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Article — Published Version

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The World Economy

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Suggested Citation: Frenkel, Michael; Ngo, Ngoc Tuyet (2023) : Service offshoring and its impacts on wages: An occupation-oriented analysis of Germany, The World Economy, ISSN 1467-9701, Wiley, Hoboken, NJ, Vol. 47, Iss. 4, pp. 1615-1641, <https://doi.org/10.1111/twec.13495>

This Version is available at:

<https://hdl.handle.net/10419/293971>

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Service offshoring and its impacts on wages: An occupation-oriented analysis of Germany

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Abstract

International trade in services has increased significantly in recent decades, mainly due to innovations in information and communication technology. This development has also increased the importance of service offshoring, as companies spread their production processes across several countries. This paper examines the intensity of offshoring of specific tasks of occupations, which in turn leads to higher imports, and explores the impact of such substitution on wages in the home economy. We use micro-level data from the Occupational Information Network and the Socio-Economic Panel in Germany and draw on the OECD's Input–Output Database. In total, we used data from about 62,000 person-years in 45 industries in Germany during 2014–2018. A particular focus of our study is on the interaction between service offshoring and the tradability as well as skill levels of workers. Our main findings suggest that service offshoring itself exerts downward pressure on workers' wages. This effect is amplified by the degree of tradability of the occupations.

KEYWORDS

international trade in services, microeconomic impacts, service offshoring, trade and labor market interactions

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1 | INTRODUCTION

The importance of services in international trade has increased in recent decades,¹ mainly due to the rapid development of information and communication technologies (ICTs). They facilitate the overcoming of geographical distances, which used to be a key feature of service provision, and enable the global transfer of many types of services without compromising quality. In the context of increasing trade in services, the wage effects of service offshoring are one of the important issues. However, they have not yet been extensively studied in the literature.

The concept of trade-in-goods is gradually being replaced by the concept of trade-in-tasks introduced by Grossmann and Rossi-Hansberg (2008), as firms can now divide their production process into tasks and have some of these tasks performed abroad. Since tasks that require the same skill level can have different offshoring costs, not all workers are equally affected by offshoring. For a given skill level, workers performing highly tradable tasks (i.e., tasks with low offshoring costs) are relatively more exposed to global competition. Hence, not only the skill levels of workers but also the tradability of the tasks they perform are relevant in determining workers' wages (Tobal, 2019). This raises the questions of how workers' wages are affected when their tasks are tradable and how the tradability of tasks affects the wage effects of offshoring. Baumgarten et al. (2013),² Hummels et al. (2014), Lee and Lee (2015), and other researchers attempt to answer these questions. Their findings vary by country, data structure, estimation method, and offshoring measure (Cardoso et al., 2021). However, most of them focus only on the manufacturing sector and leave out the service sector.

Our paper contributes to closing the described gap in the literature by extending the analysis to the service sector. For this novelty, we use German data and investigate the wage effects of service offshoring on workers in the home economy. Thus, we examine the wage effects of replacing domestic production with production abroad. Since our study is limited to the import side of the economy, we do not focus on the general effects of a greater international division of labor. In examining the effects of service offshoring on wages, we include workers' skill levels and their occupation's tradability in our model to empirically examine how these characteristics may affect the relationship between wages and service offshoring. Particular attention is given to the calculation of a tradability measure. Given the increasing "servicification" in the manufacturing sector (Lassmann, 2020; Lodefalk, 2015; Miroudot & Cadestin, 2017), defined as the increasing dependence of the manufacturing on services,³ service offshoring is expected to affect domestic service producers and the service functions of domestic goods producers. Thus, both workers employed by domestic service producers and workers employed by domestic goods producers are potentially affected. We address this issue by looking at workers in all German industries. For our analysis, we use the micro-level data on wages and wage-related characteristics of workers in

¹The share of international trade in services in the world GDP increased by 77% within three decades, from 7.6% in 1990 to 13.6% in 2019 (The World Bank, World Development Indicators, 2022). Furthermore, Miroudot and Cadestin (2017) show that services (including service inputs, service activities in manufacturing, and other services) contribute nearly two-thirds to the overall exports value of the countries covered in the Trade in Value-Added data of OECD.

²Their study also classifies the tradability of occupation with respect to the non-routine and interactive content of the occupations.

³Miroudot and Cadestin (2017) include in the increasing dependence of manufacturing sector on services also service inputs; service activities within firms such as design, logistics, R&D, etc.; and services sold bundled with goods such as installation, maintenance, or repairing services.

Germany from the Socio-Economics Panel (SOEP).⁴ As a proxy of service offshoring, we use data on foreign intermediate services used by German industries.⁵ These data are provided by the OECD's Inter-Country Input-Output Tables (ICIO; OECD, 2021). We also attempt to measure the tradability of occupations in Germany by following the method of Jensen and Kletzer (2010). As we do not have data on the occupational characteristics of Germany, we assume that occupations in Germany and the United States have similar characteristics in order to take advantage of the large Occupational Information Network database⁶ (National Center of O*NET Development, 2022) on occupations in the United States. In total, our data sample includes about 62,000 person-year observations working in 361 occupations in 45 industries in Germany in 2014–2018.

The remainder of the paper is structured as follows: Chapter 2 briefly reviews the literature on theoretical and empirical studies of the wage effects of offshoring in general. Chapter 3 describes the methodology and the data used for the analysis. Chapter 4 presents the results of the main estimates with explanations and discusses some limitations of the paper. Chapter 5 provides a summary and conclusions.

2 | LITERATURE REVIEW

2.1 | Offshoring and wages in the home country

In recent decades, the literature on international trade has produced a number of theoretical and empirical studies investigating the impacts of general offshoring on wages. Grossmann and Rossi-Hansberg (2008) introduce a theoretical framework in which countries trade tasks rather than goods. This framework reflects the fragmentation and specialisation of production, meaning that a single good or service can be a combination of tasks performed in different countries. In this way, they can analyse international trade at a more disaggregating level. They examine how a decline in offshoring costs may affect factor prices in the home economy and identify three potential effects: a productivity effect, a relative-price effect, and a labor-supply effect. Regarding the productivity effect, a decrease in offshoring costs leads to cost savings that increase firms' productivity, increase the demand for labor, and thus increase workers' wages. As for the relative-price effect, falling offshoring costs induce firms to perform more offshore work, which puts downward pressure on the relative price of offshored tasks and on the wages of workers whose tasks are offshored. Regarding the labor-supply

⁴The Socio-Economics Panel (SOEP) is an important research data infrastructure provided by the German Institute for Economic Research, DIW Berlin (Liebig et al., 2021; Schröder et al., 2020). It has designed questionnaires and conducted annual surveys to analyse households and individuals from birth to adulthood and throughout the rest of their lives since 1984.

⁵The terminology "industries" used in this paper refers to the International Standard Industrial Classification of All Economic Activities ISIC Rev. 4 and the Statistical Classification of Economic Activities in the European Community NACE Rev. 2. In our paper, we use "industries" interchangeably with "economic activities".

⁶The Occupational Information Network (O*NET) is a program sponsored by the U.S. Department of Labor/Employment and Training Administration. It collects and publishes occupation-oriented information about occupations in the U.S. such as work activities, work requirements, worker characteristics, etc. The database is widely used in many prominent studies related to the U.S. labor market and human resource management (e.g., Blinder, 2009; Crinò, 2010; Jensen & Kletzer, 2010; Liu & Treffer, 2019).

effect, workers whose tasks are offshored are free to work elsewhere, which can lead to a decline in their wages.

