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Offshoring and job polarisation between firms[☆]

Hartmut Egger[a,b,c,d,*], Udo Kreickemeier[e,b,c], Christoph Moser[f,b,g], Jens Wrona[h,b,i]

[a] University of Bayreuth, Germany
[b] CESifo, Germany
[c] GEP, United Kingdom
[d] IfW, Germany
[e] University of Göttingen, Germany
[f] Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Germany
[g] KOF, Switzerland
[h] University of Duisburg–Essen, Germany
[i] DICE, Germany

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ABSTRACT

Using linked employer–employee data for Germany, we provide evidence for job polarisation between firms and identify offshoring as an important determinant of these employment changes. To accommodate these findings, we set up a model in which offshoring to a low-wage country can lead to job polarisation in the high-wage country due to a reallocation of labour across firms that differ in productivity and pay wages that are positively linked to their profits. Offshoring is chosen only by the most productive firms, and only for those tasks with the lowest variable offshoring costs. A reduction in those variable costs increases offshoring at the intensive and at the extensive margin. Well in line with our evidence, this causes domestic employment shifts from the newly offshoring firms in the middle of the productivity distribution to firms at the tails of this distribution, paying either very low or very high wages.

1. Introduction

It is a well-documented phenomenon for many industrialised economies that the share of workers employed in medium-wage jobs has fallen, while the share of workers employed in either high-wage jobs or low-wage jobs has increased.[1] To rationalise this empirical pattern of job polarisation, economists have usually referred to the *routinisation hypothesis* (cf. Autor et al., 2003), according

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* Correspondence to: University of Bayreuth, Faculty of Law, Business and Economics, Universitätsstr. 30, 95447 Bayreuth, Germany.
E-mail address: hartmut.egger@uni-bayreuth.de (H. Egger).

[1] For instance, Autor et al. (2006, 2008) and Autor and Dorn (2013) provide evidence for the US, whereas Dustmann et al. (2009) and Goos et al. (2009, 2014), Dauth (2014), and Keller and Utar (2023) document job polarisation for various European economies.

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to which job polarisation can be understood as a movement away from routine tasks and towards tasks that are non-routine: the jobs that are lost in the middle of the wage distribution involve mainly routine tasks, whereas the jobs at the extremes of the wage distribution that experience an increase in employment are intensive in abstract or service tasks, respectively, both of which are non-routine.

An emerging empirical literature suggests a new perspective on job polarisation, with the finding that an important part of it may well be occurring between firms rather than (predominantly) between tasks (Heyman, 2016; Kerr et al., 2020; Harrigan et al., 2021). As the most important contribution of our paper, we develop a general equilibrium model that provides a theoretical mechanism for job polarisation in the firm dimension. The mechanism in our model works through North–South offshoring, and it is built on two well-established facts: (i) more productive firms pay higher wages than their less productive competitors; and (ii) there is selection of the most productive firms into international markets.[2] In support of our firm-based perspective, we provide evidence from linked employer–employee data for Germany after the millennium for job polarisation between firms, and using the same data we also identify offshoring as an important determinant of the observed employment changes. The period after the millennium is of particular interest because it covers two major globalisation shocks for Germany, the accession of China to the WTO in 2001 and the Eastern European enlargement of the EU in 2004. These improved the scope of firms to offshore production to low-cost countries, with the labour market effects at home controversially discussed in the literature (see Autor et al., 2013; Dauth et al., 2014).

The story we have in mind is simple: Suppose offshoring is costly and thus only attractive for firms with high productivity. Provided there is some mechanism linking firm productivity to the average wage a firm is paying, firm-level offshoring is positively correlated with firm-level wages. Now distinguish three types of firms, in the order of increasing productivity, and therefore increasing wages: (i) *infra-marginal non-offshorers*, which offshore neither at high nor at low offshoring cost; (ii) *marginal offshorers*, which offshore only at low offshoring cost, and (iii) *infra-marginal offshorers*, which offshore at both high and low offshoring cost. It is then natural for an across-the-board decrease in variable offshoring costs to lead to job polarisation: Marginal offshorers move a discrete number of tasks to the South, and in the process they reduce the number of domestic jobs. This reduction in labour demand causes a downward pressure on wages, and therefore infra-marginal offshorers as well as infra-marginal non-offshorers – i.e. the firms paying either very high or very low wages – increase their domestic employment.

To formalise the story outlined above and to shed light on its possible limitations, we set up a general equilibrium model with monopolistic competition among heterogeneous firms. As in Lucas (1978) each firm is run by an entrepreneur, who hires workers for production. Agents are equally productive as workers, but differ in terms of their entrepreneurial ability, which is instrumental for the productivity of firms and thus for the profit income that accrues to the entrepreneur as residual claimant. The entry of firms and the economy-wide supply of labour are then jointly determined by the decentralised occupational choice of agents, with entrepreneurial ability being pivotal for the decision of who becomes an entrepreneur and who becomes a worker. To analyse offshoring decisions, we place our analysis in an asymmetric two-country model, in which firms from an industrialised North have an incentive to offshore the production of tasks to a developing South, with lower wages. Trade in tasks is associated with fixed and variable offshoring costs. Assuming that offshoring costs are the same for all producers, there is selection of firms into offshoring by productivity, establishing an (endogenous) *extensive firm margin* that separates highly productive offshoring firms from less productive non-offshoring firms. As in Grossman and Rossi-Hansberg (2008), we consider variable offshoring costs that are task specific, which implies, in addition, an (endogenous) *extensive task margin* that separates tasks kept onshore from tasks put offshore.

We complement this framework by a directed search model for the labour market, in which firms can invest into screening in order to increase the imprecisely observed abilities of the workforce actually hired and in which workers must be compensated by firms for the additional risk of failing in the screening process (cf. Helpman et al., 2010, 2017). The proposed mechanism induces larger, more productive firms to screen their applicants more thoroughly and to pay higher wages, which establishes rent sharing between firms and workers. We associate offshoring with vertical multinational activity and assume that firms face the same labour market imperfection at home and abroad. For offshoring firms, this implies that wages of both domestic and foreign workers are positively correlated with their profits, in line with evidence from Budd and Slaughter (2004) and Budd et al. (2005). The equilibrium then features two continuous wage distributions, one in each country. As our central result, we show that with the considered labour market imperfection a reduction in offshoring costs can indeed lead to job polarisation in our model, but only if offshoring costs are sufficiently low.[3]

Since, as a byproduct of rent sharing, our model features economy-wide unemployment, we can use it to address the politically charged question of whether offshoring to low-wage countries destroys jobs in high-wage countries in the aggregate.[4] Our model gives a nuanced answer to this question, the main reason being that it is of course possible for workers who have lost their jobs due to offshoring to find employment elsewhere. Specifically, for these workers our model points to three possible alternatives to

[2] Supportive evidence for the first fact can be found in empirical labour market research (see Blanchflower et al., 1996; Abowd et al., 1999, for two early contributions and Card et al., 2013, for a more recent one). Regarding the second fact, Bernard and Jensen (1995) provide first systematic evidence that exporters are larger and more profitable than non-exporters, and the subsequent literature has pointed out that these differences are due to a selection of better firms into exporting (see Bernard and Jensen, 1999). Hummels et al. (2014) and Moser et al. (2015) show that the patterns of international market participation are similar if one considers offshoring instead of exporting.

[3] The directed search model proposed in this paper shows close resemblance to a *gift exchange* model, in which firms have to pay a fair wage in order to elicit the full level of non-contractible effort from their workforce (cf. Akerlof and Yellen, 1990; Egger and Kreickemeier, 2012; Amiti and Davis, 2012). Both frameworks accord with the established fact that larger, more productive firms pay higher wages, and in the context of our analysis they are isomorphic. We sketch the gift exchange model as an alternative to the directed search model in the Online Appendix to this manuscript.

[4] As pointed out by The Economist (2009), "Americans became almost hysterical" about the job destruction due to offshoring, when Forrester Research predicted a decade ago that 3.3 million American jobs will be offshored until 2015.

unemployment: they may be hired as production workers in a different firm, they may work in an outside sector, or they may become entrepreneurs themselves.[5] Economy-wide unemployment increases in the extent of wage dispersion between firms, ceteris paribus, since the latter is a measure for the severeness of the labour market distortion. We show that offshoring reduces wage dispersion in the North relative to autarky if the offshoring cost is very high, leading to lower aggregate unemployment in this case. This positive labour market effect can be overturned at low levels of offshoring cost, since in this case wage dispersion between firms increases.

We conclude our analysis with a quantitative exercise in which we calibrate key model parameters, relying on establishment-level and economy-wide data for Germany. We use this quantitative exercise to check whether the parameter values implied by our data put us in the job polarisation regime of our model, and to predict the employment changes along the wage distribution from observed changes in the offshoring conditions. For the period 1999 to 2007, we find clear evidence for job polarisation from our quantitative model and show that the overall employment loss by marginal offshorers dominates the employment increase by infra-marginal offshorers and infra-marginal non-offshorers, accumulating to an overall loss of 308,810 production jobs in Germany after the millennium.

Despite the voluminous empirical literature finding evidence for job polarisation (see for example Autor et al., 2006; Goos et al., 2009, 2014), there are only very few papers providing a theoretical basis for Autor et al.'s (2003) *routinisation hypothesis*. Acemoglu and Autor (2011) set up a model featuring an endogenous assignment of skills to tasks. Distinguishing three different worker types, they show that the replacement of routine tasks through technological change or offshoring can explain job polarisation, with displaced medium-skilled workers being reallocated to tasks previously performed by better-paid high-skilled workers or worse-paid low-skilled workers, respectively. Costinot and Vogel (2010) formulate a model, in which a continuum of workers sorts across a continuum of tasks depending on their comparative advantage. As pointed out by the authors, this model is also equipped to explain job polarisation, for reasons not too different from those outlined by Acemoglu and Autor (2011).[6] However, focusing on a model with atomistic firms, neither Costinot and Vogel (2010) nor Acemoglu and Autor (2011) can explain job polarisation between firms. Hence, our model complements existing theoretical work by highlighting a new channel through which job polarisation can materalise: the creation and destruction of jobs by firms that differ in their wage payments.

Our model also builds on a large literature that studies the consequences of offshoring to low-wage countries (cf. Jones and Kierzkowski, 1990; Feenstra and Hanson, 1996; Grossman and Rossi-Hansberg, 2008; Rodriguez-Clare, 2010; Acemoglu et al., 2015), including several contributions that place their analysis in a framework with heterogeneous firms (cf. Antràs and Helpman, 2004; Antràs et al., 2006; Davidson et al., 2008; Groizard et al., 2014; Egger et al., 2015, 2022). Since we are modelling labour market imperfections in an open economy, our paper is also related to an old and well established literature dealing with the effects of globalisation on unemployment and wage inequality (cf. Brecher, 1974; Davidson et al., 1988; Hosios, 1990), and more directly to the recent papers by Egger and Kreickemeier (2009, 2012), Helpman et al. (2010), and Amiti and Davis (2012), who analyse the link between international goods trade, residual wage inequality and unemployment in models with firm heterogeneity. Since international trade in all these models unambiguously reallocates labour to high-wage firms, they cannot explain job polarisation in the firm dimension. Hence, our analysis shows that explaining job polarisation between firms by a globalisation shock requires this shock to take the form of offshoring.[7]

The paper is structured as follows. In Section 2 we present evidence on job polarisation in Germany. Sections 3 and 4 present the main building blocks of our model, introduce the firm's problem, and solve for the sectoral as well as the general equilibrium. In Section 5, we analyse the effects of falling (variable) offshoring costs on the domestic employment of offshoring and non-offshoring firms and discuss the conditions under which job polarisation materialises. In Section 6, we determine the effects of offshoring on economy-wide unemployment. In Section 7, we provide a quantitative analysis to assess whether our model is capable to explain job polarisation between German establishments after millennium and to shed light on the size of employment effects due to offshoring. Section 8 concludes with a summary of the most important results.

2. Evidence on job polarisation and offshoring in Germany

In this section, we provide evidence from the linked-employer-employee dataset of the Institute for Employment Research in Nuremberg (LIAB) in favour of job polarisation between firms and its plausible links to offshoring, thereby motivating our theoretical analysis. The dataset combines rich data from an annual survey of German establishments with detailed administrative data on workers from social security files. We analyse the period 1999 to 2007.[8] A detailed data description is provided in Appendix B.1.

Before focusing on job polarisation between firms, and in order to link our analysis to the large empirical literature exploring the routinisation hypothesis, we check whether our data also shows the now-standard result of job polarisation between occupations. For

[5] Evidence from matched worker–firm-owner data shows that individuals who are unemployed (cf. Berglann et al., 2011) or displaced from their job (cf. von Greiff, 2009) are more likely to become entrepreneurs. Furthermore, Autor et al. (2014) and Artuç and McLaren (2015) provide evidence that the movement of workers to other sectors is an important channel for the adjustment of labour markets to globalisation shocks.

[6] Costinot and Vogel (2015) give an authoritative overview over assignment models in international trade.

[7] By contrast, Burstein et al. (2019) show that international trade in goods that induces technological change can lead to job polarisation in an assignment model of international trade.

[8] This sample period is recommendable, because with the accession of China to the WTO in 2001 and the Eastern European enlargement of the EU in 2004 it covers two major globalisation shocks, which we want to highlight in our analysis as key factors of explaining job polarisation. Moreover, we want to make sure that our results are not affected by the global financial crises.

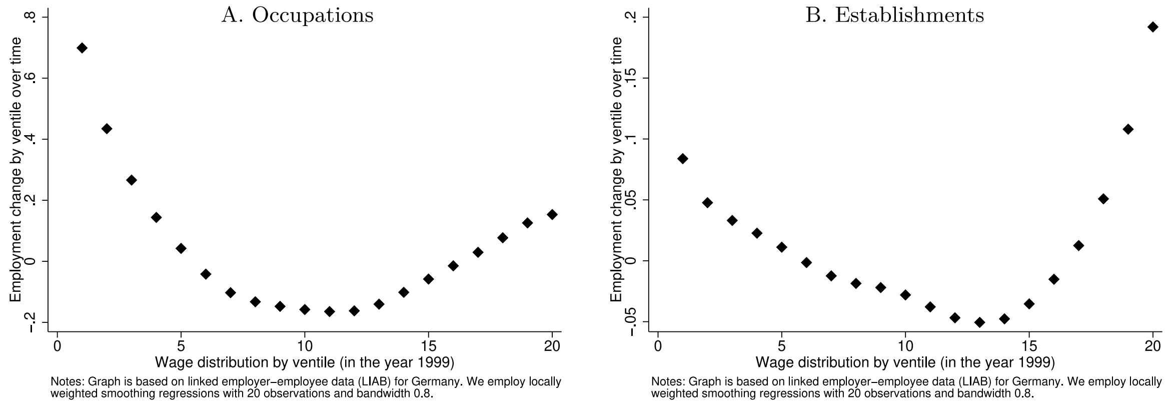

Fig. 1. Job polarisation between occupations and establishments from 1999 to 2007.

a simple graphical illustration, we follow Goos et al. (2009) and Autor and Dorn (2013), rank occupations according to the average wage received by workers in 1999, and group these occupations into wage ventiles, each of them covering 16 or 17 occupations. To isolate the role of occupations for job polarisation from other sources of influence, we rank occupations by residual instead of raw wages in the baseline year. For this purpose, we run a Mincer-type regression, in which we eliminate wage variation due to observable differences of workers, such as age, education, labour market experience, tenure in the same establishment, and gender. Importantly, we control for employer fixed effects, and hence any firm heterogeneity that might influence individual wages.[9] We report the average de-trended and smoothed log employment changes between 1999 and 2007 for the 20 wage groups in Panel A of Fig. 1.[10] The graph shows evidence for job polarisation between occupations in Germany, well in line with findings for earlier time periods reported by Spitz-Oener (2006) and Dustmann et al. (2009).

To illustrate the employment changes between establishments over the period 1999 to 2007, we follow a similar approach. We run a Mincer-type regression controlling for observable worker characteristics (including the federal state of the employer). To purge the residual wages in the baseline year from any influence stemming from the task- or occupational dimension, we also control for more than 330 occupation codes at the three-digit level of the German nomenclature from 1988 (Kldb88). We then rank establishments by the average residual wage paid to its workforce in 1999 and group them into wage ventiles. We thereby use sample weights from LIAB to make the establishment sample representative for Germany. In our preferred specification, we keep all establishments that are observed for at least two years and determine their employment changes between 1999 and the final observation year within the sample period. This gives a sample of 7592 establishments, for which we report the average de-trended and smoothed log employment changes over the sample period for the 20 wage groups in Panel B of Fig. 1. The graph shows clear evidence for job polarisation between establishments.

In Appendix B.2, we report additional evidence on job polarisation between establishments and show robustness of our results in many dimensions, including changing the number of wage groups or adding industry fixed effects. Moreover, we show that job polarisation also materialises if we rank establishments by productivities, sales, or raw wages. This finding is well in line with our theoretical model outlined in Sections 3 to 6, where we explain the similarity of employment patterns for different performance measures by a monotonic link between them. In our theoretical model, we argue that job polarisation between establishments is the result of a selection of producers into offshoring by productivity and their asymmetric adjustment in domestic employment to changes in offshoring costs. Since the LIAB data contains for the three years 1999, 2001, and 2003 qualitative information on imports of intermediates at the establishment level, we can shed light on this offshoring channel for explaining job polarisation. Thereby, we use the categorical import data to define a dummy for *infra-marginal* offshorers, which takes a value of one if an establishments reports imports of intermediates in the current observation year. We define a second dummy for *marginal* offshorers which takes a value of one if the establishment does not import intermediates now but in the next observation period (after two years). Establishments for which both dummies are zero are classified as *infra-marginal* non-offshorers and serve as the control group in our analysis.

We use data for the years 1999 and 2001, for which these two offshorer dummies are defined, to provide evidence for a selection of establishments into offshoring by productivity with the immediate consequence that offshoring producers – as the more productive establishments – achieve higher revenues and pay higher wages. For this purpose, we run parsimonious regressions of the following form

$$\log y_{vst} = \beta_0 + \beta_1 infra\text{-}marginal_{vst} + \beta_2 marginal_{vst} + \gamma_s + \zeta_t + \varepsilon_{vst}, \tag{1}$$

[9] Since we use residual wages only for a single year, this procedure controls for any establishment heterogeneity.

[10] We de-trend employment changes to isolate the observed employment changes from economy-wide trends due to common macroeconomic shocks and labour market reforms around the millennium.

