	36	3	30730	0.1	2.3	63.9	33.8
Radio operators	274013	36	0	1190	0.0	2.3	63.9	33.8
Sound engineering technicians	274014	36	1	12680	0.0	2.3	63.9	33.8
Photographers	274021	25	4	58260	0.2	2.7	50.3	47.0
Camera operators, television, video, and motion picture	274031	51	3	22530	0.1	2.9	41.4	55.6
Film and video editors	274032	95	4	15200	0.0	2.9	41.4	55.6
Media and communication equipment workers, all other	274099	36	2	17200	0.0	2.3	63.9	33.8

Table A.1: (continued)

Occupation	SOC Code	Offshorability index	Adjusted Offshorability index	Employment		Educational attainment percent distribution		
				Absolute	Percent	Low	Medium	High
Medical and clinical laboratory technologists	292011	58	25	155250	0.4	1.4	46.3	52.4
Medical and clinical laboratory technicians	292012	59	24	142330	0.4	1.4	46.3	52.4
Pharmacy technicians	292052	32	24	266790	0.8	2.5	80.9	16.7
Medical records and health information technicians	292071	83	38	160450	0.5	3.7	81.8	14.5
Medical transcriptionists	319094	95	24	90380	0.3	4.8	83.2	12.0
Travel guides	396022	86	1	3120	0.0	5.4	54.8	39.8
Advertising sales agents	413011	25	11	153890	0.4	2.1	44.7	53.2
Securities, commodities, and financial services sales agents	413031	51	36	251710	0.7	1.1	33.8	65.1
Travel agents	413041	50	13	88590	0.3	1.4	65.2	33.5
Telemarketers	419041	95	108	400860	1.1	9.0	75.2	15.8
Switchboard operators, including answering service	432011	50	28	194980	0.6	5.4	85.9	8.7
Telephone operators	432021	95	8	29290	0.1	6.0	82.3	11.7
Communications equipment operators, all other	432099	41	0	3870	0.0	4.0	69.8	26.2
Bill and account collectors	433011	65	79	431280	1.2	4.4	79.6	16.0
Billing and posting clerks and machine operators	433021	90	130	513020	1.4	3.7	81.2	15.1
Bookkeeping, accounting, and auditing clerks	433031	84	431	1815340	5.1	3.3	81.6	15.1
Payroll and timekeeping clerks	433051	67	39	205600	0.6	2.3	82.3	15.4
Procurement clerks	433061	67	14	71390	0.2	2.6	74.3	23.1
Brokerage clerks	434011	67	13	70110	0.2	3.1	70.2	26.7

Table A.1: (continued)

Occupation	SOC Code	Offshorability index	Adjusted Offshorability index	Employment		Educational attainment percent distribution		
				Absolute	Percent	Low	Medium	High
Correspondence clerks	434021	77	4	17990	0.1	9.6	74.6	15.8
Credit authorisers, checkers, and clerks	434041	80	15	65410	0.2	1.7	76.2	22.1
Customer service representatives A	434051	94	137	516925	1.5	4.5	73.9	21.6
Customer service representatives B	434051	70	102	516925	1.5	4.5	73.9	21.6
Customer service representatives C	434051	38	55	516925	1.5	4.5	73.9	21.6
File clerks	434071	50	32	229830	0.6	5.1	76.8	18.1
Interviewers A, except eligibility and loan	434111	48	14	100895	0.3	3.6	74.3	22.1
Loan interviewers and clerks A	434131	46	15	115850	0.3	2.0	76.4	21.7
Order clerks	434151	67	49	259760	0.7	9.6	74.6	15.8
Human resources assistants, except payroll and timekeeping	434161	50	23	161870	0.5	2.5	72.9	24.6
Receptionists and information clerks	434171	75	77	362800	1.0	4.7	82.4	12.9
Reservation and transportation ticket agents and travel clerks	434181	94	43	160120	0.5	3.8	68.4	27.8
Information and record clerks, all other	434199	92	75	288730	0.8	2.4	78.9	18.7
Dispatchers, except police, fire, and ambulance	435032	72	35	172550	0.5	6.0	82.6	11.3
Postal service mail sorters, processors, and processing machine operators	435053	25	15	208600	0.6	3.2	78.4	18.4
Production, planning, and expediting clerks	435061	54	44	287980	0.8	3.2	69.4	27.3
Shipping, receiving, and traffic clerks	435071	29	62	759910	2.1	15.2	77.5	7.3
Stock clerks and order fillers	435081	34	156	1625430	4.6	15.8	76.1	8.2
Weighers, measurers, checkers, and samplers, recordkeeping	435111	27	6	79050	0.2	14.5	72.6	12.9

Table A.1: (continued)

Occupation	SOC Code	Offshorability index	Adjusted Offshorability index	Employment		Educational attainment percent distribution		
				Absolute	Percent	Low	Medium	High
Secretaries, except legal, medical, and executive A	436014	69	85	436095	1.2	2.6	80.8	16.6
Secretaries, except legal, medical, and executive B	436014	38	47	436095	1.2	2.6	80.8	16.6
Computer operators	439011	75	27	129160	0.4	2.0	72.7	25.3
Data entry keyers	439021	100	84	296700	0.8	3.2	79.9	16.9
Word processors and typists	439022	94	41	153580	0.4	2.6	81.0	16.4
Desktop publishers	439031	93	8	29910	0.1	2.8	67.4	29.8
Insurance claims and policy processing clerks	439041	93	63	239120	0.7	1.8	77.6	20.6
Mail clerks and mail machine operators, except postal service	439051	26	11	148330	0.4	10.5	79.9	9.6
Office clerks, general A	439061	94	199	749343	2.1	4.3	78.2	17.5
Office clerks, general B	439061	70	148	749343	2.1	4.3	78.2	17.5
Office clerks, general C	439061	38	80	749343	2.1	4.3	78.2	17.5
Office machine operators, except computer	439071	51	13	87900	0.2	8.5	78.8	12.6
Proofreaders and copy markers	439081	95	5	18070	0.1	3.0	47.1	49.9
Statistical assistants	439111	90	5	18700	0.1	1.4	69.4	29.2
Office and administrative support workers, all other A	439199	94	19	71818	0.2	2.8	67.4	29.8
Office and administrative support workers, all other B	439199	70	14	71818	0.2	2.8	67.4	29.8
Office and administrative support workers, all other C	439199	38	8	71818	0.2	2.8	67.4	29.8
Derrick operators, oil and gas	475011	36	1	13270	0.0	26.8	68.5	4.7
Rotary drill operators, oil and gas	475012	36	2	15500	0.0	26.8	68.5	4.7

Table A.1: (continued)

Occupation	SOC Code	Offshorability index	Adjusted Offshorability index	Employment		Educational attainment percent distribution		
				Absolute	Percent	Low	Medium	High
Service unit operators, oil, gas, and mining	475013	36	2	19530	0.1	26.8	68.5	4.7
Earth drillers, except oil and gas	475021	35	2	18800	0.1	19.5	76.3	4.2
Explosives workers, ordnance handling experts and blasters	475031	35	0	4800	0.0	10.4	80.8	8.7
Continuous mining machine operators	475041	36	1	9000	0.0	17.1	79.7	3.1
Mine cutting and channelling machine operators	475042	36	1	6080	0.0	17.1	79.7	3.1
Mining machine operators, all other	475049	36	0	2450	0.0	17.1	79.7	3.1
Rock splitters, quarry	475051	36	0	3600	0.0	24.9	71.7	3.4
Roof bolters, mining	475061	36	0	4140	0.0	24.9	71.7	3.4
Roustabouts, oil and gas	475071	36	3	33570	0.1	26.8	68.5	4.7
Helpers - extraction workers	475081	36	3	25550	0.1	24.9	71.7	3.4
Extraction workers. all other	475099	36	1	9060	0.0	24.9	71.7	3.4
Camera and photographic equipment repairers	499061	26	0	3160	0.0	4.6	76.7	18.6
Watch repairers	499064	26	0	3080	0.0	4.6	76.7	18.6
First-line supervisors/managers of production and operating workers	511011	68	131	679930	1.9	11.1	73.9	15.0
Aircraft structure, surfaces, rigging, and systems assemblers	512011	55	4	22820	0.1	22.0	70.9	7.1
Coil winders, tapers, and finishers	512021	68	4	23190	0.1	22.5	71.7	5.8
Electrical and electronic equipment assemblers	512022	66	39	207270	0.6	22.5	71.7	5.8
Electromechanical equipment assemblers	512023	66	11	57200	0.2	22.5	71.7	5.8
Engine and other machine assemblers	512031	66	9	49430	0.1	12.7	84.6	2.7
Structural metal fabricators and fitters	512041	68	18	93490	0.3	13.4	79.8	6.8