Tobal (2019) develops a model of the effects of service offshoring based on the trade-in-tasks framework with an extension of task tradability. He argues that given the development of information and communication technology, which expands the range of offshored service tasks, the effects of service offshoring on each task at the same skill level are not the same. Therefore, he emphasises the need for a new model that takes into account both the skill level and the tradability of tasks. His model shows that offshoring of services can have either a positive or negative effect on workers' wages, depending on whether the productivity effect or the effect of foreign competition (similar to the relative-price effect of Grossmann & Rossi-Hansberg, 2008) dominates. In addition, with the same tradability, low-skilled workers in industrialised countries are predicted to be relatively more disadvantaged by service offshoring than high-skilled workers. On the other hand, workers of the same skill level who perform highly tradable tasks are more exposed to foreign competition and are therefore disadvantaged in terms of wages.

Based on the trade-in-tasks framework, a number of empirical studies examine the effect of task offshoring on wages in manufacturing. For instance, Baumgarten et al. (2013) examine the wage effects of offshoring using data on manufacturing workers in Germany. They classify tasks based on the consensus of previous literature that interactive and non-routine tasks are less likely to be offshored, and assign these tasks to occupations following Becker et al. (2013). Their findings suggest that offshoring has a negative effect on the wages of both low-skilled and high-skilled workers across industries. Additionally, the magnitude of the effect varies by the type of tasks performed by workers. Hummels et al. (2014) examine the impact of offshoring on the wage of a worker employed by a given firm using data on workers and firms in the manufacturing sector in Denmark. Their findings suggest that, first, offshoring benefits high-skilled labor and penalises low-skilled workers in terms of wages. Second, workers performing routine tasks are disadvantaged by offshoring, regardless of their qualifications. Last but not least, high-skilled occupations in mathematics, social sciences, and languages benefit from offshoring. In contrast, natural science and engineering occupations are just as exposed to offshoring as low-skilled occupations.

Some other researchers focus their attention on the service sector. Criscuolo and Garicano (2010) use "legal licensing requirements" to measure the task offshorability and investigate the impact of offshoring certain services on the wages of occupations subject to these requirements in the United Kingdom. They argue that these requirements prevent the offshorability of some tasks, leading to a distinction between non-offshorable (licensed) and offshorable (non-licensed) occupations. Their result shows that a decrease in the cost of offshoring services benefits workers whose occupations require legal licences. This is because the cost savings from offshoring service tasks increase the productivity of service production and increase the demand for non-offshorable tasks. Oldenski (2014) investigates the impact of offshoring in both manufacturing and service industries on the U.S. labor market. Her results suggest that, first, at the industry level, high-skilled workers in the U.S. benefit from offshoring because they have a comparative advantage when international trade increases. Second, at the occupation level, the positive wage effect of offshoring varies across occupation groups. Those whose occupations involve non-routine and communication-intensive tasks gain, while those who perform routine tasks lose from increasing offshoring.

One strand of the empirical literature focuses on international trade and the labor market in Germany. However, this research mainly focuses on manufacturing (Dauth et al., 2014, 2017, 2021) and employment (Dauth et al., 2014, 2017; Eppinger, 2019). The literature on the impact of service offshoring and wages of German workers in a trade-in-tasks setting is still pending.

Overall, the empirical literature on the wage effects of offshoring is dominated by studies from the manufacturing sector, and results vary across countries (see Cardoso et al., 2021, for a meta-analysis). Given the recent increase in international trade in services, it seems useful to examine the empirical evidence on offshoring in services in Germany in more detail.

2.2 | Classification of workers: skill levels and occupation tradability

Labor as one of major factors of production is traditionally classified by skill levels. In the literature on international trade, many studies follow this classification to investigate the impact of offshoring on the labor market outcomes in both manufacturing (Feenstra & Hanson, 1996; Geishecker & Görg, 2008; Goel, 2017, etc.) and service sectors (Geishecker & Görg, 2013). However, after the trade-in-tasks framework was introduced, this classification can no longer reflect the diversity of workers. Therefore, an additional classification has to be considered: the classification according to the tradability of the tasks that workers perform.

Although many studies on offshoring refer to the trade-in-tasks framework, the classification of tasks is still not standardised, making task tradability difficult to measure. In addition, a typical worker may perform many different tasks within his or her scope and be paid as wages for all the tasks he or she performs. In other words, it is not possible to obtain data on workers' wages at the task level. To address this problem, researchers have identified several occupational characteristics that can determine the tradability of occupations rather than tasks. This paper follows the same line of arguments. An occupation can be considered tradable if, first, it contains routine tasks (Levy & Murnane, 2006); second, it requires little face-to-face contact with customers (Blinder, 2006); and third, it is ICT-based (Garner, 2004). Based on these attributes, researchers have attempted to create tradability indices for occupations. Some of them rely on a single occupational attribute. For example, Blinder (2009) creates a tradability index for occupations in the United States based on face-to-face interaction, while Liu and Trefler (2019) classify occupations based on the degree of routine. Some others rely on more than one attribute. For example, Crinò (2010) considers the three aforementioned occupational attributes as proxies for his tradability index. He argues that occupations may have one, two, or even three attributes in reality, and hence, the tradability index is more precise if all attributes are taken into account. Jensen and Kletzer (2010) improve the accuracy of their tradability index by including two additional attributes: "information content" and "on-site nature of work" of an occupation. However, all of these tradability indices are based on the subjective assessment of researchers. To date, there are no purely objective methods that can accurately measure the tradability of occupations.

3 | DATA AND METHODOLOGY

3.1 | Data

Our dataset is compiled from three different sources: First, we use the micro-level data SOEP-Core from the Socio-Economics Panel (SOEP) for wages and wage-related characteristics of German workers. SOEP-Core is a representative annual panel survey of private households in Germany since 1984 that provides information about 15,000 households and 30,000 individuals living in households and is tended to represent the residential population in Germany. The survey aims to measure stability and detect changes in almost all domains of life of the

TABLE 1 Descriptive statistics of standard variables.

Standard variables	Observations	Mean	Std. dev.	Min	Max
Hourly wages (€)	61,580	17.5740	16.8292	6.0057	1384.8
Service offshoring intensity	61,286	0.1264	0.0414	0.0607	0.2733
Qualification	60,301	1.1502	0.6213	0	2
No prof. qualification (0)	7789				
Apprenticeship (1)	35,663				
University degree (2)	16,849				
Occupation's tradability	61,580	1.7213	1.4660	-1.3339	5.6606
Working experience (years)	61,347	15.6515	11.9807	0	56.917
Age (years old)	61,580	44.2196	11.3822	18	90
Marital status	61,404	0.6476	0.4777	0	1
Single/divorced (0)	21,636				
Married (1)	39,768				
Living in Western Germany	61,580	0.8083	0.3936	0	1
East (0)	11,804				
West (1)	49,776				
Risk aversion	61,453	4.8648	2.3547	0	10
Firm size	61,010	6.8649	3.1286	1	10
Trained for occupation	61,454	0.5888	0.4920	0	1
Not trained (0)	25,268				
Trained (1)	36,186				

Note: The sample contains about 61,580 person-year observations, 50.98% of which are women. These individuals work in 361 occupations (4-digit, ISCO-08) in 45 industries in Germany from 2014 to 2018. Data sources: SOEP-Core Data Distribution 1984–2019 (soep.v36eu), OECD's Inter-Country Input–Output Tables (ICIO) 2021 edition, and O*NET database (2022).

surveyed individuals and private households by using an (almost) identical questionnaire over time (Kara & Zimmermann, 2018). Second, we use data from the OECD's Inter-Country Input-Output (ICIO) Tables to calculate the intensity of service offshoring for each industry in Germany. The ICIO Tables database series produced by the OECD that includes input-output data of 45 industries based on ISIC Rev.4 of 66 major countries and a “rest-of-the-world” region from 1995 to 2018. The latest edition was released in February 2022. Finally, we extract data about labor activities from the O*NET database to calculate the tradability of occupations. We assume that occupations in Germany and the U.S. have similar characteristics, because both countries have a similar level of development. Due to the differences between the U.S. and German work environments, culture, and society, there may be some variation. However, as the work activities in the O*NET database are standardised across occupations, we assume that the main work activities of each occupation in Germany do not differ significantly from those in the U.S. For instance, the most important work activities of a nursing assistant are assisting and caring for others, gathering information, and communicating with supervisors, colleagues, and subordinates. This point should apply in both countries. We then use a crosswalk of occupation classification from O*NET-SOC to ISCO-08 provided by O*NET to merge with the German SOEP data.