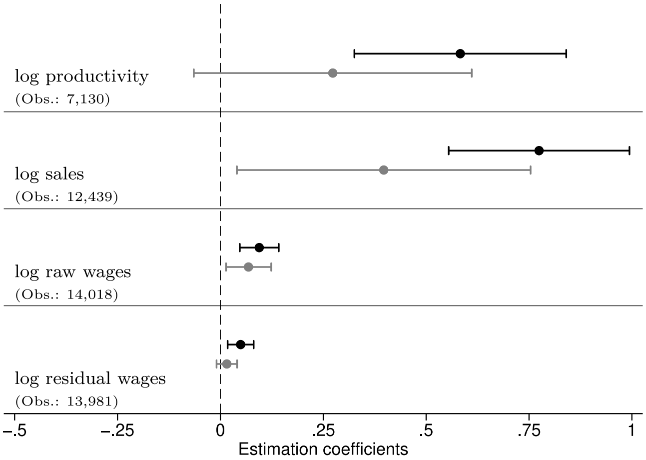

Fig. 2. Productivity, sales, and wage patterns. Notes: The graph displays estimation coefficients for infra-marginal (black) and marginal (grey) offshorer dummies on log sales, log productivity, log raw wages, and log residual wages. In all specifications, we estimate a constant, two-digit industry fixed effects, and a time dummy. Sample weights are used to make the establishment sample representative. Standard errors are clustered at the industry level and bounds for the 95 percent confidence intervals are reported.

where variable y_{vst} refers to productivity, sales, or wages, respectively, of establishment v in industry s at time t and *infra-marginal*$_{vst}$, *marginal*$_{vst}$ are our two offshorer dummies, whose values may change between 1999 and 2001 if an initially marginal offshorer becomes infra-marginal offshorer or if an initially infra-marginal non-offshorer becomes marginal offshorer in the second observation period. Moreover, γ_s are two-digit industry fixed effects and ζ_t is a time dummy to control for differences between the two observation years 1999 and 2001 that are common to all establishments. Finally, we denote the error term by ε_{vst} and cluster standard errors at the industry level. Fig. 2 summarises the estimation results.[11]

According to Fig. 2, offshoring producers have higher productivity, larger sales, and pay higher wages than the non-offshorers in the control group. Whereas this pattern is true for infra-marginal as well as marginal offshorers, we find significant differences of the two types of offshorers in the four performance measures. This is suggestive for selection of establishments into offshoring by productivity in our data. Due to their higher productivities, sales are larger for infra-marginal offshorers, inducing them to pay higher wages in the presence of rent sharing (see Helpman et al., 2010; Egger and Kreickemeier, 2012).

However, for job polarisation to materialise in response to offshoring, we need the additional requirement that marginal offshorers from the middle of the wage distribution decrease their domestic employment relative to non-offshorers and infra-marginal offshorers from the two tails of the wage distribution. To see whether this is the case in our data, we use further details on intermediate imports provided by the LIAB data and distinguish four categories regarding the use of imported intermediates: none, some, extensive, and predominant. We then employ this information to define a dummy variable *Δoffshoring*, which takes a value of one if the categorical variable for the use of foreign intermediates increases between two observation periods.[12]

It is notable that the dummy variable Δoffshoring can have a value of one for establishments not offshoring in the current observation period (featuring an infra-marginal offshorer dummy equal to zero). In this case, Δoffshoring has the same interpretation as the dummy variable for marginal offshorers in our previous analysis. It captures an increase of offshoring along the extensive margin. However, Δoffshoring can also be one for infra-marginal offshorers, implying that offshoring establishments further expand their offshoring activities along the intensive margin. To carefully distinguish the different channels through which offshoring affects domestic employment at the establishment level, we estimate a regression model of the following form:

$$\begin{aligned}\Delta empl_{vst} &= \beta_0 + \beta_1 infra\text{-}marginal_{vst} + \beta_2 \Delta offshoring_{vst} \\ &\quad + \beta_3 infra\text{-}marginal_{vst} \times \Delta offshoring_{vst} + \beta_4 routineness_{vst} + \gamma_s + \zeta_t + \varepsilon_{vst}, \end{aligned} \tag{2}$$

which explains log changes of employment in establishment v of sector s between the current period t and the subsequent observation period two years after, $\Delta empl_{vst}$, by a constant, a dummy variable for infra-marginal offshorers, *infra-marginal*$_{vst}$, a dummy variable for the expansion of offshoring, *Δoffshoring*$_{vst}$, an interaction term between *infra-marginal*$_{vst}$ and *Δoffshoring*$_{vst}$, and a routineness index for the tasks conducted by the workforce of an establishment, *routineness*$_{vst}$. We add the routineness index to ensure that our estimates of the offshoring dummies do not erroneously pick up job polarisation between occupations due to a loss of jobs intensive in the use of routine tasks (see Autor et al., 2003; Goos et al., 2014, for an argument along these lines). We also account for two-digit

[11] For Fig. 2, we consider the same establishment sample as in Panel B of Fig. 1, but now for two observation years. Missing values are possible because not all performance measures are observable for all establishments and because some of the establishments drop from our sample after 1999.

[12] Using the different categories of intermediate imports, we show in the Online Appendix that differences in the extent of offshoring between marginal and infra-marginal offshorers exist in our data only for 2001 but not for 1999.

Table 1
Employment effects of offshoring at the establishment level.

$\Delta \log employment$	FE	FE	FE	ML	ML
Infra-marginal offshorer	0.030	0.032	0.030	0.022	0.006
	(0.023)	(0.022)	(0.023)	(0.022)	(0.040)
Δoffshoring	−0.067°	−0.066°	−0.068°	−0.527**	−0.351°
	(0.038)	(0.037)	(0.038)	(0.080)	(0.208)
Infra-marginal offshorer	0.266**	0.263**	0.265**	0.287**	0.281
×Δ offshoring	(0.081)	(0.082)	(0.082)	(0.079)	(0.259)
Routineness		−0.068**	−0.032	−0.070**	−0.080**
		(0.018)	(0.029)	(0.028)	(0.027)
Δoffshoring (dummy)					
Industry exposure to offshoring				−0.350**	−0.312°
				(0.135)	(0.181)
Observations	10,906	10,906	10,891	10,891	10,891
ρ				0.508	0.283
Prob. > χ^2				0.000	0.142

Notes: The dependent variable is log employment change by establishment between two observation periods. Variable infra-marginal offshorer is a dummy variable equal to one for establishments that offshore in the current observation year. Δoffshoring is a dummy variable equal to one for establishments that expand their offshoring activity between the current and the next observation year. In Column 2, routineness is defined as a dummmy variable with a value equal to one if the establishment uses some routine tasks. In Columns 3 to 5 routineness captures the *share* of routine tasks conducted by the workforce. A constant and a time dummy are estimated but not reported. In Columns 1 to 3, we control for two-digit industry fixed effects. In Columns 4 and 5, we estimate a two-equation system with maximum likelihood, treating the Δoffshoring dummy as endogenous. In Column 5, we consider a more restrictive measure of offshoring. Sample weights are used to make the establishment sample representative. Standard errors are clustered at the industry level and reported in parentheses. Significance levels are indicated by ° $p < 0.1$, * $p < 0.05$, and ** $p < 0.01$, respectively.

industry fixed effects, γ_s, and add dummy ζ_t to control for common time-specific effects. Finally, we denote the error term by ε_{vst} and cluster standard errors at the industry level. Table 1 summarises our results.[13]

Column 1 reports the results from a parsimonious specification, in which we do not control for the routineness of tasks conducted by the workforce. We find that, compared to non-offshorers, marginal offshorers decrease their domestic workforce through an expansion of offshoring along the extensive margin. This is reflected by a negative coefficient of the Δoffshoring dummy variable. In contrast, infra-marginal offshorers increase their domestic workforce by expanding offshoring along the intensive margin. The intensive margin of offshoring can be determined by summing up the coefficients for Δoffshoring and its interaction term with the infra-marginal offshorer dummy. The combined effect adds to a direct positive though insignificant effect of the infra-marginal offshorer dummy. In Column 2, we add a binary routineness indicator which takes a value of one if some of the tasks conducted by the workforce are routine and zero otherwise. In Column 3, we measure routineness by the share of routine tasks conducted by the workforce. Controlling for routineness does not change our finding that expansion of offshoring along the extensive margin decreases employment of marginal offshorers, whereas employment changes of infra-marginal offshorers are positive but not statistically different from the control group of infra-marginal non-offshorers.

In Columns 4 and 5, we address potential endogeneity, which can materialise in our setting either due to omitted variables that are correlated with the log employment change and the expansion of offshoring, or due to measurement error, because a dummy variable does not capture all relevant facets of the expansion of offshoring along the intensive and the extensive margin. Whereas it is in general difficult (if not impossible) to predict the direction of the bias from omitted variables in a multivariate model (see Forbes, 2000), measurement error will lead to a downward bias of the endogenous regressor. Since the potentially endogenous regressor is binary, a linear first-stage projection can lead to weak identification (see Xu, 2021). To avoid this problem, we employ the endogenous treatment estimator put forward by Heckman (1976, 1978). We thereby explain the probability to expand offshoring by past industry exposure to offshoring as well as a time dummy and estimate the model using maximum likelihood. We proxy industry exposure to offshoring by sector-wide intermediate imports from China. To ensure exogeneity of Chinese imports we use their changes between 1996 and 1999 and rely on imports from China by *other* industrialised countries instead of Germany (see Autor et al., 2013; Dauth et al., 2014).[14]

From Column 4 of Table 1, we see that treating the decision to expand offshoring as endogenous leaves key results from our analysis qualitatively unchanged. However, the estimate of the offshoring dummy increases considerably in absolute terms, indicating that measurement error might be a source of endogeneity in our setting. Moreover, the total effect for infra-marginal offshorers, combining the two dummies for offshoring and their interaction term, becomes negative. But it remains statistically

[13] Due to the inclusion of additional controls, the number of observations in Table 1 is smaller than in Fig. 2.

[14] The binary treatment variable Δoffshoring is assumed to emanate from an unobservable latent variable Δoffshoring*, which is modelled as $\Delta offshoring^*_{vst} = \beta_1 \Delta imp_s + \zeta_t + \tilde{\varepsilon}_{vst}$, where Δimp_s are past changes of industry-wide imports from China, ζ_t is a time dummy, and $\tilde{\varepsilon}_{vst}$ is an error term. The binary treatment variable $\Delta offshoring_{vst}$ is equal to one if $\Delta offshoring^*_{vst} > 0$ and zero otherwise.

insignificant, implying that our estimates do not allow distinguishing the domestic employment changes of infra-marginal offshorers from those of infra-marginal non-offshorers. In Column 5, we rely on the same estimator as in Column 4 to address potential endogeneity of the offshoring dummy. However, we now use more restrictive definitions of the two offshoring dummies, associating offshoring with extensive or predominant use of imported intermediates. This leads to somewhat less precise estimates but does not change our results in a qualitative way. The Wald test reported at the bottom of Table 1 shows that for the two system estimators of our preferred specification in Column 4 the null hypothesis of independence of the error terms (and thus $\rho = 0$) is rejected at the five percent level. This indicates that treating the offshoring dummy as endogenous is justified.

The analysis in this section provides evidence for three important empirical patterns. First, there is job polarisation between establishments in Germany after the millennium. Second, our results speak for offshoring to be an important factor explaining this phenomenon. Third, we find that in response to decreasing offshoring costs marginal offshorers reduce domestic employment relative to both infra-marginal offshorers and the control group of non-offshorers. In the next four sections, we develop a theoretical model that can explain these empirical findings.

3. Partial equilibrium

Our model of North–South offshoring has as its key features a continuum of firms of differing productivity, a continuum of tasks within each of those firms, and rent sharing between firms and workers. In equilibrium, there is an endogenous separation between those firms that choose offshoring and those that do not, and also an endogenous choice of the offshoring firms as to where to produce each task. The analysis in this section is conducted for given values of general equilibrium variables that are treated parametrically by individual firms. Solving for those variables is deferred to a later stage.

3.1. Model setup

We first study an individual firm that performs a continuum of tasks $\eta \in [0,1]$. Following Acemoglu and Autor (2011) we assume a Cobb–Douglas technology that is symmetric across tasks. Output is given by

$$y = \varphi \exp\left\{ \int_0^1 \ln\left[l(\eta)^{\delta} \bar{a}(\eta) \right] d\eta \right\}, \tag{3}$$

where $l(\eta)$ is task-specific effective labour input, $\bar{a}(\eta)$ is a measure of task-level effective average labour productivity, which is a choice variable of the firm, as detailed below, and φ is a technology parameter that captures the firm's total labour productivity. Parameter $\delta \in (0,1)$ imposes decreasing returns to effective task-level employment and implies that labour quantity and labour quality enter task production asymmetrically.[15] We assume that performing tasks offshore involves variable costs of the iceberg type, and that these costs are task-specific and denoted by $T(\eta) > 1$. Hence, for tasks produced offshore, $T(\eta)$ units must be produced for one unit to enter domestic production. This requires hiring $T(\eta)^{1/\delta}$ labour units in the foreign country, given the task production technology in Eq. (3). We consider the following offshoring cost schedule, borrowed from Grossman and Rossi-Hansberg (2008):

$$T(\eta) = \left[\tau (1-\eta)^{-t} \right]^{\delta}, \tag{4}$$

with $\tau > 1$ and $t > 0$. The functional form in Eq. (4) implies that variable costs are increasing in η, τ^{δ} represents the variable offshoring cost for the task with the lowest such cost, and with the elasticity of $T(\eta)$ given by $t\delta\eta/(1-\eta)$, higher values of shape parameter t are associated with a more steeply increasing offshoring cost schedule.[16] Irrespective of the value of t offshoring the highest-η tasks is prohibitively expensive, and hence all firms produce at least some of their tasks at home. The firm's variable production costs can be written as

$$c_p = \int_0^1 T(\eta)^{\frac{I(\eta)}{\delta}} w(\eta) l(\eta) d\eta,$$

in which $w(\eta)$ denotes the wages that the firm pays to (foreign or domestic) workers performing task η, whereas $I(\eta) \in \{0,1\}$ is an indicator function that assumes a value of $I(\eta) = 1$ if task η is offshored and a value of $I(\eta) = 0$ otherwise.

Following Helpman et al. (2010), we assume that productivity a of an individual worker is match-specific, and Pareto distributed according to $B(a) = 1 - (a_{\min}/a)^{\beta}$, where $a_{\min} > 0$ and $\beta > 1$ are the location and shape parameter of this distribution, and Home and Foreign have the same distribution function. The firm can affect the productivity of its workforce by screening applicants and hiring selectively. Screening determines a threshold ability $\hat{a}(\eta)$ that allows to separate workers with labour productivity below this threshold, who are not employed, from workers with labour productivity above this threshold, who are. We denote by $h(\eta)$ the mass

[15] As pointed out by Helpman et al. (2010), we can think of the production function in Eq. (3) as capturing the time constraint of a manager who allocates a fixed amount of time symmetrically to all workers. Associating managerial time with a fixed factor input, the assumption of decreasing returns on task-level employment is well in line with rich evidence from production function estimation reporting output elasticities on labour input smaller than one (see Doraszelski and Jomandreu, 2013; Gandhi et al., 2020).

[16] Parameter δ is added in variable offshoring cost function for analytical convenience and it differentiates our offshoring costs from the original formulation in Grossman and Rossi-Hansberg (2008).

of workers entering the screening process. Naturally, tougher screening (a higher threshold ability level) for task η reduces the mass of workers employed in this task, $l(\eta)$, ceteris paribus:

$$l(\eta) = \left[\frac{a_{\min}}{\hat{a}(\eta)}\right]^{\beta} h(\eta). \tag{5}$$

The average (task-level) productivity of those workers that successfully pass the screening follows as $\bar{a}(\eta) = \hat{a}(\eta)[\beta/(\beta-1)]$.

Screening is costly to the firm, and for simplicity we assume that screening costs result from the use of business services that are produced in a perfectly competitive outside sector at a price $s > 0$ that is exogenous to the firm but endogenous in general equilibrium (see Section 4). The screening cost function c_s is increasing in the screening threshold $\hat{a}(\eta)$ but independent of the number of workers screened:

$$c_s = sc\frac{\hat{a}(\eta)^{\alpha}}{\alpha},$$

with constants $c > 0$ and $\alpha > 1$ governing the level of screening costs and the convexity of the screening cost function, respectively.

We envisage a labour market that is characterised by wage posting and directed search in the presence of matching frictions, as described in Rogerson et al. (2005). Firms post vacancies with corresponding wages for each task, and workers apply to the particular job that offers the highest expected return knowing that an application does not necessarily result in a successful match. Posting vacancies is costly to firms, and the associated hiring cost, also paid in units of business services at per-unit price s, is given by

$$c_h = sb\frac{\vartheta}{1-\vartheta}\left[\frac{h(\eta)}{z(\eta)}\right]^{\frac{1-\vartheta}{\vartheta}},$$

in which $b > 1$ and $\vartheta \in (0,1)$ are constants, $z(\eta)$ denotes the mass of applicants for task η, and therefore $h(\eta)/z(\eta)$ gives the task-specific rate at which applicants are matched with the firm.[17] Intuitively, hiring costs for each task are increasing in the matching rate, since the purchase of more business services is needed to reduce matching frictions and thereby increase the matching rate.

Firms do not benefit from posting wages higher than those necessary to fill their vacancies, and therefore they offer workers an expected return that exactly matches the workers' outside option, which in turn is the average labour income in the respective market. Denoting by $\tilde{w}$ and $\tilde{w}^*$ the average wage of employed production workers in the respective market, while u and u^* are the market-specific unemployment rates of production workers, the outside options are given by $(1-u)\tilde{w}$ at home and $(1-u^*)\tilde{w}^*$ abroad. Both variables are determined in general equilibrium and treated parametrically by both workers and firms. Workers' participation constraints for performing task η in a given firm at home and abroad, respectively, can therefore be written as

$$\frac{l(\eta)}{z(\eta)}w(\eta) = [(1-u)\tilde{w}]^{1-I(\eta)}[(1-u^*)\tilde{w}^*]^{I(\eta)}. \tag{6}$$

Since $l(\eta)$ denotes the number of workers actually employed after the screening process, $l(\eta)/z(\eta)$ is the probability of an applicant to actually be hired. Multiplying this probability with posted wage $w(\eta)$ gives the expected payoff from applying for task η.