Table A.1: (continued)

Occupation	SOC Code	Offshorability index	Adjusted Offshorability index	Employment		Educational attainment percent distribution		
				Absolute	Percent	Low	Medium	High
Fibreglass laminators and fabricators	512091	68	6	30560	0.1	21.6	73.2	5.1
Team assemblers	512092	65	228	1242370	3.5	21.6	73.2	5.1
Timing device assemblers, adjusters, and calibrators	512093	62	0	2460	0.0	21.6	73.2	5.1
Assemblers and fabricators, all other	512099	64	47	258240	0.7	21.6	73.2	5.1
Food batchmakers	513092	31	8	89400	0.3	25.6	68.9	5.5
Food cooking machine operators and tenders	513093	27	3	43100	0.1	27.1	67.7	5.2
Computer-controlled machine tool operators, metal and plastic	514011	68	26	136490	0.4	8.4	85.2	6.4
Numerical tool and process control programmers	514012	95	5	17860	0.1	8.4	85.2	6.4
Extruding and drawing machine setters, operators, and tenders, metal and plastic	514021	68	17	87290	0.2	17.2	79.5	3.3
Forging machine setters, operators, and tenders, metal and plastic	514022	68	7	33850	0.1	20.5	78.1	1.4
Rolling machine setters, operators, and tenders, metal and plastic	514023	68	7	37500	0.1	19.1	77.4	3.5
Cutting, punching, and press machine setters, operators, and tenders, metal and plastic	514031	68	51	265480	0.7	22.0	74.9	3.1
Drilling and boring machine tool setters, operators, and tenders, metal and plastic	514032	68	8	43180	0.1	24.0	73.2	2.8
Grinding, lapping, polishing, and buffing machine tool setters, operators, and tenders, metal and plastic	514033	68	20	101530	0.3	28.4	69.0	2.6
Lathe and turning machine tool setters, operators, and tenders, metal and plastic	514034	68	14	71410	0.2	21.4	75.9	2.7

Table A.1: (continued)

Occupation	SOC Code	Offshorability index	Adjusted Offshorability index	Employment		Educational attainment percent distribution		
				Absolute	Percent	Low	Medium	High
Milling and planing machine setters, operators, and tenders, metal and plastic	514035	68	6	29140	0.1	23.3	72.5	4.2
Machinists	514041	61	63	368380	1.0	11.1	85.1	3.7
Metal-refining furnace operators and tenders	514051	68	3	17960	0.1	14.4	82.3	3.3
Pourers and casters, metal	514052	68	3	14340	0.0	14.4	82.3	3.3
Model makers, metal and plastic	514061	65	1	8120	0.0	14.0	74.8	11.2
Patternmakers, metal and plastic	514062	65	1	6850	0.0	14.0	74.8	11.2
Foundry mould and coremakers	514071	65	3	15890	0.0	22.0	75.1	2.9
Moulding, coremaking, and casting machine setters, operators, and tenders, metal and plastic	514072	68	30	157080	0.4	22.0	75.1	2.9
Multiple machine tool setters, operators, and tenders, metal and plastic	514081	68	19	98120	0.3	23.3	72.5	4.2
Tool and die makers	514111	70	20	99680	0.3	7.2	88.4	4.3
Welders, cutters, solderers, and brazers	514121	70	71	358050	1.0	23.9	73.9	2.3
Welding, soldering, and brazing machine setters, operators, and tenders	514122	68	9	45220	0.1	23.9	73.9	2.3
Heat treating equipment setters, operators, and tenders, metal and plastic	514191	70	5	26310	0.1	13.5	83.0	3.5
Lay-out workers, metal and plastic	514192	70	2	10970	0.0	23.3	72.5	4.2
Plating and coating machine setters, operators, and tenders, metal and plastic	514193	70	8	40550	0.1	26.5	71.1	2.5
Tool grinders, filers, and sharpeners	514194	68	3	18180	0.1	16.6	77.9	5.5
Metal workers and plastic workers, all other	514199	70	10	49650	0.1	23.3	72.5	4.2
Bindery workers	515011	59	11	64330	0.2	18.5	74.3	7.2

Table A.1: (continued)

Occupation	SOC Code	Offshorability index	Adjusted Offshorability index	Employment		Educational attainment percent distribution		
				Absolute	Percent	Low	Medium	High
Bookbinders	515012	59	1	7660	0.0	18.5	74.3	7.2
Job printers	515021	58	8	50580	0.1	12.6	78.6	8.7
Prepress technicians and workers	515022	59	12	72050	0.2	6.4	75.4	18.1
Printing machine operators	515023	57	31	192520	0.5	13.0	80.4	6.5
Pressers, textile, garment, and related materials	516021	75	17	78620	0.2	44.8	52.1	3.1
Sewing machine operators	516031	75	49	233130	0.7	43.2	51.5	5.2
Shoe and leather workers and repairers	516041	75	2	7680	0.0	29.6	61.1	9.3
Shoe machine operators and tenders	516042	75	1	3850	0.0	37.9	57.5	4.7
Sewers, hand	516051	75	2	11090	0.0	26.3	59.5	14.2
Textile bleaching and dyeing machine operators and tenders	516061	75	5	21660	0.1	38.4	58.0	3.6
Textile cutting machine setters, operators and tenders	516062	75	5	21420	0.1	38.4	58.0	3.6
Textile knitting and weaving machine setters, operators and tenders	516063	75	9	42760	0.1	32.0	64.2	3.8
Textile winding, twisting, and drawing out machine setters, operators and tenders	516064	75	10	47670	0.1	35.9	62.8	1.3
Extruding and forming machine setters, operators, and tenders, synthetic and glass fibres	516091	68	4	23040	0.1	28.9	60.6	10.5
Fabric and apparel patternmakers	516092	80	2	9650	0.0	28.9	60.6	10.5
Upholsterers	516093	57	7	41040	0.1	33.7	61.3	5.0
Textile, apparel, and furnishings workers, all other	516099	75	5	24740	0.1	28.9	60.6	10.5
Cabinetmakers and bench carpenters	517011	57	20	121660	0.3	22.0	69.1	8.9

Table A.1: (continued)

Occupation	SOC Code	Offshorability index	Adjusted Offshorability index	Employment		Educational attainment percent distribution		
				Absolute	Percent	Low	Medium	High
Furniture finishers	517021	43	3	24610	0.1	28.4	61.8	9.8
Model makers, wood	517031	60	0	2280	0.0	19.6	65.8	14.6
Patternmakers, wood	517032	60	0	2000	0.0	19.6	65.8	14.6
Sawing machine setters, operators, and tenders, wood	517041	57	10	60280	0.2	32.4	64.4	3.2
Woodworking machine setters, operators, and tenders, except sawing	517042	57	15	94690	0.3	33.3	62.7	3.9
Woodworkers, all other	517099	57	2	10550	0.0	19.6	65.8	14.6
Stationary engineers and boiler operators	518021	55	7	43110	0.1	7.1	81.7	11.2
Chemical plant and system operators	518091	68	11	58640	0.2	7.9	83.5	8.6
Gas plant operators	518092	29	1	10530	0.0	7.9	83.5	8.6
Petroleum pump system operators, refinery operators and gaugers	518093	29	3	40470	0.1	7.9	83.5	8.6
Plant and system operators, all other	518099	29	1	13920	0.0	7.9	83.5	8.6
Chemical equipment operators and tenders	519011	68	10	50610	0.1	9.3	76.7	14.0
Separating, filtering, clarifying, precipitating, and still machine setters, operators, and tenders	519012	68	8	41250	0.1	9.3	76.7	14.0
Crushing, grinding, and polishing machine setters, operators and tenders	519021	68	8	41480	0.1	24.9	69.9	5.1
Grinding and polishing workers, hand	519022	68	9	44890	0.1	24.9	69.9	5.1
Mixing and blending machine setters, operators and tenders	519023	68	25	129440	0.4	24.9	69.9	5.1
Cutters and trimmers, hand	519031	69	6	28360	0.1	33.2	62.5	4.2
Cutting and slicing machine setters, operators and tenders	519032	68	15	78030	0.2	33.2	62.5	4.2

Table A.1: (continued)