As SOEP has used the new classification⁷ of occupations and main economic activities, i.e., ISCO-08 and NACE Rev.2, respectively, since 2013, while the most recent data released by the OECD is for the year 2018, our analysis focuses on the 5-year period between 2014 and 2018. We also exclude individuals who worked in armed forces or were still in school at the time of the survey. Table 1 presents the descriptive statistics of standard variables in our analysis. Sections 3.2 and 3.3 of this paper provide details on each of these variables.⁸

After excluding outliers, our sample contains annual data from a total of 61,580 person-year observations surveyed between 2014 and 2018. Of the 60,301 responses to the qualifications question, 16,849 had a university degree, 35,663 had an apprenticeship, and 7,789 had no professional degree. The average working experience and working age are 15.65 years and 44.22 years old, respectively. German workers with a university degree earned €22.64 per hour in 2014 and €24.34 per hour in 2018. Workers with an apprenticeship and workers without any qualifications earned on average €15.31–16.38 and €12.24–12.68 per hour, respectively, between 2014 and 2018, respectively. Regarding the tradability of occupations, the most tradable occupations are managers and professionals such as economists, actuaries, and financial analysts. In contrast, the least tradable occupations are elementary occupations such as garbage collectors, cleaners, and helpers.

3.2 | Dependent and independent variables

The dependent variable of our analysis is $wage_{ijkt}$, defined as the logarithm of the hourly wage of worker i working in occupation j in industry k at time t in the home economy. We estimate the wage effects of three independent variables, namely service offshoring, skill levels, and the workers' occupation tradability. We use the share of imported intermediate services in total intermediate services used by an industry as a proxy for the intensity of service offshoring. The rationale behind our indicator is that offshored services need to be imported as intermediate inputs for the next stages of production. Thus, the higher the indicator, the higher the service offshoring intensity is likely to be. This rationale is in line with Amiti and Wei (2009), Crinò (2012), Borghi and Crinò (2013).

The service offshoring intensity of industry k in the home economy SOI_{kt}^H is measured as follows:

$$SOI_{kt}^H = \frac{\sum_{s=1}^{20} \sum_{c=1}^{66} MIS_{sckt}}{TIS_{kt}}, \quad (1)$$

where MIS_{sckt} is the intermediate service s imported by industry k from partner country c at time t , and TIS_{kt} is total intermediate services used by industry k at time t . Our data sample includes 45

⁷Prior to 2013, SOEP used ISCO-88 and NACE for the classification of occupations and main economic activities, respectively. A crosswalk from ISCO-88 to ISCO-08 and from NACE Rev.1.1 to NACE Rev.2 would result in data turbulence. For instance, the economic activity code 55 "Hotels and Restaurants" in NACE Rev.1.1 is divided into codes 55 "Accommodation" and 56 "Food and beverages service activities" in NACE Rev.2. This means that we cannot specify whether workers classified in the activity 55 according to NACE Rev.1.1. from 2012 backwards work in activity 55 or 56 under NACE Rev.2. A similar example for occupation classification would be the occupation code 1315 "General Managers of Hotels and Restaurants" in ISCO-88, which, in the ISCO-08 system, is divided into codes 1411 "Hotel Managers" and 1412 "Restaurant Managers".

⁸See Table A3 in the Appendix for more information on the correlation matrix of main variables.

industries, including 20 service industries, from a “rest-of-the-world” region and 65 trading partner countries of Germany between 2014 and 2018. The change in SOI_{kt}^H is expected to affect the wages of employees working for domestic service producers and in-house service functions of domestic goods producers (Nordås, 2020).

There are no data available that indicate which occupations are included in the services-producing parts of an industry and which are included in the goods-producing parts of an industry. Therefore, in examining the effect of service offshoring on wages, we assume for simplicity that the effect applies to all occupations. The effect can be either positive or negative, depending on whether the productivity effect or the foreign competition effect induced by offshoring of services dominates (Grossmann & Rossi-Hansberg, 2008; Tobal, 2019).

The variable $qual_{ijkt}$ describes the workers' skills or qualification levels to perform their jobs, represented by the highest professional qualification that workers had acquired at the time of the survey. As briefly mentioned in the previous section, we use three levels of qualifications in this sample:

- Individuals with no professional qualification.
- Individuals with an apprenticeship.
- Individuals with a university degree.

We expect the qualification levels to have a positive effect on wages. In addition to examining the effect of qualifications on wages, we also examine the effect of qualification levels on the relationship between offshoring of services and wages. Offshoring of services is skill biased, i.e., it widens the wage gap in favour of skilled workers (Borghi & Crinò, 2013). Thus, we expect that skill levels also have a positive effect on the wage effect of service offshoring. This means that, in case service offshoring has a negative effect on wages, this effect will be less pronounced for high-skilled workers.

The variable $tradability_j$ describes the tradability of occupation j . It is calculated using a three-step approach. First, an occupation is described by 41 representative work activities.⁹ Second, the relevance of each work activity to the individual's occupation is described by the following two O*NET survey questions:

- How important is the activity to your current job?
- What level of the activity is needed to perform your current job?

The answer to the first question varies on a scale from 1 (not important) to 5 (extremely important). The answer to the second question varies on a scale from 1 (lowest level) to 7 (highest level). Third, Jensen and Kletzer (2010) suggest five occupational attributes that are likely to affect the tradability of an occupation, namely, “information content”, “internet enabled”, “face-to-face contact”, “routine or creative nature of work”, and “onsite nature of work”. They then select 11 out of 41 O*NET work activities that meet these attributes to calculate their tradability index. Based on the detailed description of the different work activities, we extend the selection to 20 work activities to improve the accuracy of the index. Following Blinder (2009) and Jensen and

⁹In the terminology of O*NET, “work activities” are standardised and identical for every occupation, with different scales of importance and level to describe each occupation. In contrast, “tasks” describe occupations in free-form text, i.e., they are non-standardised and hence, cannot be compared across occupations. See Table A1 in the Appendix for a detailed description of each work activity.

TABLE 2 List of work activities potentially relevant to the tradability of occupations.

Attributes of occupations	Work activities	Sign
Information content	Getting information	(+)
	Processing information	(+)
	Analysing data or information	(+)
	Documenting/recording information	(+)
	Evaluating information to determine compliance with standards	(+)
	Identifying objects, actions, and events	(+)
	Updating and using relevant knowledge	(+)
Internet enabled	Interacting with computers	(+)
Face-to-face contact	Assisting and caring for others	(-)
	Establishing and maintaining interpersonal relationships	(-)
	Performing for or working directly with the public	(-)
Routine or creative nature of work	Making decisions and solving problems	(+)
	Thinking creatively	(+)
On-site nature of work	Performing general physical activities	(-)
	Operating vehicles, mechanised devices, or equipment	(-)
	Controlling machines and processes	(-)
	Handling and moving objects	(-)
	Inspecting equipment, structures, or material	(-)
	Repairing and maintaining electronic equipment	(-)
	Repairing and maintaining mechanical equipment	(-)

Note: All activities in the list with their corresponding sign are selected by this paper's authors based on Jensen and Kletzer (2010)'s occupational attributes. The sign in the last column denotes whether the activity generally affects the tradability of an occupation positively or negatively. Data source: O*NET database (2022).