The firm faces an iso-elastic firm-specific demand function $x = A_x p^{-\sigma}$, with $\sigma > 1$ as the constant price elasticity of demand, p as the price set by the firm for good x, and A_x as a demand shifter that is exogenous to the firm but endogenous in general equilibrium. A micro-foundation for this demand curve is given in Section 4. Imposing goods market equilibrium $y = x$, the revenue of the firm can be written as

$$r = A_x^{\frac{1}{\sigma}}\left[\varphi \exp\left\{\int_0^1 \ln\left[l(\eta)^{\delta}\bar{a}(\eta)\right] d\eta\right\}\right]^{\frac{\sigma-1}{\sigma}}.$$

The maximisation of profits can be represented as a three-stage problem. First, the firm decides upon market entry, and on whether or not to engage in offshoring at all. Second, if the firm chooses to engage in offshoring, it needs to decide which tasks to offshore and which tasks to keep onshore. Third, the firm posts vacancies with corresponding wage rates and screens and hires workers for performing all tasks needed to produce output y. We solve the maximisation problem through backward induction, and we start by deriving for an individual firm the solution to stages three and two of the profit maximisation problem. Only afterwards do we need to discuss specifics about the market entry mechanism and the assumed distribution of firm productivities in order to embed this solution into sectoral equilibrium.

3.2. Profit maximisation for an individual firm

The firm maximises operating profits $\pi \equiv r - c_h - c_s - c_p$ subject to the screening constraint Eq. (5) and the participation constraint Eq. (6). Thereby, its choice variables are, for each task, the wage rate $w(\eta)$, the mass of employed workers $l(\eta)$, and the screening

[17] Helpman et al. (2010) show that this relationship can be derived from a constant returns to scale Cobb–Douglas matching function and a cost of posting vacancies. In this case, parameter b is inversely related to the efficiency parameter of the matching technology, and a value larger than one is assumed to guarantee an interior solution with matching probabilities smaller than one. As pointed out by Helpman and Itskhoki (2009), the parameter constraint of $b > 1$ becomes obsolete in a dynamic matching framework.

threshold $\hat{a}(\eta)$. By substituting Eqs. (5) and (6) into the objective function, we can transform this constrained optimisation problem into the unconstrained (operating) profit maximisation problem

$$\begin{aligned}\max_{\{\hat{a}(\eta)\},\{w(\eta)\},\{l(\eta)\}} \quad & A_x^{\frac{1}{\sigma}}\left(\frac{\beta}{\beta-1}\varphi\exp\left\{\int_0^1 \ln\left[l(\eta)^{\delta}\hat{a}(\eta)\right]d\eta\right\}\right)^{\frac{\sigma-1}{\sigma}} \\ & -\int_0^1 sb\frac{\vartheta}{1-\vartheta}\left\{\frac{[(1-u)\tilde{w}]^{1-I(\eta)}[(1-u^*)\tilde{w}^*]^{I(\eta)}}{w(\eta)}\right\}^{\frac{1-\vartheta}{\vartheta}}\left[\frac{\hat{a}(\eta)}{a_{\min}}\right]^{\frac{\beta}{\vartheta}}T(\eta)^{\frac{I(\eta)}{\delta}}l(\eta)d\eta \\ & -\int_0^1 sc\frac{\hat{a}(\eta)^{\alpha}}{\alpha}d\eta-\int_0^1 w(\eta)T(\eta)^{\frac{I(\eta)}{\delta}}l(\eta)d\eta.\end{aligned} \tag{7}$$

We can rewrite the corresponding system of the three first order conditions with respect to $\hat{a}(\eta)$, $w(\eta)$ and $l(\eta)$ as

$$\hat{a}(\eta)=\left[\frac{\sigma-1}{\sigma}\frac{(1-\delta\beta)r}{sc}\right]^{\frac{1}{\alpha}}, \tag{8}$$

$$w(\eta)=\left\{[(1-u)\tilde{w}]^{1-I(\eta)}[(1-u^*)\tilde{w}^*]^{I(\eta)}\right\}^{1-\vartheta}(sb)^{\vartheta}\left[\frac{\hat{a}(\eta)}{a_{\min}}\right]^{\beta}, \tag{9}$$

and

$$T(\eta)^{\frac{I(\eta)}{\delta}}l(\eta)=\frac{\sigma-1}{\sigma}\delta\frac{r(1-\vartheta)}{(sb)^{\vartheta}\left\{[(1-u)\tilde{w}]^{1-I(\eta)}[(1-u^*)\tilde{w}^*]^{I(\eta)}\right\}^{1-\vartheta}}\left[\frac{a_{\min}}{\hat{a}(\eta)}\right]^{\beta}. \tag{10}$$

From Eq. (8), the firm chooses the same screening threshold $\hat{a}(\eta)=\hat{a}$ for all its tasks, independent of whether the tasks are performed at home and abroad. Furthermore, as in Helpman et al. (2010), the profit-maximising screening threshold is increasing in firm revenues. Since the screening threshold is not task specific, Eq. (9) shows that the firm posts the same wage for all tasks it performs at home, and also a common – potentially different – wage for all tasks it performs abroad. The ratio of the wage paid by a given firm to its foreign and domestic workers is given by $\omega^{1-\vartheta}$ with $\omega\equiv[(1-u^*)\tilde{w}^*]/[(1-u)\tilde{w}]$. Eq. (10) shows the analogous result for employment: the firm hires the same mass of workers for all domestic tasks, and also for all the tasks it performs abroad. The ratio of task-level employment abroad and at home is $\omega^{\vartheta-1}$. Since, as shown below, the foreign country has the lower average wage rate in general equilibrium, we have $\omega<1$ and therefore firms pay lower wages in their foreign location, and hire more workers for each task performed abroad than they do for their domestic tasks.

Two requirements must be fulfilled to make Eqs. (8) to (10) valid and empirically plausible interior solutions for the profit maximisation problem of firms. First, in order to ensure a solution with $\hat{a}>a_{\min}$, c must be sufficiently small, and in addition $\delta\beta<1$ has to hold. Second, in order for task-level employment to be larger in firms with higher revenues $\beta<\alpha$ has to hold.[18] Following Helpman et al. (2010), we assume that these parameter constraints are fulfilled throughout our analysis.

Computing operating profits, using the solutions in Eqs. (8) to (10), gives

$$\pi=\bar{\pi}_0 A_x^{\frac{\xi}{\sigma-1}}\left[\frac{s}{(1-u)\tilde{w}}\right]^{(1-\vartheta)\delta\xi}\left(\frac{1}{s}\right)^{\frac{\sigma\xi}{\sigma-1}-1}\left[\varphi\kappa(\hat{\eta})^{I}\right]^{\xi}, \tag{11}$$

with

$$\kappa(\hat{\eta})\equiv\exp\left\{\int_0^{\hat{\eta}}\ln\left[\frac{1}{\omega^{(1-\vartheta)\delta}T(\eta)}\right]d\eta\right\}, \tag{12}$$

task margin $\hat{\eta}$ separating tasks $\eta\le\hat{\eta}$ that are produced abroad from tasks $\eta>\hat{\eta}$ that are produced domestically, I as an indicator function to distinguish offshorers (with $I=1$) from non-offshorers (with $I=0$), and $\xi\equiv\alpha(\sigma-1)/\{\alpha\sigma-(\sigma-1)[1+\alpha\delta(1-\beta/\alpha)]\}>0$. The constant $\bar{\pi}_0$ is a composite of different model parameters that is of no further interest in the following.[19] It is straightforward to show that ξ, the elasticity of firm-level operating profits with respect to φ, is smaller than $\sigma-1$, the corresponding elasticity in the Melitz model with a perfectly competitive labour market. This is so since our framework, like (Helpman et al., 2010), features firm-level rent sharing, and thus wages that increase in firm productivity. This dampens the effect that a higher productivity has on firm profits. Eq. (11) gives operating profits of the firm as a function of model parameters, of general equilibrium variables A_x, s, $(1-u)\tilde{w}$ and ω, which are treated parametrically by the firm, and of choice variables of the firm, namely indicator variable I ("Does the firm offshore at all?") and $\hat{\eta}$ ("If the earlier answer is yes, which tasks does the firm offshore?").

The variable $\kappa(\hat{\eta})^{I}$ multiplies firm baseline productivity φ in Eq. (11), and it is a measure of the cost savings for all infra-marginal tasks put offshore, as a function of the offshoring task margin $\hat{\eta}$. For offshoring to be attractive for at least some firms in the presence

[18] We can see this by substituting for $\hat{a}$ in Eqs. (9) and (10), which yields the result that wages and employment are increasing in firm-level revenues with elasticities β/α and $1-\beta/\alpha$, respectively.

[19] We compute

$$\bar{\pi}_0=\frac{1}{\xi}\frac{\sigma-1}{\sigma}\left[\left(\frac{\sigma-1}{\sigma}\frac{1-\vartheta}{b^{\vartheta}}\delta a_{\min}^{\beta}\right)^{\delta}\frac{\beta}{\beta-1}\left(\frac{\sigma-1}{\sigma}\frac{1-\delta\beta}{c}\right)^{\frac{1-\delta\beta}{\alpha}}\right]^{\xi}.$$

of fixed offshoring costs, $\kappa(\hat{\eta})$ has to be larger than one, and we show below that in general equilibrium this is indeed the case. Since $\kappa(\hat{\eta})^I$ is equal to one in the absence of offshoring, $\kappa(\hat{\eta})-1$ is the percentage boost in effective firm-level productivity achieved by offshoring, in analogy to the productivity effect ascribed to offshoring in Grossman and Rossi-Hansberg (2008).

We now turn to the determination of task margin $\hat{\eta}$. From Eq. (11), it is implicitly given by $\kappa'(\hat{\eta})=0$, and the solution follows from Eq. (12) as $\omega^{(1-\vartheta)\delta}T(\hat{\eta})=1$. For the assumed functional form for $T(\eta)$, we hence compute

$$\hat{\eta} = 1 - \left(\tau\omega^{1-\vartheta}\right)^{\frac{1}{t}}. \tag{13}$$

The task margin is independent of firm characteristics and only depends on the ratio of average labour incomes of the two countries, which is determined in general equilibrium. Quite intuitively, a higher relative labour income abroad (higher ω) implies that offshoring firms move fewer tasks offshore. The productivity effect resulting from an optimally chosen task margin $\hat{\eta}$ follows directly as

$$\kappa(\hat{\eta}) = \left[(1-\hat{\eta})\exp(\hat{\eta})\right]^{-\delta t}. \tag{14}$$

It is easily checked that $\kappa(\hat{\eta})$ is increasing in $\hat{\eta}$, starting from $\kappa(0)=1$. Intuitively, this reflects the fact that for a firm that optimally moves a larger share of tasks abroad the productivity boost from offshoring is larger.

With neither $\hat{\eta}$ nor $\kappa(\hat{\eta})$ depending on firm characteristics, Eq. (11) shows that firm-level operating profits are fully determined by a firm's baseline productivity φ in combination with its offshoring status. In the following, we therefore distinguish firms solely by φ and by indices o and d for offshoring and domestic/non-offshoring producers, respectively.

3.3. Sectoral equilibrium

Stage one of the firm's profit maximisation problem consists of the decision whether to offshore at all, and this decision is linked to the question of market entry, which we model in analogy to Lucas (1978) as the outcome of an occupational choice decision. Specifically, we assume that each monopolistically competitive firm is run by a single entrepreneur who acts as an owner-manager, receiving the firm's operating profits net of fixed offshoring costs as residual claimant. Operating profits depend on the entrepreneurial ability of the owner-manager, which is equal to the productivity of the firm, φ. Entrepreneurial ability is Pareto distributed in the population according to distribution function $G(\varphi)=1-\varphi^{-k}$, with shape parameter $k>\max\{\xi,1\}$.[20]

Individuals can choose to be an entrepreneur, or they can work as production workers, with an expected income of $(1-u)\tilde{w}$, or they can be self-employed in the perfectly competitive outside sector, which produces (business) services that firms require as fixed inputs in addition to production labour. Labour is the only input in the outside sector, and due to a unitary labour input coefficient the wage in this sector equals the per-unit service fee s. Differences in ability φ only matter for the income of entrepreneurs, and agents choose the occupation yielding the highest expected income.

The (business) services produced in the outside sector are also used to cover the fixed cost of offshoring, with each offshoring firm requiring one unit of this input in order to engage in offshoring at all. We focus on an outcome in which only a subset of firms choose to offshore (the parameter constraint required for this outcome is introduced below), and therefore the marginal entrepreneur runs a non-offshoring (domestic) firm, whose productivity we denote by φ_d. Assuming that agents are risk-neutral and that the occupational choice is irreversible, for instance due to occupation-specific education, the indifference condition of the marginal firm is given by

$$\pi_d(\varphi_d) = (1-u)\,\tilde{w} = s, \tag{15}$$

and all agents with entrepreneurial abilities at least as high as φ_d become owner-manager of their own firm because, as outlined above, operating profits are increasing in φ. The second indifference condition requires the gain in operating profits for the marginal offshoring firm, whose productivity we denote by φ_o, to be equal to the offshoring fixed cost,

$$\pi_o(\varphi_o) - \pi_d(\varphi_o) = s, \tag{16}$$

implying that all firms with productivity at least as high as φ_o self-select into offshoring.[21] Together, Eqs. (11), (15) and (16) imply $\kappa(\hat{\eta})^{\xi}-1=(\varphi_o/\varphi_d)^{-\xi}$.[22] The share of offshoring firms follows directly as $\chi=[1-G(\varphi_o)]/[1-G(\varphi_d)]=(\kappa^{\xi}-1)^{k/\xi}$. Hence, plausibly, a larger productivity effect of offshoring is associated with a larger share of firms that choose offshore production for some of their tasks. Using the result for $\kappa(\hat{\eta})$ from Eq. (14) finally leads to

$$\chi(\hat{\eta}) = \left\{\left[(1-\hat{\eta})\exp(\hat{\eta})\right]^{-t\delta\xi} - 1\right\}^{\frac{k}{\xi}}, \tag{17}$$

[20] Parameter constraint $k>\max\{\xi,1\}$ ensures that, in equilibrium, the size distribution and the (baseline) productivity distribution of firms have finite means. This constraint is weaker than the one usually required to achieve finite means of the variables of interest under the assumption of Pareto distributed productivities, because the positive link between firm-level productivity and firm-level wages establishes $\xi<\sigma-1$ in our model.

[21] Due to a monotonic link between sales, wages, and productivities, firms are located at the same position in either of the three distributions. As a consequence of this, a selection of firms into offshoring based on productivities, as postulated by our model, implies differences in productivities, sales, and wages of infra-marginal offshorers, marginal offshorers, and infra-marginal non-offshorers that are largely consistent with the empirical evidence reported in Fig. 2.

[22] Setting Eqs. (15) and (16) equal and dividing both sides by $\pi_d(\varphi_o)$ gives $\pi_o(\varphi_o)/\pi_d(\varphi_o)-1=\pi_d(\varphi_d)/\pi_d(\varphi_o)$. From Eq. (11), the first profit ratio equals κ^{ξ} and the second profit ratio equals $(\varphi_d/\varphi_o)^{\xi}$, which gives the result in the text.

with $d\chi/d\hat{\eta} > 0$. Hence, in an equilibrium in which more firms choose offshoring it is also true that each offshoring firm performs a larger share of its production tasks abroad. The maximum share of tasks offshored, denoted by $\hat{\eta}_{int}$, is then implicitly given by $\chi(\hat{\eta}_{int}) = 1$, which can be rewritten to give $[(1-\hat{\eta}_{int})\exp(\hat{\eta}_{int})]^{-t\delta\xi} = 2$. It is easily checked that the solution for $\hat{\eta}_{int}$ lies strictly inside the unit interval, i.e. all firms keep some of their production onshore. This is of course a consequence of the assumed offshoring technology introduced in Eq. (4).

At this stage, Eq. (17) gives a relationship between two endogenous variables that are either the choice variable of each single firm ($\hat{\eta}$) or the combined result of profit maximising choices of all firms (χ). Both variables depend on a single general equilibrium variable, namely the ratio of labour incomes between the two countries, ω, as we have shown in Eq. (13). We now embed our model into a general equilibrium framework to find a solution for ω, s and A_x, which are the economy-wide variables that matter for our analysis.

4. General equilibrium

Since offshoring in our model is low-cost seeking, it is one-directional and (for identical technologies) requires asymmetric wages. The simplest way to capture this asymmetry is to assume that entrepreneurial abilities are only available in one country, which we associate with an industrialised North (index free), so that all firms are headquartered there. Since firms only use local service input, agents in the other country, which we associate with a developing South (indicated by an asterisk), have only one career path namely the employment as production workers in Northern firms that have chosen to offshore. In this interpretation, the South serves as a labour reservoir and must have lower wages than the North in equilibrium, because firms choose to offshore only if this leads to a reduction in their production costs. Population size in the two countries is given by N and N^*, respectively, and each agent is endowed with one unit of labour. Trade is balanced, with North importing the task output produced in the South in exchange for the consumption good.

The key condition that we introduce to solve our model in general equilibrium is the labour market constraint, linking the extent of offshoring to the relative average wage of production workers between the two countries. The logic underlying the labour market constraint is straightforward: in the absence of offshoring, the relative wage of Southern production workers is equal to zero, and more offshoring increases relative demand for Southern production workers, bidding up their relative wage. In order to formalise this idea, we introduce γ to denote the endogenous share of the aggregate income of production workers that accrues to the South. Thereby the supply of Southern production labour is exogenous and equal to N^*, while in the North the supply of production labour L is endogenous and smaller than N due to the occupational choice mechanism described above. With the residual share $1-\gamma$ of aggregate production worker income accruing to the North, we have $(1-u)\tilde{w}L/(1-\gamma) = (1-u^*)\tilde{w}^*N^*/\gamma$, which implies

$$\omega = \frac{\gamma}{1-\gamma}\frac{L}{N^*}. \tag{18}$$

We show in Appendix A.1 that γ can be written as:

$$\gamma = \frac{\hat{\eta}\chi(1+\chi^{-\xi/k})}{1+\chi}, \tag{19}$$

and it is easily checked that $\partial\gamma/\partial\chi$ and $\partial\gamma/\partial\hat{\eta}$ are both positive, establishing $\gamma < \hat{\eta}_{int}$ in any interior equilibrium with $\chi < 1$. Using Eq. (17) we can write $\gamma = \gamma[\hat{\eta}, \chi(\hat{\eta})]$, with $d\gamma/d\hat{\eta} > 0$.

It follows from Eqs. (8) to (10) that wage bill and operating profits are constant shares $\rho_w \equiv (\sigma-1)(1-\vartheta)\delta/\sigma$ and $\rho_\pi \equiv (\sigma-1)/(\sigma\xi)$, respectively, of firm revenues. Using this result, the indifference condition in Eq. (15) and North's resource constraint, we show in Appendix A.2 that it is possible to write L as a function of N and γ. Using this expression to substitute for L in Eq. (18), we get the labour market constraint (LMC)

$$\omega = \frac{\rho_w\gamma}{1-\rho_w\gamma-\rho_\pi\xi/k}\frac{N}{N^*}, \qquad \text{with} \qquad d\omega/d\hat{\eta} > 0, \tag{20}$$

which gives combinations between relative population size N/N^*, ω and (via its influence on γ) $\hat{\eta}$ that are compatible with labour market equilibrium in both markets. Intuitively, for a constant relative population size more offshoring along the extensive task margin (which is accompanied by more offshoring along the extensive firm margin) drives up the relative average wage in the destination country. The labour market constraint can be combined with the condition for the optimally chosen extensive task margin (ETM) in Eq. (13) to determine the two endogenous variables ω and $\hat{\eta}$.