Occupation	SOC Code	Offshorability index	Adjusted Offshorability index	Employment		Educational attainment percent distribution		
				Absolute	Percent	Low	Medium	High
Extruding, forming, pressing, and compacting machine setters, operators and tenders	519041	68	15	80420	0.2	20.8	76.6	2.6
Furnace, kiln, oven, drier, and kettle operators and tenders	519051	59	5	28140	0.1	14.1	78.8	7.1
Inspectors, testers, sorters, samplers, and weighers	519061	60	86	506160	1.4	12.7	73.7	13.5
Jewellers and precious stone and metal workers	519071	64	5	28100	0.1	19.3	63.3	17.4
Medical appliance technicians	519082	34	1	10810	0.0	6.8	78.7	14.5
Ophthalmic laboratory technicians	519083	34	3	26740	0.1	6.8	78.7	14.5
Packaging and filling machine operators and tenders	519111	68	76	396270	1.1	37.3	58.6	4.1
Coating, painting, and spraying machine setters, operators and tenders	519121	68	19	100830	0.3	27.1	68.8	4.0
Painters, transportation equipment	519122	68	10	52650	0.1	27.1	68.8	4.0
Painting, coating, and decorating workers	519123	68	5	27830	0.1	27.1	68.8	4.0
Photographic process workers	519131	34	3	28000	0.1	7.0	72.1	20.9
Photographic processing machine operators	519132	48	7	53970	0.2	7.0	72.1	20.9
Semiconductor processors	519141	70	9	44720	0.1	23.6	71.1	5.3
Cementing and gluing machine operators and tenders	519191	68	5	25650	0.1	24.1	74.5	1.4
Cleaning, washing, and metal pickling equipment operators and tenders	519192	68	3	15250	0.0	22.7	73.7	3.5
Cooling and freezing equipment operators and tenders	519193	68	2	9640	0.0	23.6	71.1	5.3

Table A.1: (continued)

Occupation	SOC Code	Offshorability index	Adjusted Offshorability index	Employment		Educational attainment percent distribution		
				Absolute	Percent	Low	Medium	High
Etchers and engravers	519194	68	2	10050	0.0	12.2	75.4	12.4
Moulders, shapers, and casters, except metal and plastic	519195	69	8	41250	0.1	24.8	61.7	13.5
Paper goods machine setters, operators, and tenders	519196	68	21	107560	0.3	18.4	78.4	3.2
Tyre builders	519197	69	4	19860	0.1	14.9	81.8	3.4
Helpers - production workers	519198	70	105	528610	1.5	33.5	60.2	6.3
Production workers, all other	519199	68	57	296340	0.8	23.6	71.1	5.3
First-line supervisors/managers of helpers, labourers and material movers, hand	531021	28	14	176030	0.5	8.5	74.4	17.1
First-line supervisors/managers of transportation and material-moving machine and vehicle operators	531031	28	18	221520	0.6	8.5	74.4	17.1
Sailors and marine oilers	535011	34	3	31090	0.1	12.0	73.1	14.9
Ship engineers	535031	34	1	13240	0.0	12.0	73.1	14.9

Source: Blinder (2009a); Employment Projections Program, U.S. Department of Labor, U.S. Bureau of Labor Statistics, Table 1.11 (bls_ep_table_111).

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 is 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:

$$\begin{aligned}\min_{l_j(i),\xi} \mathcal{L} &= w_L \int_0^{I_L} l_L(i)\mathrm{d}i + w_M \int_{i\in\mathcal{I}_M} l_M(i)\mathrm{d}i + w_O \int_{i\in\mathcal{I}_O} l_O(i)\mathrm{d}i + w_H \int_{I_H}^1 l_H(i)\mathrm{d}i \\ &+\xi\left(E - \left[\int_0^{I_L} (\varphi_L(i)l_L(i))^{\frac{\sigma-1}{\sigma}}\mathrm{d}i + \int_{i\in\mathcal{I}_M} l_M(i)^{\frac{\sigma-1}{\sigma}}\mathrm{d}i + \int_{i\in\mathcal{I}_O}\left(\frac{l_O(i)}{\tau\zeta(i)}\right)^{\frac{\sigma-1}{\sigma}}\mathrm{d}i\right.\right. \\ &\left.\left.+\int_{I_H}^1 (\varphi_H(i)l_H(i))^{\frac{\sigma-1}{\sigma}}\mathrm{d}i\right]^{\frac{\sigma}{\sigma-1}}\right),\end{aligned} \tag{B.1}$$

where ξ is the Lagrangian multiplier and $\mathcal{I}_j$ denote the subset of tasks produced by labor type $j \in \{M, O\}$. The first-order conditions w.r.t. $l_j(i)$, $j = \{L, M, H, O\}$ are, respectively, given:

$$\frac{\partial\mathcal{L}}{\partial l_L(i)} = w_L - \xi\left(\frac{E}{l_L(i)}\right)^{1/\sigma}\varphi_L(i)^{\frac{\sigma-1}{\sigma}} = 0, \tag{B.2}$$

$$\frac{\partial\mathcal{L}}{\partial l_M(i)} = w_M - \xi\left(\frac{E}{l_M(i)}\right)^{1/\sigma} = 0, \tag{B.3}$$

$$\frac{\partial\mathcal{L}}{\partial l_H(i)} = w_H - \xi\left(\frac{E}{l_H(i)}\right)^{1/\sigma}\varphi_L(i)^{\frac{\sigma-1}{\sigma}} = 0, \tag{B.4}$$

$$\frac{\partial\mathcal{L}}{\partial l_O(i)} = w_O - \xi\left(\frac{E}{l_O(i)}\right)^{1/\sigma}(\tau\zeta(i))^{\frac{1-\sigma}{\sigma}} = 0, \tag{B.5}$$

$$\frac{\partial\mathcal{L}}{\partial\xi} = E - \left[\int_0^{I_L} (\varphi_L(i)l_L(i))^{\frac{\sigma-1}{\sigma}}\mathrm{d}i + \int_{i\in\mathcal{I}_M} l_M(i)^{\frac{\sigma-1}{\sigma}}\mathrm{d}i + \int_{i\in\mathcal{I}_O}\left(\frac{l_O(i)}{\tau\zeta(i)}\right)^{\frac{\sigma-1}{\sigma}}\mathrm{d}i + \int_{I_H}^1 (\varphi_H(i)l_H(i))^{\frac{\sigma-1}{\sigma}}\mathrm{d}i\right]^{\frac{\sigma}{\sigma-1}} = 0. \tag{B.6}$$

Solving conditions (B.2)–(B.4) w.r.t. $l_j(i)$ for $j \in \{L, M, H, O\}$ and inserting the results into condition (B.6), we get

$$\xi = \left[\int_0^{I_L} \varphi_L(i)^{\sigma-1}\mathrm{d}i w_L^{1-\sigma} + (I_H - I_L - \mathcal{I}_O)w_M^{1-\sigma} + \int_{i\in\mathcal{I}_O}\zeta(i)^{1-\sigma}\mathrm{d}i(\tau w_O)^{1-\sigma} + \int_{I_H}^1 \varphi_H(i)^{1-\sigma}\mathrm{d}i w_H^{1-\sigma}\right]^{\frac{1}{1-\sigma}}, \tag{B.7}$$

where we use $\mathcal{I}_M \equiv I_H - I_L - \mathcal{I}_O$.

By the envelope theorem, the marginal cost of task composite is denoted by the shadow price, i.e. $\frac{\partial\mathcal{L}}{\partial E} = \xi$. 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 ξ with respect to I_L and I_H, respectively:

$$\frac{\mathrm{d}\xi}{\mathrm{d}I_L} = \frac{1}{1-\sigma}\xi^\sigma\left[\varphi_L(I_L)^{\sigma-1}w_L^{1-\sigma} - w_M^{1-\sigma}\right], \tag{B.8}$$

$$\frac{\mathrm{d}\xi}{\mathrm{d}I_H} = \frac{1}{1-\sigma}\xi^\sigma\left[w_M^{1-\sigma} - \varphi_H(I_H)^{\sigma-1}w_H^{1-\sigma}\right]. \tag{B.9}$$

We then get that $\frac{\mathrm{d}\xi}{\mathrm{d}I_L} = 0$ and $\frac{\mathrm{d}\xi}{\mathrm{d}I_H} = 0$ 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 $\mathcal{I}_O$ is defined by a closed set. Let I_1 and I_2 denote the boundaries of the offshore set such that $I_1 < I_2, \mathcal{I}_O = \{I_1, I_2\}$, and $\mathcal{I}_M = I_H - I_L - (I_2 - I_1)$. Then, the optimal choice of offshoring task margins, I_1 and I_2, is obtained by minimizing λ with respect to I_1 and I_2, respectively:

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

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

Recalling $\omega = 1/(\tau w_O)$, it then follows that $\frac{\mathrm{d}\xi}{\mathrm{d}I_1} = 0$ and $\frac{\mathrm{d}\xi}{\mathrm{d}I_2} = 0$ 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 $\varepsilon_1 = -\frac{\partial \ln \zeta(I_1)}{\partial I_1} > 0$ and $\varepsilon_2 = \frac{\partial \ln \zeta(I_2)}{\partial I_2} > 0$, 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

$$\begin{aligned} \mathrm{d}\ln\tilde{w} &= -\varepsilon_1 \mathrm{d}I_1, \\ \mathrm{d}\ln\tilde{w} &= \varepsilon_2 \mathrm{d}I_2, \\ \mathrm{d}I_O &= \mathrm{d}I_2 - \mathrm{d}I_1. \end{aligned}$$

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

$$\mathrm{d}I_O = \mathrm{d}\ln\tilde{w}\left(\frac{1}{\varepsilon_2} + \frac{1}{\varepsilon_1}\right).$$

It is convenient to define $\mu = \frac{\varepsilon_2\varepsilon_1}{\varepsilon_2+\varepsilon_1} > 0$, which is increasing in both arguments. Then, after further manipulation, we obtain $\mathrm{d}\ln\tilde{w} = \mu \mathrm{d}I_O$. This is a simple first-order linear homogeneous ordinary differential equation. Thus, by integration

$$\int \mathrm{d}\ln\tilde{w}\mathrm{d}i = \int \mu \mathrm{d}I_O \mathrm{d}i,$$

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 $t_O(i) = \frac{l_O(i)}{\tau\varphi_O(i)}$, such that the first order condition (B.5) becomes

$$\frac{\partial \mathcal{L}}{\partial l_O(i)} = w_O - \xi\left(\frac{E}{l_O(i)}\right)^{1/\sigma}(\tau\varphi_O(i))^{\frac{1-\sigma}{\sigma}} = 0, \text{ for } i \in I_O. \tag{B.15}$$

■

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

$$N_L = \int_0^{I_L} l_L(i)\mathrm{d}i, \tag{B.16}$$

$$N_M = \int_{i\in\mathcal{I}_M} l_M(i)\mathrm{d}i, \tag{B.17}$$

$$N_H = \int_{I_H}^1 l_H(i)\mathrm{d}i, \tag{B.18}$$

$$n_O = \int_{i\in\mathcal{I}_O} l_O(i)\mathrm{d}i. \tag{B.19}$$

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

$$l_L(i) = l_L(i')\left(\frac{\varphi_L(i)}{\varphi_L(i')}\right)^{\sigma-1}, \ \forall i, i' \in [0, I_L], \tag{B.20}$$

$$l_M(i) = l_M(i'), \qquad \forall i, i' \in \mathcal{I}_M = I_H - I_L - I_O, \tag{B.21}$$

$$l_H(i) = l_H(i')\left(\frac{\varphi_H(i)}{\varphi_H(i')}\right)^{\sigma-1}, \ \forall i, i' \in [I_H, 1], \tag{B.22}$$

$$l_O(i) = l_O(i')\left(\frac{\varphi_O(i)}{\varphi_O(i')}\right)^{1-\sigma}, \ \forall i, i' \in [I_1, I_2], \tag{B.23}$$

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

$$l_M = \frac{N_M}{I_H - I_L - I_O}, \ \forall i \in \mathcal{I}_M. \tag{B.24}$$

Note that for low-skill and high-skill workers as well as for offshore workers Eqs. (B.20), (B.22), and (B.23) imply $l_L(i) = l_L(0)\left(\frac{\varphi_L(i)}{\varphi_L(0)}\right)^{\sigma-1}$ for $i \in [0, I_L]$, $l_H(i) = l_H(1)\left(\frac{\varphi_H(i)}{\varphi_H(1)}\right)^{\sigma-1}$ for $i \in [I_H, 1]$, and $l_O(i) = l_O(I_O)\left(\frac{\varphi_O(i)}{\varphi_O(I_O)}\right)^{1-\sigma}$ 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 $l_L(i)$, $l_H(i)$, and $I_O(i)$, we obtain

$$l_L(i) = \frac{\varphi_L(i)^{\sigma-1}}{\gamma_L(I_L)} N_L, \tag{B.25}$$

$$l_H(i) = \frac{\varphi_H(i)^{\sigma-1}}{\gamma_H(I_H)} N_H, \tag{B.26}$$

$$l_O(i) = \frac{\varphi_O(i)^{1-\sigma}}{\gamma_O(I_O)} n_O, \tag{B.27}$$

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

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 the these results into the condition (B.6) we obtain the equilibrium values of task composite derived in Lemma 3. ■

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 ω in (B.7) and manipulating slightly, we obtain the equilibrium value of marginal costs of task composite, Eq. (12). ■

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

$$\frac{w_L}{w_M} = \left(\frac{N_L}{N_M}\right)^{-\frac{1}{\sigma}} \left(\frac{\gamma_L(I_L)}{I_H - I_L - I_O}\right)^{\frac{1}{\sigma}}, \tag{B.28}$$

$$\frac{w_O}{w_M} = \left(\frac{n_O}{N_M}\right)^{-\frac{1}{\sigma}} \tau^{\frac{1-\sigma}{\sigma}} \left(\frac{\gamma_O(I_O)}{I_H - I_L - I_O}\right)^{\frac{1}{\sigma}}, \tag{B.29}$$

$$\frac{w_M}{w_H} = \left(\frac{N_M}{N_H}\right)^{-\frac{1}{\sigma}} \left(\frac{I_H - I_L - I_O}{\gamma_H(I_H)}\right)^{\frac{1}{\sigma}}. \tag{B.30}$$

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:

$$n_O = w_O^{-\sigma} \tau^{1-\sigma} \gamma_O(I_O) P_E^{\sigma} E.$$

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

$$\begin{aligned} n_O &= w_O^{-\sigma} \tau^{1-\sigma} \gamma_O(I_O) P_E^{\sigma-1/\alpha} \mathcal{B} \\ &= w_O^{-\sigma} \tau^{1-\sigma} \gamma_O(I_O) \left(\Omega(\cdot) w_M\right)^{\sigma-1/\alpha} \mathcal{B} \\ &= \tau \gamma_O(I_O) (\Omega(\cdot)\varphi_O(I_O))^{\sigma-1/\alpha} (w_O \tau)^{-\frac{1}{\alpha}} \mathcal{B} \end{aligned} \tag{B.31}$$

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

$$\frac{1}{w_M} = (\Omega(\cdot)\varphi_O(I_O))^{\frac{1}{\sigma\alpha}-1} (w_O \tau)^{\frac{1}{\sigma\alpha}-1} \mathcal{B}^{-\frac{1}{\sigma}} \left(\frac{N_M}{I_H - I_L - I_O}\right)^{\frac{1}{\sigma}}. \tag{B.29$'$}$$

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, ω, 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

$$J = \begin{pmatrix} \left(\frac{\varphi_L(I_L)^{\sigma-1}}{\gamma_L(I_L)} + \frac{1}{I_H-I_L-I_O} + \sigma\varepsilon_L\right) & \frac{1}{I_H-I_L-I_O} & -\frac{1}{I_H-I_L-I_O} \\ \left([1-\sigma\alpha]\frac{\Omega_L(\cdot)}{\Omega(\cdot)} + \frac{\alpha}{I_H-I_L-I_O}\right) & \left(\mu + [1-\sigma\alpha]\frac{\Omega_O(\cdot)}{\Omega(\cdot)} + \frac{\alpha}{I_H+I_L-I_O}\right) & \left([1-\sigma\alpha]\frac{\Omega_H(\cdot)}{\Omega(\cdot)} - \frac{\alpha}{I_H-I_L-I_O}\right) \\ -\frac{1}{I_H-I_L-I_O} & -\frac{1}{I_H-I_L-I_O} & \left(\frac{\varphi_H(I_H)^{\sigma-1}}{\gamma_H(I_H)} + \frac{1}{I_H-I_L-I_O} + \sigma\varepsilon_H\right) \end{pmatrix} \tag{B.32}$$