Kletzer (2010), we rescale “importance” (question 1 above) and “level” (question 2 above) to the 0–1 scale and assign the negative sign to activities that might reduce the tradability of the occupation.¹⁰ Table 2 presents the list of work activities with their corresponding occupational attributes.

As Jensen and Kletzer (2010) note, “importance” varies across occupations more than “level”. Hence, we follow their suggestion and assign a Cobb-Douglas weight of three-quarters to “importance” and one-quarter to “level”.¹¹ The tradability of occupation *j* is calculated as follows:

$$Tradability_j = \sum_{i=1}^{20} \left(Imp_{ij}^{3/4} Lev_{ij}^{1/4} \right) \tag{2}$$

¹⁰One may argue that even if some activities might be hard to offshore, these could still suffer from internationalisation in case the entire production of a particular economic activity is moved abroad. However, the O*NET data set does not include any information on the internationalisation level of occupations.

¹¹Jensen and Kletzer (2010) justify the use of these weights by arguing that it is not obvious how to weigh “importance” and “level,” but that “importance” varies more across occupations than “level”. On this basis, they apply weights of 3/4 and 1/4. Using similar arguments, Blinder (2009) apply weights of 2/3 and 1/3.

TABLE 3 The 10 most tradable and least tradable occupations.

ISCO-08 Occupation code	ISCO-08 occupation title	Tradability points
The 10 most tradable occupations		
2631	Economists	5.6606
2120	Mathematicians, actuaries and statisticians	5.5639
2413	Financial analysts	5.1274
2619	Legal professionals not elsewhere classified	5.0788
2634	Psychologists	4.9874
2145	Chemical engineers	4.9281
2111	Physicists and astronomers	4.8382
1211	Finance managers	4.8247
2164	Town and traffic planners	4.7604
3154	Air traffic controllers	4.7035
The 10 least tradable occupations		
9112	Cleaners and helpers in offices, hotels and other establishments	-0.4508
9329	Manufacturing labourers not elsewhere classified	-0.4635
9311	Mining and quarrying labourers	-0.5059
9122	Vehicle cleaners	-0.6202
9624	Water and firewood collectors	-0.6406
7113	Stonemasons, stone cutters, splitters and carvers	-0.6552
8172	Wood processing plant operators	-0.8704
8341	Mobile farm and forestry plant operators	-0.9025
8157	Laundry machine operators	-1.1719
9612	Refuse sorters	-1.3339

Note: Own calculations. Data source: O*NET database (2022).

where i and j denote work activity and occupation, respectively. The tradability scale ranges from -1.33 (refuse sorters) to 5.66 (economists). The scale is ordinal rather than cardinal because occupations are ranked by their tradability relative to each other rather than relative to an absolute standard. As O*NET does not provide a time dimension, we assume that workers can change their occupation within the time frame of our analysis, but the tradability of occupations remains stable over time. Table 3 lists the 10 most and least tradable occupations in our sample. It suggests that some high-skilled jobs are very much exposed to offshoring.

The effect of occupation tradability on wages can be either negative or positive. On the one hand, workers with higher tradable occupations are more exposed to foreign competition and therefore disadvantaged in terms of wages. On the other hand, these workers have the opportunity to offer their products or services abroad without sacrificing quality, which gives them more opportunities to increase their income. We also analyse the additional impact of occupational tradability on the relationship between offshoring and wages. In our sample, we find that many tradable occupations are skill-intensive and require highly skilled workers. Thus, the extent to which occupation tradability may affect the relationship between offshoring and wages depends on the extent of the skill bias in service offshoring. Particularly, if the skill bias of service

offshoring is large enough, the additional effect of tradability on the wage effect of service offshoring may be positive.

3.3 | Control variables

We include a number of control variables in our model to account for individual characteristics that might affect individuals' wages. Our choice of control variables is related to the studies of Brunello and D'Hombres (2007), Larsen et al. (2011), and Elsas (2021). Specifically, we control for working experience ($exper_{ijkt}$), measured as the total number of years an individual has worked at the time of the survey. We expect experienced workers to earn more than inexperienced workers. In addition, we control for age (age_{ijkt}), as we also expect more senior workers to earn more. Marital status is also an important determinant of wages. We use a dummy variable to divide individuals in our sample into two groups: married and single or divorced. We expect that married workers earn more than single or divorced workers. We also include a dummy variable for residence in the eastern or the western part of Germany to control for potential wage differentiation between the two regions. We expect that people living in the western part of Germany are likely to have higher wages than their eastern counterparts. We also include a dummy variable indicating whether workers work in the occupation they were trained for. We expect that workers working in their trained occupation earn relatively more.

Risk aversion is another personal characteristic that can affect workers' wages. If workers are risk-averse, they tend to stay with their current job, which provides them with a stable income over time. If, by contrast, they are very willing to take risks, they tend to switch jobs more often and their wages fluctuate accordingly. The variable on individual's willingness to take risk varies from 0 (not willing) to 10 (fully willing). The sign of the coefficient can be either positive or negative, as workers can either earn more or less at their new job than at their previous one. In addition, the size of the firm where workers currently work can also affect their wages. The firm size variable ranges from 1 (under 5 employees) to 10 (more than 2000 employees). We control for firm size and expect that workers who work in larger firms earn relatively better. We also add dummies for industries (at the two-digit level) to account for heterogeneity across industries.

3.4 | Empirical model

We begin our analysis by estimating the wage effects of service offshoring and different skill levels using fixed-effect estimator. We then extend our model to include the tradability of occupations and their interaction with service offshoring to study how workers' wages change when their occupations are tradable in the context of service offshoring. Finally, we use an interaction term of service offshoring intensity and skill levels to examine the additional effect that skill levels might have on the wage-service offshoring relationship in the presence of occupational tradability. In all specifications, we control for industrial heterogeneity and use a set of control variables described in section 3.3. Our empirical models are as follows:

$$wage_{ijkt} = \beta_0 + \beta_1 \cdot SOI_{kt}^H + \beta_2 \cdot qual_{ijkt} + \beta_3 \cdot tradability_{jkt} + \beta_4 \cdot SOI_{kt}^H \cdot tradability_{jkt} + \tau \cdot T_{ijkt} + \gamma \cdot Y_k + \theta_i + \theta_t + \epsilon_{ijkt}, \quad (3)$$

$$wage_{ijkt} = \beta_0 + \beta_1 \cdot SOI_{kt}^H + \beta_2 \cdot qual_{ijkt} + \beta_3 \cdot SOI_{kt}^H \cdot qual_{ijkt} + \beta_4 \cdot tradability_{jkt} + \tau \cdot T_{ijkt} + \gamma \cdot Y_k + \theta_i + \theta_t + \epsilon_{ijkt}, \quad (4)$$

where T_{ijkt} is the vector of individual characteristics, Y_k denotes industry dummies, and θ_i and θ_t denote individual and time fixed effects, respectively.