The equilibrium is illustrated in Fig. 3. Existence of an interior equilibrium requires that the two loci ETM and LMC intersect at $\hat{\eta} \le \hat{\eta}_{int}$.[23] Intuitively, an interior equilibrium requires the South to be sufficiently small, measured by its relative population size N^*/N. In this case, the wage differential between the two markets narrows quickly as more and more tasks are moved offshore, and hence the least productive firm always finds it advantageous to produce all tasks at home, thereby avoiding the fixed (and variable) costs of offshoring. The interior equilibrium illustrated in Fig. 3 gives joint implicit solutions for $\hat{\eta}$ and ω. It is clear that the value

[23] According to Eqs. (13) and (20), a unique intersection point exists under the sufficient parameter constraint

$$\frac{\rho_w\hat{\eta}_{int}}{1-\rho_w\hat{\eta}_{int}-\rho_\pi\xi/k}\frac{N}{N^*} > (1-\hat{\eta}_{int})^{\frac{t}{1-\vartheta}},$$

assumed in the following. To make sure that our model features an interior solution with $\chi < 1$ for all possible $\tau \ge 1$, the parameter constraint has been derived for $\tau = 1$. The condition is sufficient for an interior solution because if LMC lies above ETM for $\tau = 1$ in Fig. 3, it also lies above ETM for all $\tau > 1$ (see below).

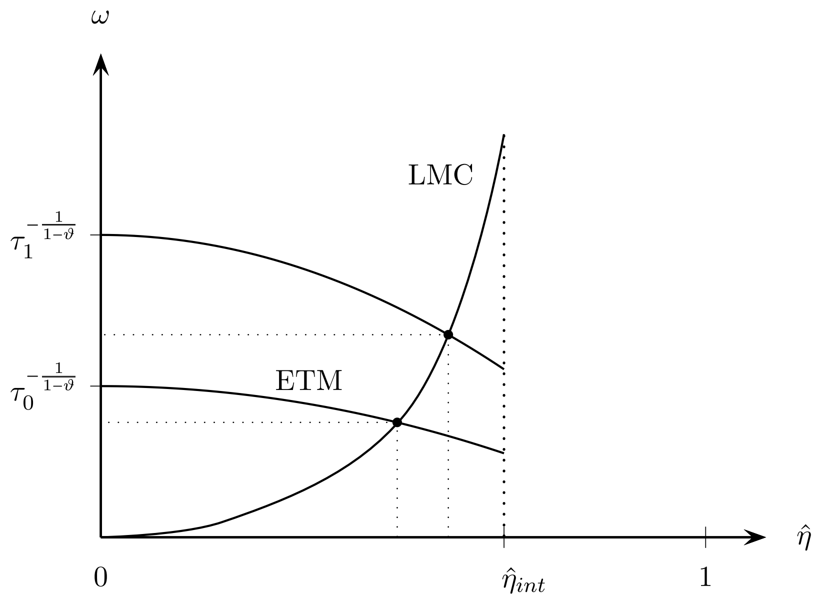

Fig. 3. General equilibrium.

for ω realised in general equilibrium is strictly smaller than one, since offshoring is costly and access to low-wage production labour is the only offshoring incentive in our model.

Using Eqs. (13) and (20) we can formally describe equilibrium by the implicit function

$$F(\hat{\eta},\tau) \equiv \frac{\rho_w \gamma}{1-\rho_w\gamma-\rho_\pi \xi/k}\,\frac{N}{N^*} - \left[\frac{(1-\hat{\eta})^t}{\tau}\right]^{\frac{1}{1-\vartheta}} = 0, \tag{21}$$

which gives combinations between $\hat{\eta}$ and offshoring cost τ that lead to a value for ω that clears the labour market. By implicitly differentiating Eq. (21) we get $d\hat{\eta}/d\tau < 0$, and therefore a reduction in variable offshoring costs – intuitively – leads to more offshoring. The effects of a reduction in τ can be readily illustrated in Fig. 3. A decline in τ from τ_0 to τ_1 implies that the ETM locus shifts upward: a given share of offshored tasks $\hat{\eta}$ is compatible with a higher average labour income in the South, ceteris paribus, if the offshoring cost is lower. The labour market constraint is unaffected, and therefore in equilibrium a reduction in the variable cost of offshoring leads to a higher relative average income for Southern workers, and to more tasks being offshored. So, while we cannot explicitly solve for the levels of ω and $\hat{\eta}$ in closed form, we know from our implicit solution that there is a negative monotonic relationship between τ and $\hat{\eta}$, and also a negative monotonic relationship between τ and ω.[24]

We now turn to deriving a solution for the yet undetermined general equilibrium variables, market size A_x and service fee s. We associate firms with intermediate goods producers whose output is assembled in a competitive industry to a homogeneous consumption good, using a CES technology à la (Ethier, 1982): $Y = \left[\int_{v\in V} x(v)^{(\sigma-1)/\sigma}\right]^{\sigma/(\sigma-1)}$, where V denotes the set of available intermediates. We choose the consumption good as the ***numéraire***, and therefore the market size variable A_x is equal to Y, the total ***volume*** and ***value*** of the consumption good produced in the North. In Appendix A.3, we show that it is possible in our model to express Y as a function of model parameters and $\hat{\eta}$ only, and that the same is true for the service fee s, which is determined in our model by an *ex ante* indifference of workers between choosing employment in a service sector that provides the fixed input to production or choosing employment as production worker. With $\hat{\eta}$ implicitly solved for, this completes the discussion of the general equilibrium in our model.

5. Offshoring and firm-level employment

In this section, we use our general equilibrium model of North–South offshoring to show how selection into offshoring can give rise to job polarisation between firms. To this end, we first derive the employment distribution across firms implied by our theory. We then show how this distribution is affected by changes in the offshoring cost.

[24] Our solution concept for the general equilibrium and its graphical representation in Fig. 3 bear a close resemblance to a diagram developed by Dornbusch et al. (1977) in their seminal paper on the Ricardian model with a continuum of goods. In their model, the two endogenous variables in the general equilibrium are the relative wage rate between the countries, and the marginal good separating the goods produced in Home from those produced in Foreign. The two loci determining the equilibrium values of these variables are a labour market equilibrium condition (more goods produced in Home means a higher relative wage in Home) and a production allocation locus (for given Ricardian production technologies, a lower relative wage in Home implies that a larger number of goods is produced there), whose close relationship to the labour market constraint and the external task margin in our model are obvious from Fig. 3.

To compute the employment distribution, we must distinguish between offshoring and non-offshoring firms. For non-offshorers, the domestic wage bill is simply a fraction ρ_w of revenues, whereas for offshorers the domestic wage bill is a fraction $(1-\hat{\eta})\rho_w$ of revenues, with a fraction $\hat{\eta}\rho_w$ of revenues going to foreign workers. We show in Appendix A.4 that log domestic employment of non-offshoring firms can be written as a function of firm productivity φ and the share of offshore tasks $\hat{\eta}$:

$$\ln l_d(\varphi,\hat{\eta}) = \ln\left(\frac{\rho_w}{\rho_\pi \bar{w}_0}\right) + \left(1-\frac{\beta}{\alpha}\right)\xi \ln\varphi + \mu(\hat{\eta}), \tag{22}$$

with

$$\mu(\hat{\eta}) \equiv -\left(1-\frac{\beta}{\alpha}\right)\xi \ln\varphi_d(\hat{\eta}), \tag{23}$$

where $(1-\beta/\alpha)\xi$ is the elasticity of firm level domestic employment with respect to firm productivity, and $\bar{w}_0 > 1$ is a constant. The term $\mu(\hat{\eta})$ summarises general equilibrium influences that affect the employment in all non-offshoring firms equally.[25] For offshoring firms, employment is given by

$$\ln l_o(\varphi,\hat{\eta}) = \ln l_d(\varphi,\hat{\eta}) + \lambda(\hat{\eta}), \tag{24}$$

with

$$\lambda(\hat{\eta}) \equiv \ln(1-\hat{\eta}) + \left(1-\frac{\beta}{\alpha}\right)\xi \ln\left\{\left[(1-\hat{\eta})\exp(\hat{\eta})\right]^{-\delta t}\right\}. \tag{25}$$

Eqs. (24) and (25) show the two counteracting influences that switching into offshoring mode has on firm-level employment in our model: it reduces the share of tasks that are performed domestically, thereby reducing domestic employment (this is the first term in Eq. (25)), and it increases effective productivity, thereby allowing the offshoring firm to increase output, which increases employment in those tasks that are kept onshore (this is the second term in Eq. (25)). As in Grossman and Rossi-Hansberg (2008), the productivity effect is larger when cost savings are realised for more tasks, and therefore it is increasing in $\hat{\eta}$. In addition, a high value of t, the shape parameter of the offshoring cost schedule, is conducive to the productivity effect since it implies large cost savings on infra-marginal tasks. We assume in the following that t exceeds the threshold value $\underline{t}$, defined in Appendix A.6, in order to ensure a sufficiently large productivity effect.

Now, consider a marginal increase in $\hat{\eta}$, starting from *initial* $\hat{\eta}_i$, that is brought about by a reduction in variable offshoring costs τ. Regarding the effect of this reduction on firm-level domestic employment, three groups of firms need to be distinguished:

1. *Infra-marginal offshorers* have overseas production prior to the reduction in offshoring costs. For them, the domestic employment effect is given by $\partial \ln l_o(\varphi,\hat{\eta}_i)/\partial\hat{\eta} = \lambda'(\hat{\eta}_i) + \mu'(\hat{\eta}_i)$.
2. *Marginal offshorers* start offshoring as a result of the reduction in offshoring costs. They move all tasks up to the marginal task abroad, and for them, the domestic employment effect is given by $\ln l_o(\varphi,\hat{\eta}_i) - \ln l_d(\varphi,\hat{\eta}_i) + \partial \ln l_o(\varphi,\hat{\eta}_i)/\partial\hat{\eta} = \lambda(\hat{\eta}_i) + \lambda'(\hat{\eta}_i) + \mu'(\hat{\eta}_i)$.
3. *Infra-marginal non-offshorers* have no offshoring activities, neither before nor after the reduction in offshoring costs. For them, the firm-level employment effect is given by $\partial \ln l_d(\varphi,\hat{\eta}_i)/\partial\hat{\eta} = \mu'(\hat{\eta}_i)$.

Conceptually, it is helpful to think of $\lambda'(\hat{\eta})$ (for infra-marginal offshoring firms) and $\lambda(\hat{\eta}) + \lambda'(\hat{\eta})$ (for marginal offshoring firms) as the direct effect of offshoring activity on those firms that are engaged in it, and of $\mu'(\hat{\eta})$ as an indirect effect on all firms that is induced by the direct effect. It is therefore clear that the λ- and μ-effects are linked in general equilibrium. To help intuition, we illustrate the direct and indirect effects of offshoring in Fig. 4.

For infra-marginal offshoring firms, the direct effect of an increase in $\hat{\eta}$ on domestic employment is given by $\lambda'(\hat{\eta})$. It is easily checked that $\lambda'(0) = -1$, and we show in Appendix A.6 that $\lambda'(\hat{\eta})$ is increasing in $\hat{\eta}$. Then, at low $\hat{\eta}$ (high offshoring costs) the direct effect of an increase in $\hat{\eta}$ on domestic employment is negative, and it becomes less negative as a larger fraction of tasks is moved offshore. $\lambda'(\hat{\eta})$ turns positive at some $\hat{\eta} < \hat{\eta}_{int}$, from which point onwards a further reduction in variable offshoring costs increases domestic employment in infra-marginal offshoring firms via the direct effect.

Turning to the direct effect for marginal offshoring firms, we again consider an increase in $\hat{\eta}$, starting from $\hat{\eta}_i$. Marginal offshorers move abroad in one go all tasks $\eta \le \hat{\eta}_i$, and therefore the direct firm-level employment effect for those firms is given by $\lambda(\hat{\eta}) + \lambda'(\hat{\eta})$. Fig. 4 depicts $\lambda(\hat{\eta})$ as the integral of $\lambda'(\hat{\eta})$. As the figure illustrates, for values of $\hat{\eta}$ above – but sufficiently close to – the value implicitly defined by $\lambda'(\hat{\eta}) = 0$ an increase in $\hat{\eta}$ is associated with a direct domestic employment effect that is positive for infra-marginal offshorers ($\lambda'(\hat{\eta})$ is positive) but negative for marginal offshorers ($\lambda(\hat{\eta}) + \lambda'(\hat{\eta})$ is negative).[26]

To see how direct domestic employment changes in offshoring firms influence $\mu'(\hat{\eta})$, the indirect effect common to all firms, we aggregate domestic employment over all offshoring and non-offshoring firms to arrive at aggregate employment of production labour $(1-u)L$. Total differentiation with respect to $\hat{\eta}$ delivers the following relationship between the direct and indirect firm-level employment effects of offshoring in semi-elasticity form:

$$\varepsilon_l = \varepsilon_\mu + \varepsilon_\lambda^i + \varepsilon_\lambda^m, \tag{26}$$

[25] Eqs. (22) and (23) show that employment in the marginal firm is equal to $\rho_w/(\rho_\pi \bar{w}_0)$, a constant.

[26] The latter effect is novel relative to Grossman and Rossi-Hansberg (2008): Since in their model the firm population is homogeneous (firms are atomistic), the extensive firm margin is absent, and hence, using our terminology, marginal offshorers do not exist in their model.

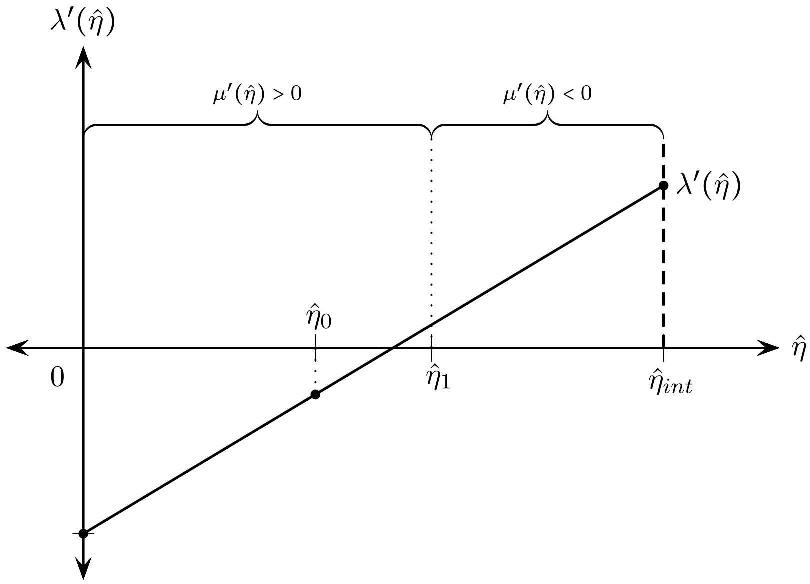

Fig. 4. Direct and indirect employment effects of offshoring.

where $\varepsilon_l \equiv d \ln[(1-u)L]/d\hat\eta$ gives the total (relative) employment change in production, ε_μ captures the employment change due to the indirect employment effect common to all firms and due to entry or exit of firms at the bottom of the productivity distribution, ε^i_λ captures the employment change due to the direct employment effect for infra-marginal offshoring firms, and ε^m_λ captures the employment change due to the direct employment effect for marginal offshoring firms (see Appendix A.5 for derivation details).

The fundamental logic behind the indirect effect is evident from Eq. (26): For a given aggregate employment in production ($\varepsilon_l = 0$), a net employment loss in offshoring firms ($\varepsilon^i_\lambda + \varepsilon^m_\lambda < 0$) tends to put downward pressure on the wages of production workers. In response to lower wages all firms (including new entrants at the lower end of the productivity distribution) increase their domestic employment ($\varepsilon_\mu > 0$). Although ε_l is not zero in our model, this fundamental logic still holds, and $\mu'(\hat\eta)$ is positive for small values of $\hat\eta$ and becomes negative for high values of $\hat\eta$. Accordingly, we show in Appendix A.6 that the following proposition holds:

Proposition 1. *The effect of a reduction in variable offshoring costs on domestic firm-level employment depends on the share of offshore tasks $\hat\eta$.*

(i) For $\hat\eta$ below the threshold $\hat\eta_0$, implicitly defined by $\lambda'(\hat\eta_0)+\mu'(\hat\eta_0) = 0$, a reduction in offshoring costs leads to lower domestic employment in both types of offshoring firms, and to higher domestic employment of infra-marginal non-offshorers.
(ii) For $\hat\eta \in (\hat\eta_0, \hat\eta_1)$, with $\hat\eta_1$ implicitly defined by $\mu'(\hat\eta_1) = 0$, a reduction in offshoring costs leads to higher domestic employment in infra-marginal offshoring firms and in infra-marginal non-offshoring firms.

Proof. See Appendix A.6.

Since firm-level wage rates are increasing in firm productivity and firms select into offshoring activity based on productivity, infra-marginal non-offshorers in our model are low-wage firms, marginal offshorers are medium-wage firms, and infra-marginal offshorers are high-wage firms. Therefore, Proposition 1 implies that for $\hat\eta \in (\hat\eta_0, \hat\eta_1)$ our model features an increase in employment in both low-wage and high-wage firms. Furthermore, inspection of Fig. 4 shows that $\lambda(\hat\eta) + \lambda'(\hat\eta) + \mu'(\hat\eta) < 0$ for at least the lower part of this interval, which guarantees an employment decline in medium wage firms and therefore job polarisation along the firm dimension.[27] By contrast, at low levels of integration more offshoring reallocates workers away from high-wage firms and towards low-wage firms so that job polarisation cannot materialise. This result is in line with the evidence reported in Section 2, with job

[27] Notably, no such result is possible in a model using the canonical two-stage entry mechanism of Melitz (2003). Intuitively, in a model of that type the free entry condition implies that better offshoring opportunities, which increase the ex ante expected profits of firms in the market and therefore make entry more attractive, must go hand in hand with a lower probability of a successful productivity draw, which makes entry less attractive. In the model, this implies a higher domestic productivity cutoff, which invariably leads to lower employment in firms just above this cutoff. We formally derive this result in the context of our offshoring model in an Online Appendix that is available upon request.

polarisation between establishments for a period in which about 22 percent of German producers are classified as infra-marginal offshorers (see Appendix B.1).[28]

6. Offshoring and unemployment

Production workers in our model can be unemployed for two reasons, as in Helpman et al. (2010): either they are not entering screening in the firm in which they seek employment, or they enter screening but the match-specific productivity is found to be below the productivity threshold set by the firm. As we have noted above, the wage by the marginal firm is linked to the unemployment rate of production workers by $w_d(\varphi_d) = \bar{w}_0(1-u)\tilde{w}$. Solving for u gives

$$u = 1 - \frac{1}{\bar{w}_0}\frac{w_d(\varphi_d)}{\tilde{w}}. \tag{27}$$

From Eq. (27) we see that a monotonic link exists in our model between unemployment rate u and the extent of wage dispersion, measured by the ratio of the average wage of domestic workers and the wage paid by the marginal firm, $\tilde{w}/w_d(\varphi_d)$. Intuitively, higher wage dispersion reflects a stronger labour market distortion from rent sharing, which results in a higher rate of unemployment among production workers.