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

By **?**, 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

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

$$\begin{aligned}
|J_{2\times 2}| &= \left(\frac{\varphi_L(I_L)^{\sigma-1}}{\gamma_L(I_L)} + \frac{1}{I_H - I_L - I_O} + \sigma\varepsilon_L\right) \times \left(\mu + [1-\sigma\alpha]\,\frac{\Omega_O(\cdot)}{\Omega(\cdot)} + \frac{\alpha}{I_H + I_L - I_O}\right) \\
&\quad - \left([1-\sigma\alpha]\,\frac{\Omega_L(\cdot)}{\Omega(\cdot)} + \frac{\alpha}{I_H - I_L - I_O}\right)\frac{1}{I_H - I_L - I_O} \\
&= \left(\frac{\varphi_L(I_L)^{\sigma-1}}{\gamma_L(I_L)} + \frac{1}{I_H - I_L - I_O} + \sigma\varepsilon_L\right) \times \left(\left(1 - [1-\sigma\alpha]\,\lambda_O\right)\mu\right) \\
&\quad + \frac{\alpha}{I_H + I_L - I_O}\left(\frac{\varphi_L(I_L)^{\sigma-1}}{\gamma_L(I_L)} + \sigma\varepsilon_L\right) + \left([1-\sigma\alpha]\,\frac{\lambda_L\varepsilon_L}{I_L}\right)\frac{1}{I_H - I_L - I_O} > 0.
\end{aligned} \tag{B.34}$$

$$\begin{aligned}
|J_{3\times 3}| &= \left(\frac{\varphi_L(I_L)^{\sigma-1}}{\gamma_L(I_L)} + \frac{1}{I_H - I_L - I_O} + \sigma\varepsilon_L\right) \times \left[\left(\mu + \left[\frac{1}{\alpha} - \sigma\right]\frac{\Omega_O(\cdot)}{\Omega(\cdot)} + \frac{\alpha}{I_H + I_L - I_O}\right) \times \left(\frac{\varphi_H(I_H)^{\sigma-1}}{\gamma_H(I_H)} + \frac{1}{I_H - I_L - I_O} + \sigma\varepsilon_H\right)\right. \\
&\quad \left. + \frac{1}{I_H - I_L - I_O}\left([1-\sigma\alpha]\,\frac{\Omega_H(\cdot)}{\Omega(\cdot)} - \frac{\alpha}{I_H - I_L - I_O}\right)\right] \\
&\quad - \frac{1}{I_H - I_L - I_O}\left[\left([1-\sigma\alpha]\,\frac{\Omega_L(\cdot)}{\Omega(\cdot)} + \frac{\alpha}{I_H - I_L - I_O}\right) \times \left(\frac{\varphi_H(I_H)^{\sigma-1}}{\gamma_H(I_H)} + \frac{1}{I_H - I_L - I_O} + \sigma\varepsilon_H\right)\right. \\
&\quad \left. + \frac{1}{I_H - I_L - I_O}\left([1-\sigma\alpha]\,\frac{\Omega_H(\cdot)}{\Omega(\cdot)} - \frac{\alpha}{I_H - I_L - I_O}\right)\right] \\
&\quad - \frac{1}{I_H - I_L - I_O}\left[-\frac{1}{I_H - I_L - I_O}\left([1-\sigma\alpha]\,\frac{\Omega_L(\cdot)}{\Omega(\cdot)} + \frac{\alpha}{I_H - I_L - I_O}\right) + \frac{1}{I_H - I_L - I_O}\left(\mu + [1-\sigma\alpha]\,\frac{\Omega_O(\cdot)}{\Omega(\cdot)} + \frac{\alpha}{I_H + I_L - I_O}\right)\right]
\end{aligned}$$

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

$$\begin{aligned}
&= \left(\frac{\varphi_L(I_L)^{\sigma-1}}{\gamma_L(I_L)} + \frac{1}{I_H - I_L - I_O} + \sigma\varepsilon_L\right) \times \left[\left(\left[1 - [1-\sigma\alpha]\,\lambda_O\right]\mu\right) \times \left(\frac{\varphi_H(I_H)^{\sigma-1}}{\gamma_H(I_H)} + \sigma\varepsilon_H\right)\right] \\
&\quad + \left(\frac{\varphi_L(I_L)^{\sigma-1}}{\gamma_L(I_L)} + \sigma\varepsilon_L\right) \times \left(\left[1 - [1-\sigma\alpha]\,\lambda_O\right]\mu\right)\frac{1}{I_H + I_L - I_O} \\
&\quad + \left(\frac{\varphi_L(I_L)^{\sigma-1}}{\gamma_L(I_L)} + \sigma\varepsilon_L\right) \times \left[\frac{\alpha}{I_H + I_L - I_O}\left(\frac{\varphi_H(I_H)^{\sigma-1}}{\gamma_H(I_H)} + \sigma\varepsilon_H\right) + \frac{1}{I_H - I_L - I_O}\left([1-\sigma\alpha]\,\frac{\lambda_H\varepsilon_H}{I_H}\right)\right] \\
&\quad + \frac{1}{I_H - I_L - I_O}\left([1-\sigma\alpha]\,\frac{\lambda_L\varepsilon_L}{I_L}\right) \times \left(\frac{\varphi_H(I_H)^{\sigma-1}}{\gamma_H(I_H)} + \sigma\varepsilon_H\right) > 0.
\end{aligned} \tag{B.35}$$

■

Proof of Proposition 2.

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

$$\mathbf{J} \times \mathbf{I} = \boldsymbol{\omega}, \tag{B.36}$$

where $\mathbf{J}$ is given by (B.32), $\mathbf{I} = \{\mathrm{d}I_L, \mathrm{d}I_O, \mathrm{d}I_H\}$ and $\boldsymbol{\omega} = \{0, \mathrm{d}\omega/\omega, 0\}$.

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

$$\frac{\mathrm{d}I_L}{\mathrm{d}\omega} = \frac{|J_1|}{|J|} = -\frac{1}{|J|}\frac{1}{\omega}\frac{1}{I_H - I_L - I_O}\left(\frac{1}{s_H} + \sigma\varepsilon_H\right) < 0, \tag{B.37}$$

$$\begin{aligned}
\frac{\mathrm{d}I_O}{\mathrm{d}\omega} &= \frac{|J_2|}{|J|} = \frac{1}{|J|}\frac{1}{\omega}\left[\left(\frac{1}{s_L} + \frac{1}{I_H - I_L - I_O} + \sigma\varepsilon_L\right)\left(\frac{1}{s_H} + \sigma\varepsilon_H\right)\right. \\
&\quad \left. + \left(\frac{1}{s_L} + \sigma\varepsilon_L\right)\left(\frac{1}{I_H - I_L - I_O}\right)\right] > 0,
\end{aligned} \tag{B.38}$$

$$\frac{\mathrm{d}I_H}{\mathrm{d}\omega} = \frac{|J_3|}{|J|} = \frac{1}{|J|}\frac{1}{\omega}\frac{1}{I_H - I_L - I_O}\left(\frac{1}{s_L} + \sigma\varepsilon_L\right) > 0. \tag{B.39}$$

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.

$$\left|\frac{\mathrm{d}I_O}{\mathrm{d}\omega}\right| \quad > \quad \left|\frac{\mathrm{d}I_H}{\mathrm{d}\omega}\right| + \left|\frac{\mathrm{d}I_L}{\mathrm{d}\omega}\right|$$

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.

$$\begin{aligned} \left|\frac{\mathrm{d}I_H}{\mathrm{d}\omega}\right| \quad &\lesseqgtr \quad \left|\frac{\mathrm{d}I_L}{\mathrm{d}\omega}\right| \\ \Leftrightarrow \left(\frac{1}{s_L} + \sigma\varepsilon_L\right) \quad &\lesseqgtr \quad \left(\frac{1}{s_H} + \sigma\varepsilon_H\right). \end{aligned}$$

■

Proof of Lemma 6.

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

$$\frac{\mathrm{d}\ln\Omega(\cdot)}{\mathrm{d}\omega} = \left(\lambda_H\varepsilon_H\frac{\mathrm{d}I_H}{\mathrm{d}\omega} - \lambda_L\varepsilon_L\frac{\mathrm{d}I_L}{\mathrm{d}\omega}\right) - \left(\lambda_O\mu\frac{\mathrm{d}I_O}{\mathrm{d}\omega}\right). \tag{B.40}$$

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

$$\begin{aligned} \frac{\mathrm{d}\ln\Omega(\cdot)}{\mathrm{d}\omega} \quad = \quad & \frac{1}{|J|}\frac{1}{\omega}\left(\lambda_H\varepsilon_H\frac{1}{I_H - I_L - I_O}\left(\frac{1}{s_L} + \sigma\varepsilon_L\right) + \lambda_L\varepsilon_L\frac{1}{I_H - I_L - I_O}\left(\frac{1}{s_H} + \sigma\varepsilon_H\right)\right. \\ & \left. -\lambda_O\mu\left[\left(\frac{1}{s_L} + \frac{1}{I_H - I_L - I_O} + \sigma\varepsilon_L\right)\left(\frac{1}{s_H} + \sigma\varepsilon_H\right) + \left(\frac{1}{s_L} + \sigma\varepsilon_L\right)\left(\frac{1}{I_H - I_L - I_O}\right)\right]\right). \end{aligned}$$

We can derive sufficient conditions under which the sign of $\frac{\mathrm{d}\ln\Omega(\cdot)}{\mathrm{d}\omega}$ is unambiguously determined. It follows $\frac{\mathrm{d}\ln\Omega(\cdot)}{\mathrm{d}\omega} < 0$ whenever

$$\mu \quad > \quad \max\left\{\frac{\lambda_L}{\lambda_O}\varepsilon_L, \frac{\lambda_H}{\lambda_O}\varepsilon_H\right\}.$$

■

Proof of Proposition 3.