We address the endogeneity issue of reverse causality, according to which high domestic wages could cause increasing offshoring intensity of services, by constructing an instrumental variable for service offshoring. Following the strategy of Hummels et al. (2014), we generate the world export supply of intermediate services $WSIS_G_{kt}$ as follows:

$$WSIS_G_{kt} = \sum_{c=1}^{66} \sum_{s=1}^{20} WSIS_G_{cskt}, c \neq \text{Germany}, \quad (5)$$

where $WSIS_G_{cskt}$ is the total supply of country c of intermediate service s to the world market of industry k at time t , minus its supply to Germany. We assume that $WSIS_G_{cskt}$ is correlated with the imports of intermediate services of an industry in Germany, but uncorrelated with the changes in the wages of workers employed in that industry. We use the natural logarithmic form of $WSIS_G_{cskt}$ in the IV-2SLS regressions and our baseline year is 2014. This IV strategy is also similar to that of Autor et al. (2013), who use Chinese exports to high-income countries other than the US to instrument US imports from China. The consistency of this instrument approach has been claimed by Borusyak et al. (2022) with their quasi-experimental framework, on the basis of which global export supply shocks can be considered as close to random and consist of many small independent shocks with sufficient average exposure. The exogeneity assumption of export supply shocks allows the exposure shares to be endogenous, particularly if German workers are supposed to be exposed to a relatively small number of these small independent shocks.

With this in mind, we perform several fundamental tests¹² to validate our choice of instrument. In the first stage, we show the F test of the excluded instruments as a proxy for the strength of the instruments. The conventional critical value is 10. An F value lower than 10 would indicate that the selected instruments are weak. Additionally, we use the Angrist–Pischke χ^2 and F statistic for underidentification and weak identification tests of individual endogenous variables, respectively (Angrist & Pischke, 2009). Under the null hypothesis that a specific endogenous variable is not identified, a significant result suggests that it is indeed identified. Likewise, under the null hypothesis that an instrument is weakly correlated with the corresponding endogenous variable, a significant result indicates that a strong correlation exists.¹³

In the second stage, we perform both underidentification test and weak identification test for excluded instruments. The underidentification test aims at determining whether the excluded instruments are relevant to the endogenous variables, i.e., the equation is identified. We report the Kleibergen–Paap rank Lagrange multiplier (LM) statistic (Kleibergen & Paap, 2006) as the test result. The statistic is distributed as χ^2 with degrees of freedom equal to one.¹⁴ The weak identification test is to determine whether the excluded instruments are strongly or weakly correlated with the endogenous variables. Conventionally, the Cragg–Donald Wald F statistic is reported as the test result under the i.i.d. errors assumption. However, as we apply robust standard errors to all specifications, the Cragg–Donald test is no longer valid. Thus, we report the Kleibergen–Paap rank Wald F statistic instead because it is robust against violations of the i.i.d.

¹²These tests are performed using the Stata package `ivreg210` contributed by Baum et al. (2015).

¹³Table A2 in Appendix shows more details of the first-stage estimation.

¹⁴The degrees of freedom $df = L - K + 1$ where L is the number of excluded instruments and K is the number of endogenous variables. In our specifications, L equals to K .

assumption. As a rule of thumb, the null hypothesis of a weak correlation between excluded instruments and endogenous variables can be rejected if the F value is greater than 10. Additionally, we perform an endogeneity test of endogenous variables under the null hypothesis that these endogenous variables can be treated as exogenous. The statistic is distributed as χ^2 with degrees of freedom equal to the number of variables tested. A significant result suggests that the variables tested are indeed endogenous.

4 | RESULTS

4.1 | Baseline results

Table 4 presents the results of our estimations. Model 1 shows the regression results for the case, in which we do not include an interaction variable between skill level or tradability and the offshoring intensity of services. The estimated coefficient of -0.2921 for the variable *SOI* indicates that the mere offshoring of services has a negative effect on wages, i.e., a one percentage point increase in service offshoring decreases the hourly wages of German workers by 0.29%. This suggests that the impact of foreign competition induced by service offshoring outweighs the productivity effect. As expected, the skill level of workers has a positive effect on wages. Workers with an apprenticeship have higher wages than workers without professional qualifications, as shown by the positive coefficient of *apprent*. The estimated coefficient of *uni* shows that this effect is even more pronounced for workers with a university degree. With the exception of the variables for risk aversion and living in western part of Germany, the estimates for all control variables are significant and have the expected sign. More specifically, the estimates suggest that wages increase with age and with more work experience; they are also higher for married workers. Workers who work in the occupation they are trained for also earn relatively better if they work in a larger company.

In Model 2, we include the explanatory variable *tradability*, which describes the possibility that an occupation can be traded internationally. The estimated coefficient is significant and positive suggesting that the ability of workers to supply their products or services abroad and thus demand higher wages outweighs the effect of foreign competition described above. This could be due to the fact that many occupations that are tradable are high-skilled. Since Germany has a comparative advantage for products that use high-skilled labor intensely, demand for skilled tradable occupations increases as international trade in services expands. As in the previous model specifications, the estimates are significant for all other explanatory variables except for risk aversion and living in the western part of Germany.

In Model 3, we add the interaction term between the service offshoring intensity (*SOI*) and tradability. The coefficient of the interaction term is negative and significant. This suggests that the tradability of occupations amplifies the dampening effect of service offshoring intensity. In other words, individuals working in occupations with high tradability are generally more affected by service offshoring in terms of wages. This finding is in line with the implications of the model of Tobal (2019).

In Model 4, we include an interaction term between the skill level and service offshoring intensity. We use the wage effect of unskilled workers as the default and include two interaction terms: the interaction between service offshoring intensity and workers with an apprenticeship ($SOI \times \textit{apprenticeship}$) and the interaction between service offshoring intensity and workers with a university degree ($SOI \times \textit{uni degree}$). In this case, the estimated coefficient of the service offshoring intensity *SOI* captures the effect of service offshoring intensity on wages of unskilled

TABLE 4 The effects of service offshoring on wages.

	Model 1	Model 2	Model 3	Model 4	Model 5
Service offshoring intensity (SOI)	-0.2921** (0.1441)	-0.2962** (0.1441)	-0.1273 (0.1545)	-0.3849 (0.2559)	-0.2587 (0.2593)
Qualification					
1. Apprenticeship	0.2270*** (0.0261)	0.2269*** (0.0261)	0.2258*** (0.0261)	0.2181*** (0.0377)	0.2116*** (0.0377)
2. Uni degree	0.2488*** (0.0481)	0.2465*** (0.0481)	0.2463*** (0.0481)	0.2249*** (0.0574)	0.1950*** (0.0578)
SOI × apprenticeship				0.0718 (0.2481)	0.1169 (0.2475)
SOI × uni degree				0.1830 (0.2854)	0.4345 (0.2907)
Tradability		0.0063** (0.0026)	0.0213*** (0.0061)	0.0062** (0.0026)	0.0255*** (0.0063)
SOI × Tradability			-0.1130*** (0.0389)		-0.1454*** (0.0402)
Working experience	0.0093*** (0.0018)	0.0093*** (0.0018)	0.0094*** (0.0018)	0.0092*** (0.0018)	0.0094*** (0.0018)
Age	0.0295*** (0.0018)	0.0295*** (0.0015)	0.0294*** (0.0015)	0.0295*** (0.0015)	0.0294*** (0.0015)
Marital status (married = 1)	0.0149* (0.0080)	0.0150* (0.0080)	0.0152* (0.0080)	0.0149* (0.0080)	0.0150* (0.0080)
Risk aversion	0.0006 (0.0007)	0.0006 (0.0007)	0.0006 (0.0007)	0.0006 (0.0007)	0.0006 (0.0007)
Living in West Germany (west = 1)	0.0693 (0.0425)	0.0697 (0.0426)	0.0689 (0.0426)	0.0694 (0.0426)	0.0682 (0.0426)
Firm size	0.0049*** (0.0009)	0.0048*** (0.0009)	0.0048*** (0.0009)	0.0049*** (0.0009)	0.0048*** (0.0009)
Trained for occupation	0.0326*** (0.0055)	0.0321*** (0.0055)	0.0320*** (0.0055)	0.0321*** (0.0055)	0.0321*** (0.0055)
Constant	0.9904*** (0.0660)	0.9856*** (0.0680)	0.9641*** (0.0686)	0.9961*** (0.0726)	0.9788*** (0.0729)
Industry fixed effect	Yes	Yes	Yes	Yes	Yes
Individual fixed effect	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes
Observations	58,904	58,904	58,904	58,904	58,904
R ² within	0.0831	0.0833	0.0835	0.0833	0.0837
R ² between	0.1254	0.1308	0.1310	0.1311	0.1317
R ² overall	0.1023	0.1076	0.1077	0.1079	0.1084