Due to this result, we can learn the effect of offshoring in our model on u from the effect it has on the extent of wage dispersion. As discussed in the previous section, more offshoring destroys high-wage jobs in the North if $\hat{\eta}$ is low. This leads to less wage dispersion, ceteris paribus, which is conducive, from Eq. (27), to a lower unemployment rate u. By contrast, high-wage jobs in infra-marginal offshoring firms are created in response to lower offshoring costs if $\hat{\eta}$ is high, which leads to more wage dispersion, ceteris paribus. We show in Appendix A.7 that there exists a unique threshold $\underline{\hat{\eta}}$, such that an increase in $\hat{\eta}$ decreases (increases) the unemployment rate of production workers if $\hat{\eta} < (>) \underline{\hat{\eta}}$.

The economy-wide unemployment rate for the North is given by $U \equiv uL/N$, where L is endogenous due to the occupational choice mechanism discussed above. We have shown in Appendix A.2 that the number of production workers falls monotonically in γ, and by implication in $\hat{\eta}$. With u decreasing in $\hat{\eta}$ as well if $\hat{\eta} < \underline{\hat{\eta}}$, we know that unemployment U definitely falls in this case. However, a further increase of $\hat{\eta}$ from an already high level is accompanied by an increase in u and therefore the effect on economy-wide unemployment U is not clear a priori in this case. We show in Appendix A.8 that depending on parameter values indeed either effect can be dominant.

7. A quantitative analysis

Around the millennium, China's accession to the WTO and the upcoming Eastern Enlargement of the European Union has induced a strong increase in German offshoring to these markets. Using input–output linkages from the World Input Output Database (WIOD, Release 2013), we compute for Germany an overall increase in imported intermediates relative to value added of about 47 percent between 1999 and 2007. However, the value of intermediate imports from China and Eastern Europe increased relative to value added by more than 126 percent and 88 percent, respectively, over the same time period. We use our model to study the employment effects of this exceptional period of economic integration at the firm and the aggregate level with the aim to show job polarisation between German establishments, complementing the evidence reported in Section 2.

For our quantitative analysis, we use the LIAB data on German establishments outlined in Section 2. This dataset provides information on 7593 producers for the baseline year 1999, for which we estimate the two composite parameters $\theta_1 \equiv \xi/k$ and $\theta_2 \equiv \beta/\alpha$ using structural equations on revenues and wages derived from our model. Moreover, we use economy-wide variables from WIOD, the OECD, and the World Bank to calibrate additional model parameters. Thereby, we set composite parameter $\theta_3 \equiv \beta\delta$ and individual parameters t, ϑ, σ to make the outcome of our model consistent with key aggregates for Germany in 1999 under the parameter constraints imposed by our model. In the next subsection, we explain in detail how the parameters of our model are determined.

7.1. Calibration of parameters and model fit

To estimate composite parameter θ_1, we make use of the important insight that under the assumption of Pareto distributed productivities, *average* sales of offshoring firms with a productivity higher than φ_p, denoted by $\tilde{r}_p$, can be expressed as a function of the percentile position of the firm with productivity φ_p in the sales distribution of all offshoring producers (see Arkolakis, 2010; Egger et al., 2020, for a similar conclusion in the context of exporting). Relating the resulting expression to the respective average for the marginal offshoring producer with productivity φ_o, denoted by $\tilde{r}_o$, we can formulate the following linear estimation equation (in log notation)

$$\log\left(\tilde{r}_p\right) - \log\left(\tilde{r}_o\right) = -\theta_1 \log\left(rank_p\right) + \varepsilon_p, \tag{28}$$

[28] It is possible (though not guaranteed) that in addition to these two regimes there exists – at high levels of international integration – a third regime, in which a reduction in offshoring costs leads to lower domestic employment of infra-marginal non-offshorers and higher domestic employment of both types of offshorers.

where $rank_p$ denotes the rank of firm p in the sales distribution of offshoring firms and ε_p is an error term. We group the 1785 offshoring producers with sales information observed in LIAB for the year 1999 into percentiles and estimate Eq. (28) for the resulting observations using standard OLS. Using sample weights from LIAB to make the establishment sample representative, we estimate a parameter value of $\theta_1 = 0.832$ with standard error 0.008.[29]

Moreover, we make use of Eqs. (8) and (9) to express log average wages of offshoring producer v as a linear function of its log revenues and formulate the following estimation equation:

$$\log w_v = \Theta + \theta_2 \log r_v + \varepsilon_v,$$

where Θ is a composite parameter that is of no further interest for our analysis and ε_v is an error term. Relying on OLS and using sample weights, we estimate a parameter value of $\theta_2 = 0.034$ with standard error 0.008.[30]

At the aggregate level, we use information on imports, input use, final consumption and labour compensation from WIOD's (Release 2013) Input–Output Tables and Socio Economic Accounts.[31] Moreover, we use information on the economy-wide number of employees and the labour force from OECD statistics and the World Development Indicators, respectively. Thereby, we associate the total German use of inputs from foreign suppliers with the *cif* value of intermediate imports and divide them by the *fob* value of foreign inputs sold to Germany to obtain a measure of total variable offshoring costs. This offshoring cost measure corresponds to

$$TC \equiv \frac{\hat{\eta}}{\int_0^{\hat{\eta}} T(\eta)^{-1} d\eta} = \frac{\hat{\eta}\tau^{\delta}(1+t\delta)}{1-(1-\hat{\eta})^{1+t\delta}} \tag{29}$$

in our model. For the baseline year 1999, we observe $TC_{1999} = 1.347$.

In a further step, we compute total labour income of production workers for Germany using information on total labour compensation. Since in our model only part of the domestic labour force is employed as production workers, we multiply total German labour compensation by the fraction of the total number of German employees in the total labour force. In line with our theoretical model, we associate foreign labour income in the production of inputs with the *cif* value of intermediate imports. This allows us to compute for the baseline year a foreign labour income share of $\gamma_{1999} = 0.305$, according to Eq. (18). Making use of the observed fraction of offshoring producers in LIAB in 1999, which amounts to 0.215, and considering the estimate of θ_1 reported above, we can further compute the fraction of tasks put offshore by offshoring firms in the baseline year. According to Eq. (19), this gives $\hat{\eta}_{1999} = 0.375$. In a final step, we divide the total of domestic and foreign labour income by the value of final goods consumption to obtain a theory-consistent measure of ρ_w. Relying on data for the baseline year 1999, we compute a value of $\rho_w = 0.856$.

We now combine the data moments from above with our estimates of composite parameters θ_1, θ_2 in two structural equations from the theoretical model to pin down parameters t and $\theta_3 = \beta\delta$. Thereby, we proceed as follows. We set $\sigma = 8$, which is in the range of estimates of the elasticity of substitution reported by previous research (see Feenstra, 1994; Broda and Weinstein, 2006). This allows us to express δ as a function of ϑ. Using the definition of ρ_w, we obtain $\delta(\vartheta) = [\sigma/(\sigma-1)][\rho_w/(1-\vartheta)]$. Moreover, we can express $\delta\xi$ as a function of θ_3 and ϑ according to

$$\delta\xi = \left[\frac{1-\vartheta}{\rho_w} - \frac{\theta_2}{\theta_3} - (1-\theta_2)\right]^{-1} \equiv \Xi(\theta_3\vartheta).$$

We then make use of Eqs. (17), (20), (21), and (29) to write down a system of two implicit equations in four unknowns:

$$\begin{aligned} \Gamma_1(t,\theta_3,\vartheta) &\equiv [(1-\hat{\eta}_{1999})\exp(\hat{\eta}_{1999})]^{-t*\Xi(\theta_3\vartheta)} - \left(1+\chi_{1999}^{\theta_1}\right) = 0, \\ \Gamma_2(t,\vartheta,\omega_{1999}) &\equiv \left\{\frac{\hat{\eta}_{1999}(1-\hat{\eta}_{1999})^{t\delta(\vartheta)}[1+t\delta(\vartheta)]}{[1-(1-\hat{\eta})^{1+t\delta(\vartheta)}]TC_{1999}}\right\}^{\frac{1}{\delta(1-\vartheta)}} - \omega_{1999} = 0. \end{aligned} \tag{30}$$

Equation system (30) describes possible combinations of the two model parameters t, θ_3 as a function of parameter ϑ, endogenous variable ω_{1999}, and observables. The two parameter constraints $0 < \delta(\vartheta) < 1$ and $\delta(\vartheta) < \theta_3 < 1$,[32] which are imposed by our model, confine the range of permissible values of ϑ and ω_{1999}. For instance, condition $0 < \delta(\vartheta) < 1$ reduces the range of permissible values of ϑ to the interval $[0, 0.021]$. We take the arithmetic mean of this interval and set $\vartheta = 0.011$. Moreover, combining constraint $\delta(\vartheta) < \theta_3 < 1$ with equation system (30) limits for any given level of ϑ the range of permissible levels of ω_{1999}. For $\vartheta = 0.011$ the respective interval for ω_{1999} shows a length of less than 0.001 and we take the arithmetic mean of 0.665 as our preferred value for ω_{1999}. With this parametrisation, we then solve for $\theta_3 = 0.995$ and $t = 0.401$.[33]

Table 2 summarises the calibrated parameters of our model. There, we also report standard errors for the four parameter values $\theta_1, \theta_2, \theta_3$, and t, which are computed relying on 1000 bootstrapped establishment samples from our LIAB data.

29 Since some of the establishment observations have fairly high weights, the number of distinct percentile observations is less than 100.

30 Note that our estimation relies on residual wages that are obtained when eliminating wage variation due to worker heterogeneity absent from our model. For a discussion on how residual wages are determined in the establishment panel, see Section 2 and Appendix B.1.

31 In its 2013 Release, WIOD covers 35 sectors and 40 individual countries, namely Australia, Austria, Belgium Bulgaria, Brazil, Canada, China, Cyprus, Czechia, Denmark, Estland, Finland, France, Germany, Great Britain, Greece, Hungary, Indonesia, India, Ireland, Italy, Japan, Rep. of Korea, Latvia, Lithuania, Luxembourg, Mexico, Malta, Netherlands, Poland, Portugal, Romania, Russia, Slovakia, Slovenia, Spain, Sweden, Turkey, Taiwan, USA, as well as a no further specified Rest of the World (see Timmer et al., 2015, for an overview).

32 The second constraint combines the formal requirements of $\beta\delta < 1$ and $\beta > 1$.

33 In the Online Appendix, we discuss robustness of our results for alternative parameter choices. In particular, we consider lower values of σ and alternative values of ϑ from its admissible interval.

Table 2
Summary of model parameters.

Variable	Coefficient	S.E.
θ_1	0.832	(0.002)
θ_2	0.034	(0.000)
θ_3	0.995	(0.000)
ι	0.401	(0.001)
ϑ	0.011	
σ	8	
ρ_w	0.856	

Notes: Parameters ϑ, σ, and ρ_w are held constant over the bootstrapped establishment samples.

Table 3
Model fit.

	Share of offshoring firms χ_t			Rel. labour income ω_t		
	1999	2001	2003	1999	2001	2003
Computed	0.215	0.255	0.256	0.665	0.692	0.685
Observed	0.215	0.194	0.216	0.676	0.701	0.678

To evaluate the aptitude of our calibrated model to fit non-targeted moments from plant-level and aggregate data, we predict the share of offshoring firms χ_t and the relative foreign labour income per worker ω_t by the observed realisations of the foreign labour share γ_t and the observed offshoring costs TC_t. We then contrast the thus computed values with the observed values for the three years with offshoring information in LIAB: 1999, 2001, and 2003. Thereby, we first combine Eqs. (17) and (19) to determine theory-consistent values of $\hat{\eta}_t, \chi_t$. In a second step, we use the theory-consistent values of $\hat{\eta}_t$ in Eq. (29) to derive year-specific levels of the offshoring cost parameter, τ_t, from observed levels of offshoring costs TC_t. We finally use the thus determined levels of $\hat{\eta}_t$ and τ_t in Eqs. (20) and (21) to compute theory-consistent values of ω_t. We show the predicted values of χ_t and ω_t in the first row of Table 3.

In the second row, we report the empirical counterparts of χ_t and ω_t from our data. To obtain an empirical measure of ω_t, we proceed as follows. We compute labour income per worker for each country in our dataset as the ratio between total labour compensation and the labour force. We then determine *foreign* labour income per worker as an import-weighted average of Germany's trading partners and divide the resulting value by labour income per worker for Germany to obtain an empirical proxy for ω_t.[34] Overall, Table 3 shows a good fit between the theory-predicted and the observed data moments, in particular with respect to the relative labour income variable ω_t. However, our model predicts higher shares of offshoring firms than those observed in 2001 and 2003.[35] The observed drop in the share of offshoring firms in 2001 may be the result of the burst of the dot-com bubble in 2000 or it may reflect anticipation effects of German labour market reforms after the millennium, which could have reduced the attractiveness of offshoring for reasons that are outside of our model.

7.2. Quantitative model predictions

We use our calibrated model to evaluate how the expansion of German offshoring around the millennium has changed domestic employment levels along the wage distribution. Relying on the sample weights in LIAB, the 7593 establishments in our sample represent 17,828,130 full-time employees in 1999, who are subject to social security payments. Compared with the 29.903 million full-time employees reported by the OECD for this period, the coverage of our establishment sample seems fairly high. Therefore, we refrain from further adjustments and use the weighted establishment data for projecting the employment effects of the observed increase in offshoring between 1999 and 2007. Over this period, we find evidence for job polarisation between firms in LIAB and for a considerable drop of offshoring cost TC_t from 1.347 to 1.250 in WIOD (Release 2013). In our quantitative analysis, we study the employment effects of the observed increase in endogenous γ_t from $\gamma_{1999} = 0.305$ to $\gamma_{2007} = 0.413$. Holding all other model parameters in Table 2 constant, this corresponds to an exogenous decline in the offshoring cost parameter from $\tau_{1999} = 1.240$ to $\tau_{2007} = 1.172$ in our model.

To determine the employment changes brought about by the observed increase in the relative foreign labour income share γ_t, we group firms into wage ventiles based on their observed wage payments in 1999. The initial employment shares of the different wage ventiles in 1999 and the corresponding employment changes for the observed increase in γ_t are displayed in the first and the second column of Table 4.[36] For computing the employment changes, we assume that the German labour force (and thus N

[34] In the specification reported in Table 2, we have set relative foreign labour income per capita for non-OECD countries lacking information on labour compensation or labour force, which are the Rest of the World and Taiwan, to the observed minimum in our data. Treating the relative foreign labour income of these countries as missing values would somewhat increase the observed level of ω_t.

[35] In 1999 the predicted value of χ_t coincides with the observed value because this data moment has been used as input in the calibration of model parameters.

[36] To determine the employment changes in Table 4, we first multiply the initial employment shares in the first column with the total number of employees reported above. This gives the initial employment levels at the ventile level. We then compute for each ventile the relative change of employment (with derivation details shown in an Online Appendix) and multiply the resulting expressions with the initial employment levels.

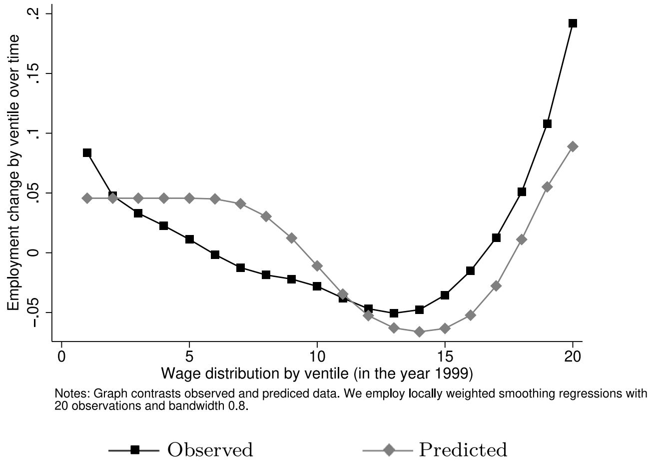

Fig. 5. Observed and predicted job polarisation between establishments from 1999 to 2007.

Table 4
Employment change 1999–2007 due to $\Delta\gamma_t$.

vent.	Share 1999	Baseline	Counterfactual 1	Counterfactual 2
1	0.007	367	454	520
2	0.013	674	835	957
3	0.018	961	1,190	1,363
4	0.017	877	1,086	1,244
5	0.027	1,384	1,715	1,965
6	0.027	1,423	1,763	2,020
7	0.030	1,571	1,946	2,230
8	0.038	1,957	2,424	2,778
9	0.035	1,842	2,282	2,615
10	0.043	2,251	2,789	3,195
11	0.061	3,157	3,910	4,480
12	0.063	−104,624	−6,548	4,674
13	0.075	−267,472	−268,397	−172,190
14	0.081	−290,094	−291,097	−292,110
15	0.077	−274,238	−275,186	−276,144
16	0.089	−225,481	−226,661	−227,851
17	0.092	14,510	13,071	11,618
18	0.075	11,769	10,602	9,423
19	0.104	16,283	14,667	13,036
20	0.028	4,329	3,899	3,466

Notes: In Baseline, we report employment changes predicted by our model for observed changes in γ_t. In Counterfactual 1, we keep imports of China at their 1999 level to construct counterfactual changes in γ_t, while in Counterfactual 2, we keep the imports of the EU accession countries constant at their 1999 level to construct counterfactual changes in γ_t.

in our model) stays constant over the considered time period. The reported results confirm the conjecture from Section 2 that the increase of German offshoring has led to job polarisation after the millennium. Whereas the positive employment effects for infra-marginal non-offshorers and infra-marginal offshorers are relatively small, the negative employment effects for the group of marginal offshoring firms are sizable and lead to an overall decline in the economy-wide employment of production workers $(1-u)L$.