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

$$\frac{\mathrm{d}\ln w_L}{\mathrm{d}\omega} \quad = \quad \left(\frac{\alpha}{s_L} - (1-\alpha\sigma)(1-\lambda_L)\varepsilon_L\right)\frac{\mathrm{d}I_L}{\mathrm{d}\omega} + (1-\alpha\sigma)\lambda_O\mu\frac{\mathrm{d}I_O}{\mathrm{d}\omega} - (1-\alpha\sigma)\lambda_H\varepsilon_H\frac{\mathrm{d}I_H}{\mathrm{d}\omega}, \tag{B.41}$$

$$\begin{aligned} \frac{\mathrm{d}\ln w_M}{\mathrm{d}\omega} \quad = \quad & \left((1-\alpha\sigma)\lambda_L\varepsilon_L - \frac{\alpha}{I_H - I_L - I_O}\right)\frac{\mathrm{d}I_L}{\mathrm{d}\omega} + \left((1-\alpha\sigma)\lambda_O\mu - \frac{\alpha}{I_H - I_L - I_O}\right)\frac{\mathrm{d}I_O}{\mathrm{d}\omega} \\ & + \left(\frac{\alpha}{I_H - I_L - I_O} - (1-\alpha\sigma)\lambda_H\varepsilon_H\right)\frac{\mathrm{d}I_H}{\mathrm{d}\omega}, \end{aligned} \tag{B.42}$$

$$\frac{\mathrm{d}\ln w_H}{\mathrm{d}\omega} \quad = \quad (1-\alpha\sigma)\lambda_L\varepsilon_L\frac{\mathrm{d}I_L}{\mathrm{d}\omega} + (1-\alpha\sigma)\lambda_O\mu\frac{\mathrm{d}I_O}{\mathrm{d}\omega} - \left(\frac{\alpha}{s_H} - (1-\alpha\sigma)(1-\lambda_H)\varepsilon_H\right)\frac{\mathrm{d}I_H}{\mathrm{d}\omega}. \tag{B.43}$$

From the first terms in (B.41) and (B.42), we get the lower and upper boundaries for ε_L, respectively. Similarly, from the third terms in (B.42) and (B.43), we get the upper and lower boundaries for ε_H, respectively. Finally, from the second in (B.42) we obtain the lower boundary for μ. 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. ■

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

$$\bar{W} \quad = \quad \tilde{\xi}\left(\frac{E}{l_L(i)}\right)^{\frac{1}{\sigma}}\varphi_L(i)^{\frac{\sigma-1}{\sigma}}, \tag{B.44}$$

where $\tilde{\xi}$ denotes the modified Lagrangian multiplier and is now given by

$$\tilde{\xi} = \left[\int_0^{I_L} \varphi_L(i)^{\sigma-1} \mathrm{d}i \bar{W}^{1-\sigma} + (I_H - I_L - I_O) w_M^{1-\sigma} + \int_{i\in I_O} \zeta(i)^{1-\sigma} \mathrm{d}i (\tau w_O)^{1-\sigma} + \int_{I_H}^1 \varphi_H(i)^{1-\sigma} \mathrm{d}i w_H^{1-\sigma}\right]^{\frac{1}{1-\sigma}}. \tag{B.45}$$

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 $\tilde{xi}$ is minimized, i.e.

$$\frac{\mathrm{d}\tilde{\xi}}{\mathrm{d}I_L} = \frac{1}{1-\sigma}\tilde{\xi}^{\sigma}\left[\varphi_L(I_L)^{\sigma-1}\bar{W}^{1-\sigma} - w_M^{1-\sigma}\right].$$

It follows that $\frac{\mathrm{d}\tilde{\xi}}{\mathrm{d}I_L} = 0$ 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 $\int_0^{I_L} l_L(i)\mathrm{d}i = n_L$. 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

$$\bar{W} = P_E \frac{E}{n_L}^{\frac{1}{\sigma}} \gamma_L(I_L)^{\frac{1}{\sigma}}.$$

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). ■

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

$$\tilde{\mathbf{J}} \times \mathbf{I} = \bar{\boldsymbol{W}}, \tag{B.46}$$

where $\mathbf{I} = \{\mathrm{d}I_L, \mathrm{d}I_O, \mathrm{d}I_H\}$, $\bar{\boldsymbol{W}} = \{-\mathrm{d}\bar{W}/W, 0, 0\}$, and $\tilde{\mathbf{J}}$ is given by

$$\tilde{J} = \begin{pmatrix} \left(\frac{\alpha}{I_H - I_L - I_O} + (1-(1-\alpha\sigma)\lambda_L)\,\varepsilon_L\right) & -\left((1-\alpha\sigma)\lambda_O\mu - \frac{\alpha}{I_H-I_L-I_O}\right) & -\left(\frac{\alpha}{I_H-I_L-I_O} - (1-\alpha\sigma)\lambda_H\varepsilon_H\right) \\ \left(\frac{\alpha}{I_H-I_L-I_O} - (1-\alpha\sigma)\lambda_L\varepsilon_L\right) & \left(\frac{\alpha}{I_H-I_L-I_O} + (1-(1-\alpha\sigma)\lambda_O)\mu\right) & -\left(\frac{\alpha}{I_H-I_L-I_O} - (1-\alpha\sigma)\lambda_H\varepsilon_H\right) \\ -\frac{1}{I_H-I_L-I_O} & -\frac{1}{I_H-I_L-I_O} & \left(\frac{1}{I_H-I_L-I_O} + \sigma\varepsilon_H + \frac{\varphi_H^{\sigma-1}}{\gamma_H(I_H)}\right) \end{pmatrix} \tag{B.47}$$

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

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:

$$\left|\tilde{J}_{1\times 1}\right| = \left(\frac{\alpha}{I_H - I_L - I_O} + (1-(1-\alpha\sigma)\lambda_L)\,\varepsilon_L\right) > 0,$$

$$\begin{aligned} \left|\tilde{J}_{2\times 2}\right| &= \left(\frac{\alpha}{I_H - I_L - I_O} + (1-(1-\alpha\sigma)\lambda_L)\,\varepsilon_L\right) \times \left(\frac{\alpha}{I_H - I_L - I_O} + (1-(1-\alpha\sigma)\lambda_O)\mu\right) \\ &\quad + \left((1-\alpha\sigma)\lambda_O\mu - \frac{\alpha}{I_H - I_L - I_O}\right) \times \left(\frac{\alpha}{I_H - I_L - I_O} - (1-\alpha\sigma)\lambda_L\varepsilon_L\right) > 0, \end{aligned}$$

and

$$\begin{aligned}\left|\tilde{J}_{3\times 3}\right| &= \left(\frac{\alpha}{I_H - I_L - I_O} - (1-\alpha\sigma)\lambda_L\varepsilon_L\right)\left(\sigma\varepsilon_H + \frac{\varphi_H^{\sigma-1}}{\gamma_H(I_H)}\right)\mu \\ &+(1-\alpha\sigma)\left(\frac{1}{I_H - I_L - I_O}\right)\mu\left(\lambda_H\varepsilon_H - \lambda_L\varepsilon_L\right) \\ &+\varepsilon_L\left(\frac{\alpha}{I_H - I_L - I_O}\right)\left(\sigma\varepsilon_H + \frac{\varphi_H^{\sigma-1}}{\gamma_H(I_H)}\right) \\ &+\varepsilon_L\left((1-(1-\alpha\sigma)\lambda_O)\mu\right)\left(\frac{1}{I_H - I_L - I_O} + \sigma\varepsilon_H + \frac{\varphi_H^{\sigma-1}}{\gamma_H(I_H)}\right) \\ &+\varepsilon_L\left(\frac{1}{I_H - I_L - I_O}\right)\left((1-\alpha\sigma)\lambda_H\varepsilon_H\right) > 0\end{aligned} \tag{B.48}$$