Note: The table shows the results of the regressions on person-year panel data using fixed-effects estimators. Dependent variable: log of hourly wage. Robust standard errors in parentheses. ***/**/* denote statistical significance at the 1%, 5% and 10% levels, respectively. Reference group for qualification dummies: individuals who do not have any professional qualifications. Reference group for marital status dummy: individuals who are single or divorced. Reference group for regional sample: individuals living in eastern Germany. Data sources: SOEP, OECD's ICIO and O*NET databases.

workers. Since the coefficients of the interaction terms are not significant, this suggests that the skill level neither strengthens nor weakens the impact of service offshoring on wages. This is different from the effect of tradability as a reinforcing factor on the relationship between service offshoring and wages.

In Model 5, we include all interactions from Models 3 and 4. The result is consistent with what we obtained above from these two models, namely that the coefficient of the interaction between *SOI* and tradability is negative and statistically significant, while the coefficients of the interactions between *SOI* and qualifications are not significant.

It is important to note that this result exclusively reflects the effects of offshoring and substitution by imports. It thus excludes possible changes of the domestic production structure and of exports, which – as trade theory suggests – should lead to a general increase of productivity and wages.

4.2 | Robustness check with instrumental variable

We address the endogeneity issue of reverse causality that higher domestic wages could increase service offshoring by using the world export supply of intermediate services as an instrumental variable to re-estimate the impact of service offshoring on wages. Table 5 presents the results of the IV-2SLS regressions with fixed-effects estimators.

The *SOI* coefficients in Models 1 and 2 are negative and statistically significant, suggesting that workers' wages are negatively affected by increasing service offshoring. The magnitude of the impact is considerably larger than the baseline results in Table 4, namely that a one percentage point increase in service offshoring leads to a 2.7% decrease in German workers' hourly wages. This implies that the sole impact of service offshoring on wages is likely to be mitigated by the reverse causality between service offshoring and wages. In other words, the positive impact that wages in the home economy might have on service offshoring is likely to mitigate the dampening effect of service offshoring on wages. Other independent variables such as skill levels and tradability, and control variables are robust and consistent with the baseline results.

We further run the IV-2SLS estimation for models with interaction terms. In Model 3, the coefficient of the interaction between *SOI* and tradability is significant and slightly more negative than in the OLS estimation. This confirms our finding that workers with tradable occupations are on average more exposed to increasing service offshoring in terms of wages. The result of Model 4 is also similar to the one shown in Table 4 where the coefficients of the interactions between *SOI* and qualifications are not significant. In Model 5 where we include all interaction terms, none of them are statistically significant. Nevertheless, including more and more interactions in a regression is likely to cause distortion and difficulties in interpreting the main effect, especially when we have a category variable (e.g., qualifications). Thus, we propose to look at the interaction of *SOI* with tradability and qualification separately to capture the individual effect of each dimension on the relationship between wages and service offshoring. A more comprehensive view requires better data sources. When we test for the endogeneity of the endogenous variables, the statistics in Models 1 and 2 suggest that service offshoring is indeed endogenous. As a rule of thumb, the interactions of service offshoring with tradability and qualifications are also endogenous as indicated by the test result in Models 3 and 4, and need to be instrumented (see Table A2 in the Appendix for first-stage estimation). However, as we add more and more interactions leading to more and more corresponding endogenous variables, the degrees of freedom of χ^2 continue

TABLE 5 The effects of service offshoring on wages.

	IV-2SLS				
	Model 1	Model 2	Model 3	Model 4	Model 5
Service offshoring intensity	-2.7146** (1.084)	-2.7102** (1.0844)	-2.3996** (1.0784)	-3.2280** (1.3608)	-3.0136** (1.3693)
Qualification					
1. Apprenticeship	0.2348*** (0.0263)	0.2178*** (0.0377)	0.2329*** (0.0152)	0.1585* (0.0913)	0.1514* (0.0911)
2. Uni degree	0.2523*** (0.0484)	0.2262*** (0.0573)	0.2494*** (0.0236)	0.2159** (0.1078)	0.1850* (0.1086)
SOI × apprenticeship				0.5910 (0.7060)	0.6386 (0.7041)
SOI × uni degree				0.2908 (0.8534)	0.5493 (0.8629)
Tradability		0.0066** (0.0026)	0.0283** (0.0121)	0.0066** (0.0026)	0.0288* (0.0165)
SOI × Tradability			-0.1633* (0.0902)		-0.1673 (0.1197)
Control variables	Yes	Yes	Yes	Yes	Yes
Constant	1.1650*** (0.1029)	1.1593*** (0.1027)	1.1234*** (0.0944)	1.2190*** (0.1359)	1.1936*** (0.1379)
Endog. test of endog. regressors					
χ^2	5.221	5.189	5.326	6.958	6.928
p-value	.0223	.0227	.0697	.0733	.1398
Under-identification test					
Kleibergen–Paap rank LM stat. (χ^2)	439.481	439.596	433.987	421.188	418.201
p-value	.0000	.0000	.0000	.0000	.0000
Weak identification test					
Kleibergen–Paap rank Wald F stat.	425.890	425.980	210.475	136.366	101.603
Industry fixed effect	Yes	Yes	Yes	Yes	Yes
Individual fixed effect	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes
Observations	58,904	58,904	58,904	58,904	58,904
R^2 within	0.0753	0.0755	0.0762	0.0745	0.0753
R^2 between	0.1197	0.1247	0.1251	0.1253	0.1260
R^2 overall	0.0966	0.1015	0.1018	0.1021	0.1028

Note: IV-2SLS regressions on person-year panel data using fixed-effects estimators. Dependent variable: log of hourly wage. Robust standard errors in parentheses. ***/**/* denote statistical significance at the 1%, 5% and 10% levels, respectively. The Kleibergen–Paap rank LM statistic has a χ^2 distribution with degrees of freedom equal to one. The endogeneity test statistic has a χ^2 distribution with degrees of freedom equal to the number of endogenous regressors in each model, namely, service offshoring intensity and its interactions with qualifications and tradability. Data sources: SOEP, OECD's ICIO and O*NET databases.

to increase. Finally, in Model 5, we can no longer reject the null hypothesis that the endogenous variables tested in the model can be treated as exogenous. This emphasises the distortion that arises from including too many interactions in a single model.

The validity and strength of our instruments are demonstrated by the statistics of the under-identification and weak identification tests. In all five models, these statistics suggest that the excluded instruments are relevant and strongly correlated with the endogenous variables. Looking more closely at the first stage estimation, the F test of excluded instruments also indicates that we have relatively strong instruments for our models. Moreover, the Angrist–Pischke (AP) statistics used to test the identification of individual endogenous variables show significant results, confirming our choice of instrument (see Table A2 in the Appendix).

In summary, the IV estimation suggests that the results obtained from OLS estimation are likely biased due to the endogeneity of service offshoring. When isolating the reversal effect of wages in the home economy on service offshoring, the sole effect of service offshoring on wages becomes more negative. This effect is amplified when workers are in relatively tradable occupations. Since the world export supply of intermediate services is shown to be a good instrument to address the endogeneity of service offshoring, we believe that the results from IV estimation can provide better insight into the relationship between service offshoring and wages of workers in Germany.