To assess how well our model captures job polarisation between establishments over the ventiles reported in Fig. 1, we compute log employment changes at the wage group level and normalise the respective changes by eliminating the average change over all wage ventiles. The log employment changes predicted by our model are reported in Fig. 5, with the observed employment changes from Panel B of Fig. 1 added to facilitate the comparison. From this comparison, we conclude that our model does a fairly good job in explaining the job polarisation between establishments over the period 1999 to 2007.

The employment changes over all wage ventiles reported in Table 4 add up to a total loss of more than 1.099 million production jobs between 1999 and 2007. However, this strong negative employment effect is partly compensated by new entry of firms at the bottom of the productivity distribution, and we find that after accounting for this extensive-margin effect on net only 308,810 production jobs are lost due to the increase in offshoring between 1999 and 2007.

We contrast the results from Column 2 with two counterfactual experiments in order to analyse to what extent the particularly strong increase in offshoring to China and Central and Eastern European countries joining the EU after the millennium are responsible for the observed pattern of employment effects. In the first counterfactual experiment reported in Column 3, we keep German intermediate imports from China constant at their level in 1999. We see that this somewhat reduces the dispersion in the employment effects over the various wage ventiles but leaves the main finding that increased offshoring has led to job polarisation in the firm dimension unchanged. Without the expansion of offshoring to China 29,222 production jobs would have been secured according to our model. Finally, in Column 4 we report the employment changes for a counterfactual situation in which intermediate imports from Central and Eastern European countries joining the EU after the millennium would have stayed at their 1999 level. Again, this leaves the main insights about the role of offshoring for the job polarisation in Germany unchanged, while the reduced employment effects would have secured 58,459 production jobs according to our model.

8. Conclusion

Using linked employer–employee data for Germany, we show evidence for job polarisation between firms. Our evidence further suggests that offshoring has been a driving force behind this phenomenon. To rationalise our empirical findings, we propose an offshoring model that is rooted in two well-documented empirical facts that are also in line with our data: the selection of more productive firms into offshoring; and the positive link between firm performance measures and wage payments.

In our framework the decrease in variable offshoring costs implies that more firms choose offshoring, and that they choose it for a wider range of tasks. At moderate levels of offshoring costs this leads to job polarisation in the source country of offshoring, since the following three things happen: marginal offshorers, which have intermediate productivity, reduce the number of domestic jobs, while infra-marginal offshorers with high productivity as well as infra-marginal non-offshorers with low productivity increase the number of domestic jobs. At very high offshoring costs a reduction in those costs induces infra-marginal offshorers to reduce rather than increase the number of domestic jobs, and hence our model allows us to describe the conditions under which job polarisation between firms can be expected to occur.

Wage differences between firms in our model are the result of a labour market distortion from rent sharing that also leads to involuntary unemployment among production workers, and we show that changes in offshoring costs lead to non-monotonic effects on the rate of involuntary unemployment of production workers in the source country of offshoring. Accounting for the endogenous adjustment in the supply of production workers due to an occupational choice mechanism, we also show that lower offshoring costs lead to lower economy-wide unemployment when offshoring costs are high, whereas the opposite can happen when offshoring costs are already low. To round off our analysis we calibrate key model parameters relying on establishment-level and economy-wide data for Germany. The calibrated model confirms a pattern of job polarisation between firms after the millennium, and it shows that the negative domestic employment effect in marginal offshoring firms dominates the positive domestic employment effects in all other firms, amounting to an aggregate loss of more than 300,000 production jobs between 1999 and 2007.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Theoretical appendix

A.1. Derivation of Eq. (19)

The global wage bill is the aggregate labour income of production workers in the North and the South. Because firm-level wage bills are proportional to firm-level operating profits the global labour income of production workers is proportional to global operating profits

$$(1-u)L\tilde{w} + (1-u^*)N^*\tilde{w}^* = N\frac{\rho_w}{\rho_\pi}\left[\int_{\varphi_d}^{\varphi_o}\pi_d(\varphi)dG(\varphi) + \int_{\varphi_o}^{\infty}\pi_o(\varphi)dG(\varphi)\right].$$

Making use of $\pi_o(\varphi_o)/\pi_d(\varphi_o) = \kappa^{\xi}$ and $\pi_d(\varphi_o)/\pi_d(\varphi_d) = \chi^{-\xi/k}$ from the main text, we can compute

$$(1-u)L\tilde{w} + (1-u^*)N^*\tilde{w}^* = M\frac{\rho_w}{\rho_\pi}\frac{k}{k-\xi}(1+\chi)\pi_d(\varphi_d). \tag{A.1}$$

In a similar vein, we can compute the wage bill accruing to domestic workers, according to

$$\begin{aligned}(1-u)L\tilde{w} &= N\frac{\rho_w}{\rho_\pi}\left[\int_{\varphi_d}^{\varphi_o}\pi_d(\varphi)dG(\varphi) + (1-\hat{\eta})\int_{\varphi_o}^{\infty}\pi_o(\varphi)dG(\varphi)\right]\\ &= M\frac{\rho_w}{\rho_\pi}\frac{k}{k-\xi}\left[1+(1-\hat{\eta})\chi - \hat{\eta}\chi^{\frac{k-\xi}{k}}\right]\pi_d(\varphi_d).\end{aligned} \tag{A.2}$$

Dividing Eq. (A.2) by Eq. (A.1) and subtracting the resulting expression from one establishes γ in Eq. (19) as the endogenous share of the aggregate income of production workers that accrues to the South. This completes the proof.

A.2. Derivation of Eq. (20)

Combining Eqs. (19) and (A.2) gives

$$(1-u)L\tilde{w} = M\frac{\rho_w}{\rho_\pi}\frac{k}{k-\xi}(1+\chi)(1-\gamma)\pi_d(\varphi_d), \tag{A.3}$$

which can be further simplified by considering $\pi_d(\varphi_d) = (1-u)\tilde{w}$ from the indifference condition in Eq. (15). Since each firm spends a constant fraction $1-\rho_\pi-\rho_w$ of its revenues on hiring and screening, we can express the resource constraint in the North as

$$N = (1-\rho_\pi-\rho_w)M\frac{k}{k-\xi}(1+\chi)\frac{r_d(\varphi_d)}{s} + M(1+\chi) + L, \tag{A.4}$$

which can be further simplified into

$$N = \frac{k}{k-\xi}\frac{1-\rho_\pi\xi/k-\rho_w}{\rho_\pi}(1+\chi)M + L, \tag{A.5}$$

by considering $r_d(\varphi_d)/s = 1/\rho_\pi$ from Eq. (15). Eqs. (A.3) and (A.5) can be used to solve for

$$L = \frac{\rho_w(1-\gamma)}{1-\rho_w\gamma-\rho_\pi\xi/k}N, \tag{A.6}$$

with $dL/d\gamma < 0$ due to $\rho_w < 1-\rho_\pi$. Eq. (20) can be obtained from substituting the above expression into Eq. (18). This completes the proof.

A.3. Expressing total income Y and the mass of firms M as a functions of $\hat{\eta}$

We know that the link between aggregate income and the total income of domestic production labour is given by $(1-\gamma)\rho_w Y = (1-u)\tilde{w}L$. Using indifference condition $(1-u)\tilde{w} = \pi_d(\varphi_d)$, we can write

$$Y = \frac{\pi_d(\varphi_d)L}{(1-\gamma)\rho_w}. \tag{A.7}$$

Evaluating Eq. (11) for the marginal firm moreover yields

$$\pi_d(\varphi_d) = \bar{\pi}_0 Y^{\frac{\xi}{\sigma-1}}\pi_d(\varphi_d)^{1-\frac{\sigma}{\sigma-1}\xi}\varphi_d^{\xi}. \tag{A.8}$$

The system of Eqs. (A.7) and (A.8) can be solved for Y as a function of φ_d, which leaves us with the task of expressing φ_d in terms of $\hat{\eta}$. To this end, we first use the result that with Pareto distributed entrepreneurial abilities the share of entrepreneurs in the population is given by $M/N = 1-G(\varphi_d) = \varphi_d^{-k}$. To determine M/N, we can combine Eqs. (A.5) and (A.6) and obtain

$$\frac{M}{N} = \frac{\rho_\pi(k-\xi)/k}{(1+\chi)(1-\rho_\pi\xi/k-\gamma\rho_w)}, \tag{A.9}$$

with χ and γ expressed as functions of $\hat{\eta}$ in Eqs. (17) and (19), respectively. This completes the proof.

A.4. Solutions for Eqs. (22) and (24) in terms of $\hat{\eta}$

Constant markup pricing implies $w_d(\varphi)l_d(\varphi) = (\rho_w/\rho_\pi)\pi_d(\varphi)$ and $w_o(\varphi)l_o(\varphi) = (1-\hat{\eta})(\rho_w/\rho_\pi)\pi_o(\varphi)$. Noting that $l_d(\varphi)$ and $l_o(\varphi)/(1-\hat{\eta})$ give the respective employment levels per task domestically produced by non-offshoring and offshoring firms, respectively, it follows from the first-order conditions in Eqs. (8) and (9), using $\pi_j(\varphi) = \rho_\pi r_j(\varphi)$, $\rho_w = (1-\vartheta)(\sigma-1)\delta/\sigma$, and $(1-u)\tilde{w} = s$, that

$$w_j(\varphi) = \bar{w}_0\pi_j(\varphi)^{\frac{\beta}{\alpha}}\left[(1-u)\tilde{w}\right]^{1-\frac{\beta}{\alpha}}, \qquad \text{with} \qquad \bar{w}_0 \equiv b^{\vartheta}\left(\frac{\sigma-1}{\sigma}\frac{1-\delta\beta}{\rho_\pi c}\right)^{\frac{\beta}{\alpha}}\left(\frac{1}{a_{min}}\right)^{\beta} > 1. \tag{A.10}$$

Combining $w_d(\varphi)l_d(\varphi) = [\rho_w/\rho_\pi]\pi_d(\varphi)$ with Eq. (A.10), we compute

$$\frac{l_d(\varphi)}{l_d(\varphi_d)} = \frac{\pi_d(\varphi)/w_d(\varphi)}{\pi_d(\varphi_d)/w_d(\varphi_d)} = \left[\frac{\pi_d(\varphi)}{\pi_d(\varphi_d)}\right]^{1-\frac{\beta}{\alpha}}.$$

Substituting $\pi_d(\varphi)/\pi_d(\varphi_d) = (\varphi/\varphi_d)^{\xi}$ and $l_d(\varphi_d) = \rho_w/\rho_\pi\bar{w}_0$ before taking logs leads directly to Eq. (22), with $\mu(\hat{\eta})$ given by Eq. (23). We now use $M/N = \varphi_d^{-k}$, substitute for M/N from Eq. (A.9), take logs, and substitute for γ from Eq. (19) to obtain

$$\mu(\hat{\eta}) = -\left(1-\frac{\beta}{\alpha}\right)\frac{\xi}{k}\left(\ln\left\{\left(1-\rho_\pi\frac{\xi}{k}\right)[1+\chi(\hat{\eta})] - \rho_w\hat{\eta}\chi(\hat{\eta})\left[1+\chi(\hat{\eta})^{-\frac{\xi}{k}}\right]\right\} + \ln\left[\frac{k}{\rho_\pi(k-\xi)}\right]\right)$$

as the explicit solution for $\mu(\hat{\eta})$ in terms of $\hat{\eta}$. Turning to Eq. (24), we use the result that under constant mark-up pricing the domestic employment of non-offshoring and offshoring producers can be expressed as functions of their operating profits:

$$l_d(\varphi) = \frac{\rho_w}{\rho_\pi}\frac{\pi_d(\varphi)}{w_d(\varphi)} \qquad \text{and} \qquad l_o(\varphi) = (1-\hat{\eta})\frac{\rho_w}{\rho_\pi}\frac{\pi_o(\varphi)}{w_o(\varphi)},$$

in which $1-\hat{\eta}$ denotes the range of domestically produced tasks in offshoring firms. Accounting for Eq. (A.10), we can solve for firm-level employment of offshoring firms (in logs) in Eq. (24), with $\lambda(\hat{\eta})$ given by Eq. (25). Substituting Eq. (14) for $\kappa(\hat{\eta})$, we can express $\lambda(\hat{\eta})$ in terms of $\hat{\eta}$ as follows

$$\lambda(\hat{\eta}) = \ln l_o(\varphi) - \ln l_d(\varphi) = \left[1 - t\left(1-\frac{\beta}{\alpha}\right)\delta\xi\right]\ln(1-\hat{\eta}) - t\left(1-\frac{\beta}{\alpha}\right)\delta\xi\hat{\eta}. \tag{A.11}$$

This completes the proof.

A.5. Aggregate employment of production labour

Aggregating domestic firm-level employment over all producers gives

$$(1-u)L = N\int_{\varphi_d}^{\varphi_o} l_d(\varphi)dG(\varphi) + N\int_{\varphi_d}^{\varphi_o} l_o(\varphi)dG(\varphi). \tag{A.12}$$

Substituting $l_d(\varphi) = (\varphi/\varphi_d)^{(1-\beta/\alpha)\xi} l_d(\varphi_d)$ from Eq. (22) and $l_o(\varphi) = (1-\hat{\eta})\kappa(\hat{\eta})^{(1-\beta/\alpha)\xi} l_d(\varphi)$ from Eq. (24), we can compute

$$(1-u)L = M l_d(\varphi_d)\varepsilon(\hat{\eta})\frac{k}{k-(1-\beta/\alpha)\xi}, \tag{A.13}$$

with $\varepsilon(\hat{\eta}) \equiv 1 + \chi(\hat{\eta})^{1-(1-\beta/\alpha)\xi/k}\{\exp[\lambda(\hat{\eta})]-1\}$, in which we have used $M = [1-G(\varphi_d)]N$, $\chi = [1-G(\varphi_o)]/[1-G(\varphi_d)] = (\varphi_o/\varphi_d)^{-k}$, and the definition of $\lambda(\hat{\eta})$ from Eq. (25) to replace $\kappa(\hat{\eta})$. Using $l_d(\varphi_d) = \rho_w/\rho_\pi\bar{w}_0$ to replace $l_d(\varphi_d)$ and $M = [1-G(\varphi_d)]N = \varphi_d^{-k}N$ in combination with the definition of $\mu(\hat{\eta})$ from Eq. (23) to replace φ_d^{-k}, we finally establish

$$(1-u)L = N\frac{\rho_w}{\bar{w}_0}\frac{k-\xi}{k-(1-\beta/\alpha)\xi}\exp\left[\mu(\hat{\eta})\frac{k}{(1-\beta/\alpha)\xi}\right]\left[1+\chi(\hat{\eta})^{\frac{k-(1-\beta/\alpha)\xi}{k}}\{\exp[\lambda(\hat{\eta})]-1\}\right].$$

Taking logs and (totally) differentiating the resulting expression with respect to $\hat{\eta}$ gives Eq. (26), with $\varepsilon_\mu \equiv \mu'(\hat{\eta})k/[(1-\beta/\alpha)\xi]$, $\varepsilon_\lambda^i \equiv \lambda'(\hat{\eta})\text{sh}_o$, and $\varepsilon_\lambda^m \equiv [\chi'(\hat{\eta})/\chi(\hat{\eta})]\{1-\exp[-\lambda(\hat{\eta})]\}[1-(1-\beta/\alpha)\xi/k]\text{sh}_o$, in which

$$\text{sh}_o \equiv \frac{\chi(\hat{\eta})^{\frac{k-(1-\beta/\alpha)\xi}{k}}\exp[\lambda(\hat{\eta})]}{1+\chi(\hat{\eta})^{\frac{k-(1-\beta/\alpha)\xi}{k}}\{\exp[\lambda(\hat{\eta})]-1\}} \tag{A.14}$$

denotes the fraction of aggregate domestic employment in offshoring firms.

A.6. Proof of Proposition 1

The proof of Proposition 1 is complex, which is why we organise it in four steps, which jointly establish Proposition 1. Thereby, we characterise step-by-step the two curves and the critical values of $\hat{\eta}$ shown in Fig. 4.

Step 1 — Properties of $\lambda(\hat{\eta})$

Differentiating $\lambda(\hat{\eta})$, we can show that there exists a unique $\hat{\eta}_{tm} = 1/\zeta$, with $\zeta \equiv t(1-\beta/\alpha)\delta\xi$, such that $\lambda'(\hat{\eta}) >,=,< 0$ if $\hat{\eta} >,=,< \hat{\eta}_{tm}$. Then, $\hat{\eta}_{tm} < 1$ requires $\zeta > 1$. However, this is not sufficient for $\hat{\eta}_{tm} < \hat{\eta}_{int}$. From Eqs. (17) and (25), we can infer that $\hat{\eta}_{tm} = \hat{\eta}_{int}$ is reached if

$$\Gamma(\zeta) = -\frac{1}{1-\beta/\alpha}\left[\zeta\ln\left(\frac{\zeta-1}{\zeta}\right)+1\right] - \ln 2 = 0. \tag{A.15}$$

Since $\lim_{\zeta\to 1}\Gamma(\zeta) = \infty$, $\lim_{\zeta\to\infty}\Gamma(\zeta) = -\ln 2$ and $\Gamma'(\zeta) < 0$, we know that $\Gamma(\zeta) = 0$ has a unique solution in ζ and, in extension, also in t, which we denote by t_1. Finally, $\hat{\eta}_{tm} < \hat{\eta}_{int}$ requires $\Gamma(\zeta) < 0$ and thus $t > t_1$, which is assumed from now on.

Step 2 — Properties of $\mu(\hat{\eta})$ and characterisation of $\hat{\eta}_1$

From Eq. (17) we can infer that

$$\chi'(\hat{\eta}) = t\delta k\chi(\hat{\eta})^{\frac{k-\xi}{k}}\left[1+\chi(\hat{\eta})^{\frac{\xi}{k}}\right]\frac{\hat{\eta}}{1-\hat{\eta}}. \tag{A.16}$$

Differentiation of $\mu(\hat{\eta})$ then gives

$$\mu'(\hat{\eta}) = -\left(1-\frac{\beta}{\alpha}\right)\frac{\xi}{k}\frac{\chi'(\hat{\eta})f(\hat{\eta})}{(1-\rho_\pi\xi/k)[1+\chi(\hat{\eta})]-\rho_w\hat{\eta}\chi(\hat{\eta})[1+\chi(\hat{\eta})^{-\xi/k}]}, \tag{A.17}$$

with

$$f(\hat{\eta}) \equiv 1-\rho_\pi\frac{\xi}{k}-\rho_w+\rho_w\left[1-\hat{\eta}-\frac{1}{t\delta k}\frac{1-\hat{\eta}}{\hat{\eta}}-\frac{k-\xi}{k}\hat{\eta}\chi(\hat{\eta})^{-\frac{\xi}{k}}\right]. \tag{A.18}$$

Since $\chi'(\hat{\eta}) > 0$ holds for all positive values of $\hat{\eta}$, it is immediate that $\mu'(\hat{\eta}) >,=,< 0$ if $0 >,=,< f(\hat{\eta})$. From $\lim_{\hat{\eta}\to 0} f(\hat{\eta}) = -\infty$, we can thus conclude that $\mu(\hat{\eta})$ increases at low levels of $\hat{\eta}$. As a consequence, we either have $\mu'(\hat{\eta}) > 0$ for all possible $\hat{\eta}$ or $\mu'(\hat{\eta}) = 0$ at some $\hat{\eta} \in (0,1)$. In the latter case, $\mu(\hat{\eta})$ has an interior extremum, and we show in the following that if an interior extremum exists, it is unique and, in view of $\mu'(0) = 0$, a maximum.[37] This is equivalent to showing that $f(\hat{\eta}) = 0$ has a unique interior solution, provided that it has a solution at all.