Given (B.49) and by Cramer's Rule, the solution to the 3×3 system (B.46) yields

$$\begin{aligned}\frac{\mathrm{d}I_L}{\mathrm{d}\bar{W}} &= -\frac{1}{\left|\tilde{J}\right|}\frac{1}{\bar{W}}\Bigg[\left(\frac{\alpha}{I_H - I_L - I_O}\right)\left(\sigma\varepsilon_H + \frac{\varphi_H^{\sigma-1}}{\gamma_H(I_H)}\right) + ((1-(1-\alpha\sigma)\lambda_O)\mu)\left(\frac{1}{I_H - I_L - I_O} + \sigma\varepsilon_H + \frac{\varphi_H^{\sigma-1}}{\gamma_H(I_H)}\right) \\ &\quad + \left(\frac{1}{I_H - I_L - I_O}\right)((1-\alpha\sigma)\lambda_H\varepsilon_H)\Bigg] < 0 \\ \frac{\mathrm{d}I_O}{\mathrm{d}\bar{W}} &= \frac{1}{\left|\tilde{J}\right|}\frac{1}{\bar{W}}\Bigg[\left(\frac{\alpha}{I_H - I_L - I_O} - (1-\alpha\sigma)\lambda_L\varepsilon_L\right)\left(\sigma\varepsilon_H + \frac{\varphi_H^{\sigma-1}}{\gamma_H(I_H)}\right) + (1-\alpha\sigma)\left(\frac{1}{I_H - I_L - I_O}\right)(\lambda_H\varepsilon_H - \lambda_L\varepsilon_L)\Bigg] > 0 \\ \frac{\mathrm{d}I_H}{\mathrm{d}\bar{W}} &= -\frac{1}{\left|\tilde{J}\right|}\frac{1}{\bar{W}}\left(\frac{1}{I_H - I_L - I_O}\right)\left[((1-(1-\alpha\sigma)\lambda_O)\mu) + (1-\alpha\sigma)\lambda_L\varepsilon_L\right] < 0.\end{aligned}$$

Next we compute the impact of easier offshoring on the equilibrium task margins under the minimum-wage regime. In doing so, take the total differentiation of the adjusted implicit system equations (B.49) w.r.t. to ω, and rearrange to obtain

$$\tilde{\mathbf{J}} \times \mathbf{I} = \boldsymbol{\omega}, \tag{B.49}$$

where $\mathbf{I} = \{\mathrm{d}I_L, \mathrm{d}I_O, \mathrm{d}I_H\}$, $\boldsymbol{\omega} = \{0, \mathrm{d}\omega/\omega, 0\}$, and $\tilde{\mathbf{J}}$ is given by (B.47). Applying Cramer's Rule, the solution to the system (B.49) yields

$$\begin{aligned}\frac{\mathrm{d}I_L}{\mathrm{d}\omega} &= -\frac{1}{\left|\tilde{J}\right|}\frac{1}{\omega}\Bigg[\left((1-\alpha\sigma)\lambda_O\mu - \frac{\alpha}{I_H - I_L - I_O}\right)\left(\frac{1}{I_H - I_L - I_O} + \sigma\varepsilon_H + \frac{\varphi_H^{\sigma-1}}{\gamma_H(I_H)}\right) \\ &\quad + \left(\frac{1}{I_H - I_L - I_O}\right)\left(\frac{\alpha}{I_H - I_L - I_O} - (1-\alpha\sigma)\lambda_H\varepsilon_H\right)\Bigg] < 0 \\ \frac{\mathrm{d}I_O}{\mathrm{d}\omega} &= \frac{1}{\left|\tilde{J}\right|}\frac{1}{\omega}\Bigg[\left(\frac{\alpha}{I_H - I_L - I_O} + (1-(1-\alpha\sigma)\lambda_L)\varepsilon_L\right)\left(\frac{1}{I_H - I_L - I_O} + \sigma\varepsilon_H + \frac{\varphi_H^{\sigma-1}}{\gamma_H(I_H)}\right) + \left(\frac{\alpha}{I_H - I_L - I_O}\right)\left(\sigma\varepsilon_H + \frac{\varphi_H^{\sigma-1}}{\gamma_H(I_H)}\right) \\ &\quad + \left(\frac{1}{I_H - I_L - I_O}\right)((1-\alpha\sigma)\lambda_H\varepsilon_H)\Bigg] > 0 \\ \frac{\mathrm{d}I_H}{\mathrm{d}\omega} &= \frac{1}{\left|\tilde{J}\right|}\frac{1}{\omega}\left(\frac{1}{I_H - I_L - I_O}\right)\Bigg[\left(\frac{\alpha}{I_H - I_L - I_O} + (1-(1-\alpha\sigma)\lambda_L)\varepsilon_L\right) + \left((1-\alpha\sigma)\lambda_O\mu - \frac{\alpha}{I_H - I_L - I_O}\right)\Bigg] > 0.\end{aligned}$$

■

Proof of Proposition 5.

Inserting in equation (24) the solution from equation (B.40), we obtain

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

It follows that easier offshoring will reduce the low-skill unemployment rate, i.e. $\frac{\mathrm{d}\ln n_L}{\mathrm{d}\omega} > 0$, 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 $\int_0^{I_L} l_L(i)\mathrm{d}i = n_L$. Then, recalling the first-order condition (B.2) and following similar formal steps as in the proof of Lemma 3, we obtain

$$w_L \quad = \quad P_E \left(\frac{E}{n_L}\right)^{\frac{1}{\sigma}} \gamma_L(I_L)^{\frac{1}{\sigma}}. \tag{B.50}$$

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

$$\frac{w_L}{w_M} = \left(\frac{N_M}{n_L}\right)^{\frac{1}{\sigma}} \left(\frac{\gamma_L(I_L)}{I_H - I_L - I_O}\right)^{\frac{1}{\sigma}}.$$

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 ω and rearranging, yields

$$\hat{\mathbf{J}} \times \hat{\mathbf{I}} = \hat{\boldsymbol{\omega}}, \tag{B.51}$$

where $\hat{\mathbf{I}} = \{\mathrm{d}I_L, \mathrm{d}I_O, \mathrm{d}I_H, \mathrm{d}u_L\}$, $\hat{\boldsymbol{\omega}} = \{0, 0, \mathrm{d}\omega/\omega, 0\}$, and $\hat{\mathbf{J}}$ is given by

$$\hat{J} = \begin{pmatrix} \left([1-\alpha\sigma](1-\lambda_L)\varepsilon_L - \frac{\alpha}{s_L}\right) & -(1-\alpha\sigma)\lambda_O\mu & (1-\alpha\sigma)\lambda_H\varepsilon_H & -\left(\frac{\alpha}{1-u_L} + \delta\right) \\ \left(\frac{1}{s_L} + \frac{1}{I_H - I_L - I_O} + \sigma\varepsilon_L\right) & \frac{1}{I_H - I_L - I_O} & -\frac{1}{I_H - I_L - I_O} & \frac{1}{1-u_L} \\ \left(\frac{\alpha}{I_H - I_L - I_O} - [1-\sigma\alpha]\lambda_L\varepsilon_L\right) & \left((1-[1-\sigma\alpha]\lambda_O)\mu + \frac{\alpha}{I_H + I_L - I_O}\right) & \left([1-\sigma\alpha]\lambda_H\varepsilon_H - \frac{\alpha}{I_H - I_L - I_O}\right) & 0 \\ -\frac{1}{I_H - I_L - I_O} & -\frac{1}{I_H - I_L - I_O} & \left(\frac{1}{s_H} + \frac{1}{I_H - I_L - I_O} + \sigma\varepsilon_H\right) & 0 \end{pmatrix}, \tag{B.52}$$