5 | CONCLUSION

This paper examines the wage effects of service offshoring on workers in Germany and how they depend on workers' characteristics, in particular their skill levels and the tradability of their occupations. To this end, we construct an index of the tradability of occupations in Germany using data on standardised work activities from the O*NET database. We combine this index with individual-level data from the Socio-Economic Panel and with industry-level data from OECD's Input-Output Tables. Our estimates control for a range of individual characteristics, occupations, and industries.

Our analysis yields two main findings. First, service offshoring leads to a negative effect on the wages of German workers on average. This means that wages of German workers generally suffer from foreign competition more than they benefit from the productivity gains resulting from service offshoring. However, the magnitude of the effect is rather small. After controlling for reverse causality, the net effect of service offshoring on wages becomes larger. Second, the tradability of occupations plays an important role in the relationship between offshoring of services and wages. Our tradability index highlights that many tradable occupations are highly skilled, and many lower tradable occupations require only low occupational skills. However, skill levels and occupation tradability are not necessarily correlated, as there are also many unskilled and tradable occupations as well as skilled and less tradable occupations. Our results suggest that the wages of workers in highly tradable occupations are negatively affected by offshoring of services. This implies that tradable occupations in Germany, regardless skill levels, are more exposed to foreign competition resulted from service offshoring than less tradable occupations. Since our study is deliberately limited to the import side of the economy, it highlights the challenges to individuals who work in occupations that compete with imports but do not suggest that service offshoring has overall negative effects on the domestic economy.

Overall, our paper contributes to the existing literature on service offshoring by providing empirical evidence on the wage effects of service offshoring in Germany. Since we explicitly focus on

the import side, a more comprehensive study at the macroeconomic level would be a possible research extension to capture the overall impact of service offshoring. Our analysis also emphasises the need to consider tradability in the classification of the labor force in the context of studies of increasing globalisation. Although we cannot find significant evidence for the role of skill levels in the relationship between wages and service offshoring in Germany, our results suggest that a more in-depth study of the interplay between skill levels and tradability and its impact on wages would be another interesting area for future research. This could be of particular interest for policy makers to improve the resilience of workers to increasing competitive pressures from abroad.

Our analysis is not without limitations. Our results only reflect the effects of service offshoring on the import side of the production process. Increasing service offshoring also leads to productivity increases and is therefore likely to induce changes in the structure of production and exports. However, studying this effect in more detail poses significant challenges. The reason is that, in our data set, domestic service producers export intermediate services and domestic goods producers export intermediate goods, including services, which are usually bundled with goods and cannot be separated, as pointed out also by Miroudot and Cadestin (2017). Therefore, studying the effects of service offshoring on the export side requires a different approach, which is beyond the scope of the present paper. Another limitation stems from the fact that we do not have data linking individual workers to individual firms, but only to industries, i.e., we do not have matched worker-firm data. As a result, we cannot further analyse in-house activities and re-estimate the tradability of routine and non-routine activities within the boundaries of the firm.

ACKNOWLEDGEMENTS

we would like to thank the editor and the two anonymous referees for their valuable comments and suggestions. Open Access funding enabled and organized by Projekt DEAL.

DATA AVAILABILITY STATEMENT

A part of the data that support the findings of this study is provided by the German Institute for Economic Research, DIW Berlin. Restrictions apply to the availability of these data, which were used under licence for this paper. Data access is only available under a signed agreement with DIW Berlin. More information at https://www.diw.de/en/diw_01.c.678568.en/research_data_center_soep.html.

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How to cite this article: Frenkel, M., & Ngo, N. T. (2024). Service offshoring and its impacts on wages: An occupation-oriented analysis of Germany. *The World Economy*, 47, 1615–1641. <https://doi.org/10.1111/twec.13495>

APPENDIX

TABLE A1 Work activities' detailed description.

No.	Work activity	Work activity description
1	Analysing data or information	Identifying the underlying principles, reasons, or facts of information by breaking down information or data into separate parts
2	Assisting and caring for others	Providing personal assistance, medical attention, emotional support, or other personal care to others such as coworkers, customers, or patients
3	Coaching and developing others	Identifying the developmental needs of others and coaching, mentoring, or otherwise helping others to improve their knowledge or skills
4	Communicating with persons outside organisation	Communicating with people outside the organisation, representing the organisation to customers, the public, government, and other external sources. This information can be exchanged in person, in writing, or by telephone or e-mail
5	Communicating with supervisors, peers, or subordinates	Providing information to supervisors, co-workers, and subordinates by telephone, in written form, e-mail, or in person
6	Controlling machines and processes	Using either control mechanisms or direct physical activity to operate machines or processes (not including computers or vehicles)
7	Coordinating the work and activities of others	Getting members of a group to work together to accomplish tasks
8	Developing and building teams	Encouraging and building mutual trust, respect, and cooperation among team members
9	Developing objectives and strategies	Establishing long-range objectives and specifying the strategies and actions to achieve them
10	Documenting/recording information	Entering, transcribing, recording, storing, or maintaining information in written or electronic/magnetic form
11	Drafting, laying out, and specifying technical devices, parts, and equipment	Providing documentation, detailed instructions, drawings, or specifications to tell others about how devices, parts, equipment, or structures are to be fabricated, constructed, assembled, modified, maintained, or used
12	Establishing and maintaining interpersonal relationships	Developing constructive and cooperative working relationships with others, and maintaining them over time
13	Estimating the quantifiable characteristics of products, events, or information	Estimating sizes, distances, and quantities; or determining time, costs, resources, or materials needed to perform a work activity
14	Evaluating information to determine compliance with standards	Using relevant information and individual judgement to determine whether events or processes comply with laws, regulations, or standards

(Continues)

TABLE A1 (Continued)

No.	Work activity	Work activity description
15	Getting information	Observing, receiving, and otherwise obtaining information from all relevant sources
16	Guiding, directing, and motivating subordinates	Providing guidance and direction to subordinates, including setting performance standards and monitoring performance
17	Handling and moving objects	Using hands and arms in handling, installing, positioning, and moving materials, and manipulating things
18	Identifying objects, actions, and events	Identifying information by categorising, estimating, recognising differences or similarities, and detecting changes in circumstances or events
19	Inspecting equipment, structures, or material	Inspecting equipment, structures, or materials to identify the cause of errors or other problems or defects
20	Interacting with computers	Using computers and computer systems (including hardware and software) to program, write software, set up functions, enter data, or process information
21	Interpreting the meaning of information for others	Translating or explaining what information means and how it can be used
22	Judging the qualities of things, services, or people	Assessing the value, importance, or quality of things or people
23	Making decisions and solving problems	Analysing information and evaluating results to choose the best solution and solve problems
24	Monitor processes, materials, or surroundings	Monitoring and reviewing information from materials, events, or the environment, to detect or assess problems
25	Monitoring and controlling resources	Monitoring and controlling resources and overseeing the spending of money
26	Operating vehicles, mechanised devices, or equipment	Running, manoeuvring, navigating, or driving vehicles or mechanised equipment, such as forklifts, passenger vehicles, aircraft, or water craft
27	Organising, planning, and prioritising work	Developing specific goals and plans to prioritise, organise, and accomplish your work
28	Performing administrative activities	Performing day-to-day administrative tasks such as maintaining information files and processing paperwork
29	Performing for or working directly with the public	Performing for people or dealing directly with the public. This includes serving customers in restaurants and stores, and receiving clients or guests
30	Performing general physical activities	Performing physical activities that require considerable use of your arms and legs and moving your whole body, such as climbing, lifting, balancing, walking, stooping, and handling of materials