Differentiation of $f(\hat{\eta})$ gives

$$f'(\hat{\eta}) = -\frac{\rho_w}{1-\hat{\eta}}\left[1-\hat{\eta}-\frac{1}{t\delta k}\frac{1-\hat{\eta}}{\hat{\eta}}-\frac{k-\xi}{k}\hat{\eta}\chi(\hat{\eta})^{-\frac{\xi}{k}}-\frac{1}{t\delta k}\left(\frac{1-\hat{\eta}}{\hat{\eta}}\right)^2+\frac{k-\xi}{k}\chi^{-\frac{\xi}{k}}g(\hat{\eta})\right], \tag{A.19}$$

with $g(\hat{\eta}) \equiv 1 - t\delta\xi\hat{\eta}^2\chi(\hat{\eta})^{-\xi/k}[1+\chi(\hat{\eta})^{\xi/k}]$, which in view of Eq. (17) can be rewritten as

$$g(\hat{\eta}) = 1 - t\delta\xi\frac{\hat{\eta}^2}{1-[(1-\hat{\eta})\exp(\hat{\eta})]^{t\delta\xi}}. \tag{A.20}$$

Evaluated at $f(\hat{\eta}) = 0$, we find that the first three terms in the bracket expression add up to $[f(\hat{\eta}) - 1 + \rho_\xi\xi/k - \rho_w]/\rho_w = -(1+\rho_\xi\xi/k-\rho_w)/\rho_w < 0$. Thus, $g(\hat{\eta}) \le 0$ is sufficient for an extremum of $\mu(\hat{\eta})$ to be a maximum and, if $g(\hat{\eta}) \le 0$ holds for all possible $\hat{\eta}$, this maximum must be unique. Making use of $g_0(\hat{\eta}) \equiv [(1-\hat{\eta})\exp(\hat{\eta})]^{t\delta\xi}$, with $g_0(0) = 1$, $g_0(1) = 0$, and $g_0'(\hat{\eta}) = -t\delta\xi g_0(\hat{\eta})\hat{\eta}/(1-\hat{\eta})$, we compute

$$g'(\hat{\eta}) = -t\delta\xi\frac{\hat{\eta}}{1-g_0(\hat{\eta})}\left[2-t\delta\xi\frac{g_0(\hat{\eta})}{1-g_0(\hat{\eta})}\frac{\hat{\eta}^2}{1-\hat{\eta}}\right],$$

$$g''(\hat{\eta})\Big|_{g'(\hat{\eta})=0} = t\delta\xi\frac{g_0(\hat{\eta})}{1-g_0(\hat{\eta})}\left(\frac{\hat{\eta}}{1-\hat{\eta}}\right)^2\frac{g(\hat{\eta})+1-\hat{\eta}}{1-g_0(\hat{\eta})},$$

which imply that if $g(\hat{\eta})$ has an extremum with $g(\hat{\eta}) > 0$, this extremum must be a minimum. Because $g(\hat{\eta})$ is a continuous function, it takes negative values for all permissible levels of $\hat{\eta}$ provided that $\lim_{\hat{\eta}\to 0} g(\hat{\eta}) = -1$ and $g(1) = 1 - t\delta\xi < 0$. The negative sign of $g(1)$ thereby follows from $t > t_1$ and the observation that $t > t_1$ requires $t(1-\beta/\alpha)\delta\xi > 1$ (see Step 1). Together with our earlier results this implies that $\mu(\hat{\eta})$ has a unique maximum, which is either in the interior of interval $(1, \hat{\eta}_{int})$ and determined by $\mu'(\hat{\eta}) = 0$ or it is given by the corner solution $\hat{\eta}_{int}$ if $\mu'(\hat{\eta}) > 0$ for all possible $\hat{\eta}$. For either case, we denote the maximum of $\mu(\hat{\eta})$ by $\hat{\eta}_1$.

Step 3 — Ranking of $\hat{\eta}_1$ and $\hat{\eta}_{tm}$

We now determine a formal condition ensuring $f(\hat{\eta}_{tm}) < 0$ and thus $\mu'(\hat{\eta}_{tm}) > 0$. This condition then implies that $\hat{\eta}_1 > \hat{\eta}_{tm}$ as illustrated in Fig. 4. Evaluating $f(\hat{\eta})$ at $\hat{\eta}_{tm} = [t(1-\beta/\alpha)\delta\xi]^{-1}$ gives $f(\hat{\eta}_{tm}) = 1 - \rho_\pi\xi/k - \rho_w + \rho_w[(k-\xi)/k]f_0(\zeta)$, with

$$f_0(\zeta) \equiv \left[\frac{k-(1-\beta/\alpha)\xi}{k-\xi} - \frac{1}{n(\zeta)}\right]\frac{\zeta-1}{\zeta}, \quad n(\zeta) \equiv (\zeta-1)\left[\left(\frac{\zeta-1}{\zeta}\right)^{-\frac{\zeta}{1-\beta/\alpha}}\exp\left(-\frac{1}{1-\beta/\alpha}\right)-1\right],$$

and $\zeta = t(1-\beta/\alpha)\delta\xi > 1$. Hence, $f(\hat{\eta}_{tm}) < 0$ requires $1 - \rho_\pi\xi/k - \rho_w + \rho_w[(k-\xi)/k]f_0(\zeta) < 0$. Imposing parameter constraint

$$1 - \rho_\pi\frac{\xi}{k} - \rho_w\left(1-\frac{\beta}{\alpha}\right)\left(2-\frac{\xi}{k}\right) < 0, \tag{A.21}$$

function $f_0(\zeta)$ has the following two properties, which we formally show in an Online Appendix, that is available upon request:

(i) There exists a unique $\underline{\zeta} \in (1,\infty)$, such that $f_0(\zeta) >,=,< 0$ if $\underline{\zeta} >,=,< \zeta$;
(ii) If $f_0(\zeta)$ has an extremum at $\zeta > \underline{\zeta}$, this must be a minimum.

From property (i) it follows that $f_0(\zeta) < 0$ if ζ is higher than a finite lower threshold $\underline{\zeta}$. To see the important role of parameter constraint (A.21) for this result, note that $\lim_{\zeta\to\infty} f_0(\zeta) = (\beta/\alpha)k/(k-\xi) - (1-\beta/\alpha)$. Since the parameter constraint in (A.21) can be rewritten as $1-\rho_\pi\xi/k-\rho_w+\rho_w[(k-\xi)/k]\lim_{\zeta\to\infty} f_0(\zeta) < 0$, it follows that the constraint is sufficient for $\lim_{\zeta\to\infty} f_0(\zeta) < 0$ and thus for a finite lower threshold $\underline{\zeta}$ to exist. Furthermore, from property (ii), we can infer that either $f_0(\zeta)$ is negatively sloped over the whole interval $(\underline{\zeta},\infty)$ or there exists a unique $\hat{\zeta}_0 > \underline{\zeta}$, such that $f_0(\zeta)$ decreases over subinterval $(\underline{\zeta},\hat{\zeta}_0)$ and increases over subinterval $(\hat{\zeta}_0,\infty)$. In both cases, it follows that – under parameter constraint (A.21) – condition $1 - \rho_\pi\xi/k - \rho_w + \rho_w[(k-\xi)/k]f_0(\zeta_2) = 0$ establishes a unique $\zeta_2 > \underline{\zeta}$ and in extension a unique $t_2 = \zeta_2/[(1-\beta/\alpha)\delta\xi]$, such that $0 >,=,< 1 - \rho_\pi\xi/k - \rho_w + \rho_w[(k-\xi)/k]f_0(\zeta)$ and thus $\mu'(\hat{\eta}_{tm}) >,=,< 0$ if $t >,=,< t_2$. We impose $t > t_2$ (and thus parameter constraint (A.21)) in the following.

Step 4 — Characterisation of $\hat{\eta}_0$

Let $\hat{\eta}_0$ be implicitly defined by $\lambda'(\hat{\eta}) + \mu'(\hat{\eta}) = 0$. Then, existence of $\hat{\eta}_0 \in (0,\hat{\eta}_{tm})$ is guaranteed if (i) $\lambda'(0)+\mu'(0) < 0$ and (ii) $\lambda'(\hat{\eta}_{tm})+\mu'(\hat{\eta}_{tm}) > 0$ hold. The second condition holds since (by definition) $\lambda'(\hat{\eta}_{tm}) = 0$, and $\mu'(\hat{\eta}_{tm}) > 0$ if parameter constraints (A.21) and $t > \max\{t_1,t_2\}$ are fulfilled. To show that the first condition also holds, we compute

$$\begin{aligned}\lambda'(\hat{\eta})+\mu'(\hat{\eta}) = &-\left[1-t\left(1-\frac{\beta}{\alpha}\right)\delta\xi\right]\frac{1}{1-\hat{\eta}} - t\left(1-\frac{\beta}{\alpha}\right)\delta\xi \\ &-\left(1-\frac{\beta}{\alpha}\right)\frac{\xi}{k}\frac{\chi'(\hat{\eta})f(\hat{\eta})}{(1-\rho_\pi\xi/k)[1+\chi(\hat{\eta})]-\rho_w\hat{\eta}\chi(\hat{\eta})[1+\chi(\hat{\eta})^{-\xi/k}]},\end{aligned} \tag{A.22}$$

[37] While showing $\mu'(0) = 0$ is a tedious task, its correctness can be easily confirmed by noting that (i) $\lambda'(0) = -1$ follows from differentiating (A.11); and that (ii) $\lambda'(0)+\mu'(0) = -1$ is formally shown in Step 4 of the proof.

according to Eqs. (25) and (A.17). This establishes

$$\lim_{\hat{\eta}\to 0}\left[\lambda'(\hat{\eta})+\mu'(\hat{\eta})\right] = -1-\left(1-\frac{\beta}{\alpha}\right)\frac{\xi}{k}\frac{1}{1-\rho_\pi\xi/k}\lim_{\hat{\eta}\to 0}\chi'(\hat{\eta})f(\hat{\eta}). \tag{A.23}$$

From Eq. (A.16) it follows that $\lim_{\hat{\eta}\to 0}\chi'(\hat{\eta})=0$. Substituting Eq. (A.18) for $f(\hat{\eta})$, we can then compute

$$\begin{aligned}\lim_{\hat{\eta}\to 0}\left[\lambda'(\hat{\eta})+\mu'(\hat{\eta})\right] &= -1+t\left(1-\frac{\beta}{\alpha}\right)\delta\xi\frac{k-\xi}{k}\frac{\rho_w}{1-\rho_\pi\xi/k}\lim_{\hat{\eta}\to 0}\frac{\hat{\eta}^2}{1-\hat{\eta}}\chi(\hat{\eta})^{1-2\xi/k},\\ &= -1+2\left(1-\frac{\beta}{\alpha}\right)\frac{k-\xi}{k}\frac{\rho_w}{1-\rho_\pi\xi/k}\lim_{\hat{\eta}\to 0}\left[(1-\hat{\eta})^{-t\delta\xi}\exp(-\hat{\eta}t\delta\xi)-1\right]^{\frac{k-\xi}{\xi}},\end{aligned}$$

which establishes $\lambda'(0)+\mu'(0)=-1$.

Combining Steps 1 to 4 to a proof of Proposition 1

Part (i) of the proof is established by $\mu'(\hat{\eta})>0$ and $\lambda'(\hat{\eta})+\mu'(\hat{\eta})<0$ for small levels of $\hat{\eta}$ (from Steps 2 and 4). The first result implies that non-offshorers increase employment if offshoring costs decline at low levels of international integration. The second result combined with $\lim_{\hat{\eta}\to 0}\lambda(\hat{\eta})=0$ (from Eqs. (14) and (25)) and $\lambda'(0)=-1$ (from Eq. (A.11)) implies that infra-marginal as well as marginal offshorers decrease domestic employment if offshoring costs decline at low levels of international integration. To establish part (ii) of the proposition, we define $\underline{t}\equiv\max\{t_1,t_2\}$. Then, it follows from $t>\underline{t}$ that $\hat{\eta}_0<\hat{\eta}_{tm}<\hat{\eta}_1$ (see Steps 1 to 4). As illustrated by Fig. 4, $\hat{\eta}\in(\hat{\eta}_0,\hat{\eta}_1)$ implies an increase in the domestic employment of infra-marginal non-offshorers and infra-marginal offshorers if offshoring costs decrease. Moreover, since $\lambda'(\hat{\eta})<0$ for all $\hat{\eta}<\hat{\eta}_{tm}$, it must be true that $\lambda(\hat{\eta})+\lambda'(\hat{\eta})+\mu'(\hat{\eta})<0$ and thus a decrease of domestic employment by marginal offshorers in response to a decline in offshoring costs is guaranteed for at least part of interval $(\hat{\eta}_0,\hat{\eta}_1)$. This confirms the respective conclusion in the text below Proposition 1 regarding the existence of job polarisation and completes the proof.

A.7. Offshoring and the unemployment rate of production workers u

Together Eqs. (A.3), in which $\pi_d(\varphi_d)$ can be replaced by $(\rho_w/\rho_\pi)w_d(\varphi_d)l_d(\varphi_d)$, and (A.13) determine the wage ratio $w_d(\varphi_d)/\tilde{w}=\iota(\hat{\eta})(k-\xi)/[k-(1-\beta/\alpha)\xi]$, where we have used $\iota(\hat{\eta})\equiv\varepsilon(\hat{\eta})/(1-\gamma)[1+\chi(\hat{\eta})]$, with $\varepsilon(\hat{\eta})$ defined in Appendix A.5. Substitution into Eq. (27) then establishes

$$u=\frac{(\beta/\alpha)\xi+(k-\xi)\left[1-\iota(\hat{\eta})/\iota\bar{w}_0\right]}{(\beta/\alpha)\xi+(k-\xi)}. \tag{A.24}$$

From Eq. (A.24), we can infer that offshoring decreases (increases) the unemployment rate u relative to autarky if $\iota(\hat{\eta})>(<)1$. Substituting Eqs. (17) and (19) for $\chi(\hat{\eta})$ and γ, respectively, and accounting for $\varepsilon(\hat{\eta})$ with $\lambda(\hat{\eta})$ given by Eq. (25), it follows that $\iota(\hat{\eta})>,=,<1$ is equivalent to

$$\begin{aligned}&\left[(1-\hat{\eta})^{-t\delta\xi}\exp(-t\delta\xi\hat{\eta})-1\right]^{\frac{k-\xi}{\xi}+\frac{\beta}{\alpha}}\left\{(1-\hat{\eta})^{1-t(1-\beta/\alpha)\delta\xi}\exp\left[-\hat{\eta}t\left(1-\frac{\beta}{\alpha}\right)\delta\xi\right]-1\right\}\\ &\qquad >,=,<\left[(1-\hat{\eta})^{-t\delta\xi}\exp(-\hat{\eta}t\delta\xi)-1\right]^{\frac{k-\xi}{\xi}}\left[(1-\hat{\eta})^{1-t\delta\xi}\exp(-\hat{\eta}t\delta\xi)-1\right].\end{aligned} \tag{A.25}$$

Let us define

$$\psi(\hat{\eta})\equiv\left[(1-\hat{\eta})^{-t\delta\xi}\exp(-\hat{\eta}t\delta\xi)-1\right]^{\frac{\beta}{\alpha}},\qquad \psi_1(\hat{\eta})\equiv(1-\hat{\eta})^{1-t\delta\xi}\exp(-\hat{\eta}t\delta\xi)-1, \tag{A.26}$$

$$\psi_2(\hat{\eta})\equiv(1-\hat{\eta})^{1-t\left(1-\frac{\beta}{\alpha}\right)\delta\xi}\exp\left[-\hat{\eta}t\left(1-\frac{\beta}{\alpha}\right)\delta\xi\right]-1. \tag{A.27}$$

Then, $\psi_1(\hat{\eta})=0$ characterises a unique $\hat{\eta}_b^1>0$, such that $\psi_1(\hat{\eta})>,=,<0$ if $\hat{\eta}>,=,<\hat{\eta}_b^1$. Furthermore, we know from Step 1 in the proof of Proposition 1 that $\psi_2(\hat{\eta})=\exp[\lambda(\hat{\eta})]-1$ has a unique minimum at $\hat{\eta}_{tm}$, whereas $\psi_2(\hat{\eta})=0$ characterises a unique $\hat{\eta}_b^2>\hat{\eta}_b^1$, such that $\psi_2(\hat{\eta})>,=,<0$ if $\hat{\eta}>,=,<\hat{\eta}_b^2$. It is worth noting that $t>\underline{t}$ is sufficient for $\hat{\eta}_{tm}<\hat{\eta}_{int}$ (see Appendix A.6), but not for $\hat{\eta}_b^1,\hat{\eta}_b^2<\hat{\eta}_{int}$.