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

Computing the determinant of the Jacobian (B.52), we show that by sufficient conditions in Proposition 3 the adjusted Jacobian $\hat{J}$ is a P-Matrix too:

$$\left|\hat{J}_{1\times1}\right| \quad = \quad \left([1-\alpha\sigma](1-\lambda_L)\varepsilon_L - \frac{\alpha}{s_L}\right) > 0,$$

$$\left|\hat{J}_{2\times2}\right| \quad = \quad \left([1-\alpha\sigma](1-\lambda_L)\varepsilon_L - \frac{\alpha}{s_L}\right) \times \frac{1}{I_H - I_L - I_O} + (1-\alpha\sigma)\lambda_O\mu\left(\frac{1}{s_L} + \frac{1}{I_H - I_L - I_O} + \sigma\varepsilon_L\right) > 0,$$

$$\begin{aligned} \left|\hat{J}_{3\times3}\right| \quad = \quad & \left([1-\alpha\sigma](1-\lambda_L)\varepsilon_L - \frac{\alpha}{s_L}\right)\left(\frac{1}{I_H - I_L - I_O}\right)([1-\sigma\alpha]\lambda_H\varepsilon_H + (1-[1-\sigma\alpha]\lambda_O)\mu) \\ & +(1-\alpha\sigma)\lambda_O\mu\left(\left(\frac{1}{s_L} + \frac{1}{I_H - I_L - I_O} + \sigma\varepsilon_L\right) \times \left([1-\sigma\alpha]\lambda_H\varepsilon_H - \frac{\alpha}{I_H - I_L - I_O}\right)\right. \\ & \left. + \frac{1}{I_H - I_L - I_O}\left(\frac{\alpha}{I_H - I_L - I_O} - [1-\sigma\alpha]\lambda_L\varepsilon_L\right)\right) \\ & (1-\alpha\sigma)\lambda_H\varepsilon_H\left(\left(\frac{1}{s_L} + \frac{1}{I_H - I_L - I_O} + \sigma\varepsilon_L\right) \times \left((1-[1-\sigma\alpha]\lambda_O)\mu + \frac{\alpha}{I_H + I_L - I_O}\right)\right. \\ & \left. - \frac{1}{I_H - I_L - I_O}\left(\frac{\alpha}{I_H - I_L - I_O} - [1-\sigma\alpha]\lambda_L\varepsilon_L\right)\right) > 0. \end{aligned}$$

To compute the determinant of the Jacobian (B.52), we apply the cofactor expansion along the 1st row, i.e. $\left|\hat{J}_{4\times4}\right| = \Sigma_{q=1}^{4} a_{1q}\hat{J}_{1q}$, where $\hat{J}_{1q}$ is the cofactor of the element a_{1q}. Formally,

$$\left|\hat{J}_{4\times 4}\right| = \left([1-\alpha\sigma]\,(1-\lambda_L)\,\varepsilon_L - \frac{\alpha}{s_L}\right)\hat{J}_{11} + (1-\alpha\sigma)\lambda_O\mu\hat{J}_{12} + (1-\alpha\sigma)\lambda_H\varepsilon_H\hat{J}_{13} + \left(\frac{\alpha}{1-u_L}+\delta\right)\hat{J}_{14} > 0, \tag{B.53}$$

where

$$\hat{J}_{11} = \frac{1}{1-u_L}\left(\left((1-[1-\sigma\alpha]\,\lambda_O)\mu + \frac{\alpha}{I_H+I_L-I_O}\right)\times\left(\frac{1}{s_H}+\frac{1}{I_H-I_L-I_O}+\sigma\varepsilon_H\right) + \frac{1}{I_H-I_L-I_O}\left([1-\sigma\alpha]\,\lambda_H\varepsilon_H - \frac{\alpha}{I_H-I_L-I_O}\right)\right) > 0,$$

$$\hat{J}_{12} = \frac{1}{1-u_L}\left(\left(\frac{\alpha}{I_H-I_L-I_O} - [1-\sigma\alpha]\,\lambda_L\varepsilon_L\right)\times\left(\frac{1}{s_H}+\frac{1}{I_H-I_L-I_O}+\sigma\varepsilon_H\right) + \frac{1}{I_H-I_L-I_O}\left([1-\sigma\alpha]\,\lambda_H\varepsilon_H - \frac{\alpha}{I_H-I_L-I_O}\right)\right) > 0,$$

$$\hat{J}_{13} = \frac{1}{1-u_L}\left(\frac{1}{I_H-I_L-I_O}\right)\left(\left((1-[1-\sigma\alpha]\,\lambda_O)\mu + \frac{\alpha}{I_H+I_L-I_O}\right) - \left(\frac{\alpha}{I_H-I_L-I_O} - [1-\sigma\alpha]\,\lambda_L\varepsilon_L\right)\right) > 0,$$

and finally from (B.49) it follows $\hat{J}_{14} > 0$.

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

$$\frac{\mathrm{d}I_L}{\mathrm{d}\omega} = -\frac{1}{\left|\hat{J}\right|}\frac{\left[\alpha(1+s_H\sigma\varepsilon_H) + (1+s_H\sigma\varepsilon_H)\Big((1-u_L)\delta - \mu\lambda_O(1-\alpha\sigma)\big[s_H + (I_H-I_L-I_O)\big]\Big) + (1-\alpha\sigma)s_H\lambda_H\varepsilon_H\right]}{\omega s_H\,(1-u_L)\,(I_H-I_L-I_O)} \lesseqgtr 0,$$

$$\Rightarrow \frac{\mathrm{d}I_L}{\mathrm{d}\omega} < 0,\ \text{for } (1-u_L)\delta > \mu\lambda_O(1-\alpha\sigma)[s_H + (I_H-I_L-I_O)],$$

$$\begin{aligned}\frac{\mathrm{d}I_O}{\mathrm{d}\omega} = {} & \frac{1}{\left|\hat{J}\right|}\frac{1}{\omega s_H s_L\,(1-u_L)\,(I_H+I_L+I_O)^2} \\ & \Big(s_H + (1+s_H\sigma\epsilon_H)\,(I_H+I_L+I_O)\Big)\Big[\,(I_H-I_L-I_O)\,((1-\alpha\sigma)\,(1-\lambda_L)\,s_L\varepsilon_L - \alpha) \\ & + (\alpha + (1-u_L)\delta)\,(1+s_L\sigma\epsilon_L)\,(I_H-I_L-I_O)\Big] + s_H s_L(1-\alpha\sigma)\lambda_H\epsilon_H\,(I_H-I_L-I_O) \\ & + (\alpha+(1-u_L)\delta)\,s_L(1+s_H\sigma\epsilon_H)\,(I_H+I_L+I_O) > 0,\end{aligned}$$

$$\frac{\mathrm{d}I_H}{\mathrm{d}\omega} = \frac{1}{\left|\hat{J}\right|}\frac{\left[s_L\,((1-\alpha\sigma)\,((1-\lambda_L)\epsilon_L + \mu\lambda_O) + \alpha\sigma\varepsilon_L) + (1-u_L)\,(\delta + \delta s_L\sigma\varepsilon_L)\,\right]}{\omega s_L\,(1-u_L)\,(I_H-I_L-I_O)} > 0,$$

$$\begin{aligned}\frac{\mathrm{d}u_L}{\mathrm{d}\omega} = {} & -\frac{1}{\left|\hat{J}\right|}\frac{1}{\omega s_H s_L\,(I_H-I_L-I_O)} \\ & \Big[(1-\alpha\sigma)s_H(\lambda_H\varepsilon_H - \lambda_O\mu) + (1+s_H\sigma\varepsilon_H)[(1-\alpha\sigma)\mu\lambda_O\,(I_H-I_L-I_O) - \alpha] \\ & +(1-\alpha\sigma)s_L\Big(\,(1+s_H\sigma\varepsilon_H)\,\mu\lambda_O(1+\sigma\varepsilon_L\,(I_H-I_L-I_O)) + (1+(1-\lambda_H)\sigma s_H\varepsilon_H)(1-\lambda_L)\varepsilon_L + \sigma\varepsilon_L s_H\lambda_O\mu\Big)\Big] < 0.\end{aligned}$$

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-sill real wages requires further steps, which we discuss below.

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

$$\frac{\mathrm{d}w_L}{\mathrm{d}\omega} = -\delta\frac{\mathrm{d}u_L}{\mathrm{d}\omega} \tag{B.54}$$

$$\frac{\mathrm{d}w_L}{\mathrm{d}\omega} = -\Delta\frac{\mathrm{d}I_L}{\mathrm{d}\omega} - (1-\alpha\sigma)\frac{\mathrm{d}\Omega(\cdot)}{\mathrm{d}\omega} + \frac{\alpha}{1-u_L}\frac{\mathrm{d}u_L}{\mathrm{d}\omega}, \tag{B.55}$$

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

$$\frac{\mathrm{d}w_L}{\mathrm{d}\omega} = -\frac{(1-u_L)\delta}{\alpha + (1-u_L)\delta}\left(\Delta\frac{\mathrm{d}I_L}{\mathrm{d}\omega} + (1-\alpha\sigma)\frac{\mathrm{d}\Omega(\cdot)}{\mathrm{d}\omega}\right). \tag{B.56}$$

By Proposition 3 and for $\delta > \mu\frac{\lambda_O(1-\alpha\sigma)[s_H+(I_H-I_l-I_O)]}{1-u_L}$, it follows $\frac{\mathrm{d}I_L}{\mathrm{d}\omega} < 0$ and $\frac{\mathrm{d}\ln\Omega(\cdot)}{\mathrm{d}\omega} < 0$.Thus, from equation (B.56) $\frac{\mathrm{d}w_L}{\mathrm{d}\omega} > 0$. ■