TABLE A1 (Continued)

No.	Work activity	Work activity description
31	Processing information	Compiling, coding, categorising, calculating, tabulating, auditing, or verifying information or data
32	Provide consultation and advice to others	Providing guidance and expert advice to management or other groups on technical, systems-, or process-related topics
33	Repairing and maintaining electronic equipment	Servicing, repairing, calibrating, regulating, fine-tuning, or testing machines, devices, and equipment that operate primarily on the basis of electrical or electronic (not mechanical) principles
34	Repairing and maintaining mechanical equipment	Servicing, repairing, adjusting, and testing machines, devices, moving parts, and equipment that operate primarily on the basis of mechanical (not electronic) principles
35	Resolving Conflicts and negotiating with others	Handling complaints, settling disputes, and resolving grievances and conflicts, or otherwise negotiating with others
36	Scheduling work and activities	Scheduling events, programs, and activities, as well as the work of others
37	Selling or influencing others	Convincing others to buy merchandise/goods or to otherwise change their minds or actions
38	Staffing organisational units	Recruiting, interviewing, selecting, hiring, and promoting employees in an organisation
39	Thinking creatively	Developing, designing, or creating new applications, ideas, relationships, systems, or products, including artistic contributions
40	Training and teaching others	Identifying the educational needs of others, developing formal educational or training programs or classes, and teaching or instructing others
41	Updating and using relevant knowledge	Keeping up-to-date technically and applying new knowledge to your job

Note: Work activities with detailed description. Source: O*NET database (2022).

TABLE A2 IV-2SLS regressions – first stage.

	Model 1	Model 2	Model 3
	SOI	SOI	SOI × tradability
ln(WISIS_G)	-0.0239*** (0.0010)	-0.0239*** (0.0010)	-0.0238*** (0.0011)
ln(WISIS_G) × Tradability			-0.0199*** (0.0007)
Qualification			
1. Apprenticeship	0.0030*** (0.0009)	0.0030*** (0.0009)	0.0030*** (0.0009)
2. Uni degree	0.0014 (0.0009)	0.0013 (0.0009)	0.0028 (0.0060)
Tradability			
	0.0001 (0.0001)	0.0001 (0.0001)	0.4089*** (0.0112)
Control variables	Yes	Yes	Yes
Constant	0.3652*** (0.3652)	0.3651*** (0.0137)	0.3628*** (0.0139)
F test of excl. instruments	425.89	425.98	215.49
AP χ^2	426.48	426.58	403.04
AP χ^2 p-value	.0000	.0000	.0000
AP F statistic	425.89	425.98	402.46
Industry fixed effect	Yes	Yes	Yes
Individual fixed effect	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes
Observations	58,904	58,904	58,904
R ² within	0.8274	0.8274	0.8538

TABLE A.2 (Continued)

	Model 1		Model 2		Model 3	
	SOI	SOI × apprent.	SOI	SOI × apprent.	SOI	SOI × tradability
R^2 between	0.6171		0.6174		0.6174	0.8809
R^2 overall	0.6670		0.6673		0.6674	0.8831
	Model 4		Model 5			
	SOI	SOI × apprent.	SOI	SOI × apprent.	SOI × uni	SOI × tradability
ln(WISIS_G)	-0.0230*** (0.0011)	-0.0059*** (0.0016)	-0.0230*** (0.0011)	-0.0062*** (0.0016)	-0.0021* (0.0012)	-0.0141*** (0.0051)
ln(WISIS_G)×apprent.	-0.0008** (0.0003)	-0.0190*** (0.0010)	-0.0008** (0.0003)	-0.0191*** (0.0010)	0.0012*** (0.0004)	0.0020 (0.0022)
ln(WISIS_G)×uni	-0.0014*** (0.0003)	-0.0005 (0.0013)	-0.0013*** (0.0004)	-0.0009 (0.0013)	-0.0166*** (0.0012)	0.0031 (0.0032)
ln(WISIS_G)×Tradability			-0.00003 (0.00008)	0.0002* (0.0001)	-0.0002* (0.0001)	-0.0200*** (0.0007)
Qualification						
1. Apprenticeship	0.0148*** (0.0052)	0.3961*** (0.0152)	0.0147*** (0.0052)	0.3975*** (0.0153)	-0.0198*** (0.0065)	-0.0331 (0.0317)
2. Uni degree	0.0212*** (0.0057)	0.0083 (0.0190)	0.0205*** (0.0060)	0.0147 (0.0194)	0.3490*** (0.0185)	-0.0406 0.0459
Tradability	0.0001 (0.0001)	-0.00004 (0.0001)	0.0006 (0.0012)	-0.0041 (0.0023)	0.0037* (0.0020)	0.4108*** (0.0115)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.3524*** (0.0142)	0.0191 (0.0217)	0.3519*** (0.0143)	0.0234 (0.0219)	0.0119 (0.0156)	0.0430 (0.0664)

(Continues)

TABLE A2 (Continued)

	Model 4			Model 5			
	SOI	SOI × <i>apprent.</i>	SOI × <i>uni</i>	SOI	SOI × <i>apprent.</i>	SOI × <i>uni</i>	SOI × <i>tradability</i>
F test of excl. instruments	147.71	387.7	156.77	111.08	291.49	118.67	317.44
AP χ^2	321.42	410.59	320.22	314.32	410.59	302.86	1126.73
AP χ^2 p-value	.0000	.0000	.0000	.0000	.0000	.0000	.0000
AP F statistic	320.95	409.99	319.75	313.85	409.98	302.41	1125.05
Industry fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individual fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	58,904	58,904	58,904	58,904	58,904	58,904	58,904
R ² within	0.8275	0.7188	0.5116	0.8275	0.7188	0.5118	0.8538
R ² between	0.6173	0.8713	0.9043	0.6173	0.8713	0.9045	0.8808
R ² overall	0.6672	0.8750	0.9006	0.6672	0.8750	0.9007	0.8832

Note: First stage of IV-2SLS regressions on person-year panel data using fixed-effects estimators. Robust standard errors in parentheses. ***/**/* denote statistical significance at the 1%, 5% and 10% levels, respectively. The Angrist-Pischke (AP) χ^2 is distributed with degrees of freedom equal to one. Data sources: SOEP, OECD's ICIO and O*NET databases.

TABLE A3 Correlation matrix.

	Ln wage	SOI	no qual	Apprent	Uni	Tradability	Exper	Age	Married	Risk	West	Firm size	Trained
Ln wage	1.00												
SOI	.1341	1.00											
No qual	-.2428	.0180	1.00										
Apprent	-.1902	.0618	-.4533	1.00									
Uni	.3889	-.0789	-.2351	-.7562	1.00								
Tradability	.4878	-.0786	-.2530	-.2891	.5036	1.00							
Exper	.2601	.1406	-.1292	.1399	-.0536	-.0351	1.00						
Age	.2098	-.0309	-.1789	.0824	.0490	.0387	.7080	1.00					
Married	.1347	.0386	-.0533	.0040	.0395	.0102	.1972	.2777	1.00				
Risk	.0412	.0591	.0144	-.0113	-.0003	-.0160	.0288	-.0850	-.0483	1.00			
West	.1465	.0452	.1026	-.0586	-.0117	.0185	-.0864	-.0418	.0370	-.0100	1.00		
Firm size	.2886	.1278	-.0670	-.0567	.1118	.1748	.0479	-.0079	-.0145	-.0152	.0419	1.00	
Trained	.3124	-.0728	-.2994	.0110	.2110	.3422	.0077	-.0142	.0161	-.0020	-.0035	.0466	1.00