Let us now define $\hat{\psi}(\hat{\eta})\equiv\psi_1(\hat{\eta})/\psi_2(\hat{\eta})$. We can then infer from (A.25) that $\iota(\hat{\eta})>,=,<1$ is equivalent to $\hat{\psi}(\hat{\eta})>,=,<\psi(\hat{\eta})$ if $\hat{\eta}<\hat{\eta}_b^2$, whereas $\iota(\hat{\eta})>,=,<1$ is equivalent to $\psi(\hat{\eta})>,=,<\hat{\psi}(\hat{\eta})$ if $\hat{\eta}>\hat{\eta}_b^2$. We can distinguish the following cases, regarding the sign and size of $\hat{\psi}(\hat{\eta})$: (i) $0>\psi_1(\hat{\eta})>\psi_2(\hat{\eta})$ and thus $\hat{\psi}(\hat{\eta})\in(0,1)$ if $\hat{\eta}<\hat{\eta}_b^1$; (ii) $\psi_1(\hat{\eta})>0>\psi_2(\hat{\eta})$ and thus $\hat{\psi}(\hat{\eta})<0$ if $\hat{\eta}\in(\hat{\eta}_b^1,\hat{\eta}_b^2)$; (iii) $\psi_1(\hat{\eta})>\psi_2(\hat{\eta})>0$ and thus $\hat{\psi}(\hat{\eta})>1$ if $\hat{\eta}>\hat{\eta}_b^2$.[38] We can thus safely conclude that $\psi(\hat{\eta})>\hat{\psi}(\hat{\eta})$ and thus $\iota(\hat{\eta})<1$ if $\hat{\eta}\in(\hat{\eta}_b^1,\hat{\eta}_b^2)$, whereas $\psi(\hat{\eta})<\hat{\psi}(\hat{\eta})$ and thus $\iota(\hat{\eta})<1$ if $\hat{\eta}>\hat{\eta}_b^2$ and at the same time $\hat{\eta}<\hat{\eta}_{int}$. The latter follows from the observation that $\psi(\hat{\eta})<1$ for all $\hat{\eta}<\hat{\eta}_{int}$. In both cases (and hence whenever $\hat{\eta}\geq\hat{\eta}_b^1$), the unemployment rate of production workers in the North is higher under offshoring than in autarky. We now look at the remaining domain and note first that $\psi(\hat{\eta})$ increases over interval $(0,\hat{\eta}_{int})$ from a minimum level of $\psi(0)=0$ to a maximum level of $\psi(\hat{\eta}_{int})=1$. Hence, showing that $\hat{\psi}(\hat{\eta})$ falls monotonically over interval $[0,\hat{\eta}_b^1]$ from a maximum level of $\hat{\psi}(0)=1$ to a minimum level of $\hat{\psi}\left(\hat{\eta}_b^1\right)=0$, suffices to prove that $\psi(\hat{\eta})=\hat{\psi}(\hat{\eta})$ has a unique solution $\underline{\hat{\eta}}<\hat{\eta}_{int}$, such that $\psi(\hat{\eta})>,=,<\hat{\psi}(\hat{\eta})$ if $\hat{\eta}>,=,<\underline{\hat{\eta}}$. This can be done by using higher differentials of $\hat{\psi}(\hat{\eta})$ and a detailed proof for this result is available upon request. We can thus safely conclude that $1>,=,<\iota(\hat{\eta})$ if $\hat{\eta}>,=,<\underline{\hat{\eta}}$. This completes the proof.

[38] For completeness, we also have $\lim_{\hat{\eta}\to 0}\hat{\psi}(\hat{\eta})=1$, $\hat{\psi}(\hat{\eta}_b^1)=0$, $\lim_{\hat{\eta}\to(\hat{\eta}_b^2)^-}\hat{\psi}(\hat{\eta})=-\infty$, and $\lim_{\hat{\eta}\to(\hat{\eta}_b^2)^+}\hat{\psi}(\hat{\eta})=\infty$.

A.8. Economy-wide unemployment effects

We can write the economy-wide unemployment in the North as $U = \Lambda(\hat{\eta})U^A$, with

$$\Lambda(\hat{\eta}) \equiv \frac{uL}{u^A L^A} = \frac{(\beta/\alpha)\xi\bar{w}_0 + (k-\xi)\left[\bar{w}_0 - \imath(\hat{\eta})\right]}{(\beta/\alpha)\xi\bar{w}_0 + (k-\xi)\,(\bar{w}_0 - 1)}\,\frac{(1-\rho_\pi\xi/k)(1-\gamma)}{1-\rho_w\gamma - \rho_\pi\xi/k} \tag{A.28}$$

and superscript A referring to autarky. That offshoring increases the economy-wide rate of unemployment in the North at low levels of $\hat{\eta}$ then follows from the observation that $\imath(\hat{\eta}) > 1$ and thus $u < u^A$ if $\hat{\eta} < \underline{\hat{\eta}}$ (see above) and the fact that the number of production workers decreases monotonically in $\hat{\eta}$. Furthermore, the economy-wide rate of unemployment U is larger (smaller) at $\hat{\eta} = \hat{\eta}_{int}$ and thus $\chi = 1$ than under autarky if $\Lambda(\hat{\eta}_{int}) > (<)1$, which is equivalent to $\zeta_U >,=,< \hat{\eta}_{int}$ with

$$\zeta_U \equiv \frac{(k-\xi)(1-2^{-\beta/\alpha})(1-\rho_\pi\xi/k)}{[(\beta/\alpha)\xi\bar{w}_0 + (k-\xi)(\bar{w}_0-1)](1-\rho_\pi\xi/k-\rho_w) + (k-\xi)(1-2^{-\beta/\alpha})(1-\rho_\pi\xi/k)}.$$

Taking into account that $\hat{\eta}_{int}$ is implicitly defined as function of t by $\chi = 1$ and thus by $[(1-\hat{\eta}_{int})^{-t\delta\xi}\exp(-\hat{\eta}_{int}t\delta\xi) - 1]^{k/\xi} = 1$, it follows that $\lim_{t\to 0}\hat{\eta}_{int} = 1$, $\lim_{t\to\infty}\hat{\eta}_{int} = 0$, and $d\hat{\eta}_{int}/dt < 0$. Hence, there exists a unique t for which $\zeta_U >,=,< \hat{\eta}_{int}$ holds with equality. This critical t is denoted t_U and given by $t_U \equiv -\ln 2/\delta\xi\left[\zeta_U + \ln(1-\zeta_U)\right]$. For $t >,=,< t_U$, we have $\Lambda(\hat{\eta}_{int}) >,=,< 1$. This completes the proof.

Appendix B. Data appendix

In this Appendix, we provide further details on the data input for the analysis in Sections 2 and 7.

B.1. Data description

As outlined in Section 2, we use the linked employer–employee dataset (LIAB) from the Institute for Employment Research (IAB) to provide evidence on job polarisation in Germany and its determinants. We use the LIAB Cross-Sectional Model 2,1993–2008 in this study.[39] Employer information in LIAB stems from the IAB Establishment Panel, which is based on a high-quality annual survey. The sample of establishments is stratified along three dimensions: establishment size, region and industry. Larger establishments are over-represented and the IAB provides sample weights that allow to make the sample of establishments representative for the German economy. We use these sample weights in the empirical analysis dealing with establishments. The data has been collected since 1993 and the coverage of establishments has increased over time. The first wave of the IAB Establishment Panel has included around 4000 establishments in Western Germany. Since 1996 the sample also covers Eastern Germany. In the waves 1999, 2001, and 2003 the establishment survey contains categorical information on the usage of foreign intermediate inputs, which we use to construct our offshoring dummies as outlined in the main text.

Employee information comes from Integrated Employment Biographies that cover administrative data from the German Federal Employment Agency, including inter alia all workers subject to social security contributions. This gives detailed individual data for 80 percent of the German labour force (excluding the self-employed, civil servants, workers in marginal employment, and family workers). The data contains information on daily wages, age, gender, tenure and more than 330 occupations (*Berufsordnungen*) according to the German nomenclature from 1988 (KldB88, 3-digit) at the worker level. Establishments are required by law to report these data at least once a year. We follow Fitzenberger et al. (2006) and impute missing educational data for individuals by using information of the same worker in previous or following years. Furthermore, an important feature of the data is the right-censoring of wages. Wages are reported up to the upper limit for statutory pension insurance. To deal with this censoring problem, we proceed as recommended in the literature and impute the missing wage information, following Card et al. (2013). Details on the wage imputation are available upon request. From the available employee data, we exclude all part-time workers (because we lack information on their exact working time), home workers, observations with one-time income, interns, workers during vocational training or retraining. Due to data availability in the Establishment Panel and to rule out that the global financial crisis impacts our results, we restrict the sample period to the years 1999 to 2007.

Based on our data input, we run a Mincer-type regression to take out wage variation due to observable worker characteristics that are not captured by our theoretical model. This includes differences in age, education (a categorical variable with six values), labour market experience, tenure in the same establishment, gender (a dummy variable with value 1 for women), and an indicator for the federal state in which the worker is employed. We run the regression separately for an occupation and an establishment panel. In the occupation panel, we add an employer fixed effect to eliminate any wage differences associated with establishment factors.[40] In the establishment panel, we add an occupation fixed effect to eliminate any wage differences associated with the tasks performed in the workplace. We estimate a model of the following form

$$\begin{aligned}\log w_{ij} = \beta_0 + \beta_1 age_i + \beta_2 age_i^2 + \beta_3 education_i + \beta_4 experience_i \\ + \beta_5 tenure_i + \beta_6 gender_i + \beta_7 state_i + \beta_8 fixed_j + \varepsilon_{ij},\end{aligned}$$

[39] The LIAB is confidential but not exclusive, available for non-commercial research by visiting the Research Data Centre (FDZ) of the Federal Employment Agency at the Institute of Employment Research in Nuremberg, Germany. For further information, we refer to http://fdz.iab.de.

[40] When analysing a cross section, the state indicator is not separately identified from the establishment fixed effects.

Table B.1
Task definitions.

Nr.	Description	Possible answers	Routine
1	Train, teach	Often/sometimes/never	No
2	Consult, inform	Often/sometimes/never	No
3	Measure, inspect	Often/sometimes/never	Yes
4	Monitor	Often/sometimes/never	No
5	Repair	Often/sometimes/never	Yes
6	Purchase, sell	Often/sometimes/never	No
7	Organise	Often/sometimes/never	No
8	Advertise, market	Often/sometimes/never	No
9	Evaluate information	Often/sometimes/never	Yes
10	Negotiate	Often/sometimes/never	No
11	Develop	Often/sometimes/never	No
12	Produce	Often/sometimes/never	No
13	Provide, supply	Often/sometimes/never	Yes
14	Apply labour or collective bargaining law	Yes/no	No
15	Apply other law	Yes/no	No

Table B.2
Descriptives for the establishment panel.

Variable	Obs.	Mean	Std. Dev.	Median	Min.	Max.
Monthly imputed wages	7593	1888.73	806.77	1777.12	435.19	11,504,21
Monthly residual wages	7593	2632.24	598.26	2594.01	1363.01	5391.84
Employment	7593	13.78	92.42	3.00	1.00	22,181
Sales (in 1000)	6722	7064.46	627,885.85	457.05	1.02	3.24e+08
Productivity (in 1000)	4560	550.12	16,816.23	99.37	0.16	7.02e+06
Infra-marginal offshorer	7593	0.22	0.41	0.00	0.00	1.00
Marginal offshorer	7593	0.07	0.25	0.00	0.00	1.00
Routineness	7583	0.21	0.35	0.10	0.00	1.00

Notes: The descriptives refer to the establishment panel used for the empirical analysis in Section 2 and Appendix B.2. Data moments are computed, relying on sample weights.

where w_{ij} is the log daily wage of worker i (employed in a given federal state) in establishment or occupation j, and ε_{ij} is an error term. We then predict residual wages and add the initial mean of $\log w_{ij}$. In exponential form, this gives a residual daily wage that is on average of similar magnitude as the raw wage but varies over a considerably lower interval. We aggregate daily wages to the monthly level, drop the highest and lowest one percent of the residual wages to protect our results against outlier effects and average the remaining wages over occupations or establishments, respectively.

In addition, we also use information from the German Qualification and Career Surveys. These surveys are representative and conducted by the Federal Institute for Vocational Training (BiBB) and the Federal Institute for Occupational Safety and Health (BAuA) in six-to-eight year intervals since 1979. The surveys cover several 10,000 employees and provide information on the activities of workers at their workplace (see Becker and Muendler, 2015, for an overview). We use the 1999 survey, distinguish 15 activities, and classify them as either routine or non-routine, following the taxonomy of Spitz-Oener (2006), Becker et al. (2013), and Becker and Muendler (2015). Table B.1 gives an overview of the tasks. Possible answers to the question on whether a task has been performed are either *often*, *sometimes*, and *never* or *yes* and *no*.

We count a task as being conducted by a worker if the answer is *often*, *sometimes*, or *yes* and compute the share of routine tasks at the occupation level by adding up the routine tasks of all workers in this occupation and dividing the respective sum by the total number of routine plus non-routine tasks conducted by these workers. This gives a routine task share that varies between 0 and 1. For distinguishing professions, we rely on the 3-digit KldB88 nomenclature and compute the share of routine tasks for 312 occupations. For 281 occupations the routineness measure is based on the responses of at least three interviewees and for these occupations data protection rules of the Institute for Employment Research allow us to merge the routineness measure from BIBB-BAuA to LIAB, relying on common occupational codes. In a final step, we determine the share of routine tasks at the establishment level by computing the mean over all workers employed in an establishment.

Table B.2 summarises the main descriptives for the establishment panel in the initial observation year of 1999, which we use for the regression analysis outlined in Section 2 and in Appendix B.2.[41]

[41] For our analysis, we also use industry- and economy-wide data from WIOD 2013, the OECD, and the World Bank, which we describe in the text. Further details on this data input and descriptives for the occupation panel are available upon request.

Table B.3
Job polarisation between establishments in Germany.

	20 groups	100 groups	10 groups	20 groups	
	OLS	OLS	OLS	FE	FE
Initial wage	−0.876**	−0.857**	−0.808**	−0.773**	−0.723**
	(0.187)	(0.167)	(0.111)	(0.215)	(0.212)
Initial wage squared	0.165**	0.161**	0.151**	0.147**	0.138**
	(0.035)	(0.030)	(0.021)	(0.040)	(0.040)
Observations	7593	7593	7593	7593	7577

Notes: The dependent variable is log employment change by establishment between the base year 1999 and the last year of observation within the sample period. The variable initial wage is the residual wage (in 1000 EUR) for base year 1999. We measure the initial wage as the average residual wage across establishments of a given wage group. In Columns 4 and 5, we control for industry fixed effects. A constant is estimated but not reported. Sample weights are used to make the establishment sample representative. Standard errors in parentheses are two-way clustered at the wage-group and the industry level. Significance levels are indicated by * $p < 0.05$ and ** $p < 0.01$, respectively.

Table B.4
Job polarisation in Germany: Further results.

	Single plant	Manu-facturing	Constant # service jobs	Continuously observed	Attrition	Productivity	Sales	Raw wage
Initial perform.	−0.729**	−0.923**	−0.388**	−0.821**	−0.719**	−0.301**	−0.019°	−0.159**
	(0.155)	(0.282)	(0.091)	(0.138)	(0.223)	(0.073)	(0.009)	(0.043)
Initial perform. squared	0.141**	0.161*	0.068**	0.162**	0.144**	0.037**	0.000°	0.043**
	(0.030)	(0.059)	(0.015)	(0.020)	(0.040)	(0.010)	(0.000)	(0.014)
Observations	5018	1869	7573	2804	6366	4603	6829	7568

Notes: The dependent variable is the log employment change by establishment between the base year 1999 and the last year of observation within the sample period. In Columns 1–4, the variable initial performance is the average residual wage across establishments of a given wage group in the base year 1999. In Columns 4, 5, and 6 initial performance refers to average productivity, sales, and raw wage of a given performance group in 1999. In all specifications, we estimate (but do not report) a constant, two-digit industry fixed effects, and a time dummy. Sample weights are used to make the establishment sample representative. Standard errors in parentheses are two-way clustered at the wage-group and the industry level. Significance levels are indicated by ° $p < 0.1$, * $p < 0.05$, and ** $p < 0.01$, respectively.

B.2. Further evidence

To further assess the evidence on job polarisation between establishments, we can transfer our graphical analysis from Panel B of Fig. 1 into a simple regression framework given by

$$\Delta empl_{vgs} = \beta_0 + \beta_1 wage_g + \beta_2 wage_g^2 + \gamma_s + \varepsilon_{vgs}, \tag{B.29}$$

which explains log changes of employment in establishment v from wage group g and industry s between the first and the last year of observation, $\Delta empl_{vgs}$, by a constant, the average wage paid by the establishments of a given wage group g in the base year 1999, $wage_g$, and an industry fixed effect, γ_s. The initial (group) wage also enters as a squared term, $wage_g^2$, to account for the non-monotonicity in employment changes displayed in Panel B of Fig. 1.[42] Finally, we denote the error term by ε_{vgs} and cluster standard errors at the wage-group as well as the industry level.

Column 1 of Table B.3 presents the result for a parsimonious specification, in which we distinguish 20 wage groups and do not control for industry fixed effects. The estimated coefficients provide further evidence for job polarisation between establishments in Germany. In Columns 2 and 3, we show robustness of this result, when changing the number of wage groups. To mitigate a potential omitted variable bias, we control for 56 two-digit NACE Rev. 1 industry fixed effects in Column 4 and find that this does not change our results in a substantive way. The results in Column 5 show that using more granular three-digit industry fixed effects has only small effects on our estimates.

In Table B.4, we present the results from further robustness checks, relying on our preferred fixed effects estimator from Column 4 of Table B.3. In Column 1, we restrict the sample to single-plant establishments. These establishments can be classified as *firms*, and we see that the distinction between establishments and firms is not crucial for our results. In Column 2, we zoom in on manufacturing producers. This reduces sample size considerably but has only minor consequences for the estimated coefficients. In Column 3, we keep employment in service occupations constant at its level in 1999 to rule out that our results erroneously pick up changes in the number of service jobs (as put forward by Autor and Dorn, 2013; Goos et al., 2014, as a major determinant of job polarisation). Whereas this changes the estimated coefficients considerably, it does not change our main finding of a job polarisation between establishments.

[42] Following Goos et al. (2009) and in contrast to the graphical representation in Fig. 1, we use wage levels instead of the categorical wage groups as explanatory variables in the regression analysis.

In Column 4, we restrict our sample to establishments continuously observed between 1999 and 2007. This reduces sample size, but has only small effects on the estimated coefficients. In Column 5, we address the problem of a potential attrition bias by controlling for selection on observables. Following Wooldridge (2002, Ch. 17), we first predict the survival probability of establishments for their final observation year, relying on observed sales, skill structure, and wages in 1999 as well as two-digit industry fixed effects and federal state dummies. We then use the inverse of the estimated survival probabilities as weights in our regression of log employment changes. Column 5 shows that following this procedure does not change the estimated coefficients.

In a final set of regressions, we show that job polarisation also exists for other performance measures of establishments. In Column 6, we rank establishments by their productivities instead of wages.[43] This does not change our results in a qualitative way. In Column 7, we proxy establishment performance by sales (in millions) and find again support for job polarisation in our data.[44] Finally, in Column 8, we consider raw instead of residual wages and find again clear evidence for job polarisation in our data.

Appendix C. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.jinteco.2024.103892.

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[43] Since productivities are not observable, we estimate them. We thereby follow Zwick (2006), consider replacement investment for the first year reported in our data, set the average depreciation rate and growth rate of investment at ten percent and five percent, respectively, and compute capital stocks using the perpetual inventory method. Making use of the thus determined capital stock, observed employment, intermediate goods, and sales (all measured in logs), we then estimate productivities following the procedure described in Wooldridge (2009).

[44] The coefficient for squared initial sales amounts to 0.0002.

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