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Bergmann, Friedrich

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ESSAYS ON INTERNATIONAL TRADE

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CBS COPENHAGEN BUSINESS SCHOOL
HANDELSHØJSKOLEN

Essays on International Trade

Friedrich Bergmann

Supervisor: Dario Pozzoli

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Preface

This Ph.D. thesis is the result of my studies at the Department of Economics at Copenhagen Business School. I am grateful for all the support and I want to thank the Danish Research Council for Social Science for providing the research grant (#DFF 4003-00004B) "FDI productivity spillovers and profit shifting" that included the funding of my studies and supported my stay at the University of Oxford.

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I would like to thank David Jinkins, Pascalis Raimondos and Lisbeth La Cour for supervising my studies. Thank you for all the guidance, the encouragement, the support when applying for grants and the discussion of my chapters. I have learnt a lot from you. I am also very grateful to Fane Groes and Anna Maria Pinna for providing me with useful comments and suggestions how to improve my chapters during the closing seminar. I had the excellent opportunity to spend part of my studies as a recognised student at the University of Oxford. My deepest appreciation to Pascalis Raimondos and Beata Javorcik for making that stay possible. Furthermore, I want to thank Beata Javorcik for being my academic advisor during that period and for discussing research ideas with me. That was truly an enriching experience and your comments helped me a lot.

A special mention should also go to my co-authors, Federico Clementi, Ben Kett and Katherine Stapleton. It was a great pleasure working with you. Thank you so much for the countless hours and all the hard work you have put in our papers.

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Abstract

This Ph.D. thesis consists of three independent chapters that cover different topics of International Economics. While independent, each chapter attempts to contribute to our understanding of international trade.

The first chapter, entitled “Vertically Integrated Multinationals and Productivity Spillovers”, is written together with Federico Clementi and studies how vertical integration of multinational companies affects the productivity spillover to local suppliers. Previous studies have identified that interaction with a foreign company can influence the production of the local company, leading to a productivity spillover. We argue that foreign affiliates of vertically integrated multinational companies will likely source inputs within the boundaries of their group, and source less from local suppliers. This decrease in interactions with local suppliers reduces the potential for productivity spillovers. Therefore we expect that local suppliers receive a lower productivity spillover from interactions with foreign affiliates of vertically integrated multinational companies compared to spillovers arising from interactions with non-integrated multinational companies. We test our hypothesis using a rich firm-level panel data set of European manufacturing companies. Our results indicate that productivity spillovers to local suppliers only occur if the foreign affiliate does not belong to a multinational company that is vertically integrated in the industry of the local firm.

In the second chapter, “Technology and Global Value Chains: Evidence from Denmark”, written together with Katherine Stapleton, we study the consequences of automation on offshoring to developing countries. The offshoring of low-skilled labour intensive manufacturing from high-income countries to developing countries has been an important force for productivity growth and development. The recent advances in automation technologies could allow firms to substitute low-skilled labour in developing countries with automation in their home countries. In this case we would expect a decline in offshoring, and a ’reshoring’

of manufacturing production back towards the home country. To test this hypothesis, we use a matched worker-firm dataset of Danish manufacturing firms and construct measures of narrow offshoring to high, middle and low-income countries. We then construct measures of supply-side improvements in the capabilities of robots by mapping categories of commercially available robots to occupations conducting similar tasks. This allows us to construct firm-level shift-share instruments for industrial robot exposure. Our results indicate that firms more exposed to industrial robots increase their offshoring to all countries, in particular to low and middle income countries. Furthermore, we find that only those low and middle income countries that already had a standing business relationship benefit from the increase in offshoring.

The third chapter, entitled "Firm Upskilling in Response to Trade Shocks: Evidence from Denmark", is written together with Ben Kett, and studies how international trade shocks influence upskilling on the firm- and worker-level. If the trading activity of a firm increases the skill intensity in production, workers might need to adapt their skill sets to meet the new demands. We analyze whether an increase the trading activity of the firm increases workers‘ participation in adult education and training using a matched employer-employee dataset of Danish manufacturing firms over the period 2001-2013. We identify exogenous changes in the firms' trading activity using World Import Demand, World Export Supply and transport costs to instrument for exporting, importing and offshoring, respectively. Our results indicate that trade shocks lead to upskilling of firms and workers. On the firm-level we find that importers and offshorers increase their skill intensity and importers train their workers. At the worker level we find that both exporting and importing increase the probability that workers start vocational courses. For importing we find a different effect depending on the education of the worker, with unskilled workers being more likely to start vocational courses than skilled workers.

Sammanfattning (Abstract – Swedish)

Det första kapitlet, med titeln “Vertically Integrated Multinationals and Productivity Spillovers ”, är skriven tillsammans med Federico Clementi och studerar hur vertikal integration av multinationella företag påverkar produktivitetsspillovers till lokala leverantörer. Tidigare studier har visat att interaktion med ett utländskt företag kan påverka produktionen hos det lokala företaget, vilket kan leda till ökad produktivitet. Vi argumenterar att utländska dotterbolag till vertikalt integrerade multinationella företag sannolikt kommer att inhandla insatsvaror inom deras egen företagsgrupp, och därför kommer handla mindre med lokala leverantörer. Denna minskning av interaktioner med lokala leverantörer leder då till mindre produktivitetsökningar. Vi förväntar oss därför att lokala leverantörer får ett lägre produktivitetsutbyte från interaktioner med utländska dotterbolag till vertikalt integrerade multinationella företag jämfört med interaktioner som härrör från interaktion med icke-integrerade multinationella företag. Vi testar denna hypotes med hjälp av en rik paneldatasats för europeiska tillverkningsföretag. Våra resultat indikerar att produktivitetsökningar hos lokala leverantörer endast inträffar om det utländska medlemsföretaget inte tillhör ett multinationellt företag som är vertikalt integrerat i det lokala företagets bransch.

I det andra kapitlet, “ Technology and Global Value Chains: Evidence from Denmark ”, skriven tillsammans med Katherine Stapleton, studerar vi konsekvenserna av automatisering på offshoring för utvecklingsländer. Offshoring av lågkvalificerad, arbetskraftsintensiv tillverkning från höginkomstländer till utvecklingsländer har varit en viktig kraft för produktivitetstillväxt och utveckling. De senaste framstegen inom automationsteknik kan dock ha möjliggjort för företag att ersätta lågutbildade arbetskraft i utvecklingsländer med högkvalificerad, automatiserad produktion i sina hemländer. Om det har skett förväntar vi oss en minskning av offshoring och en "reshoring" av tillverkningsproduktionen tillbaka mot hemlandet. För att testa den här hypotesen använder vi en databas där vi kan koppla sam-

man arbetare med danska tillverkningsföretag, och konstruerar mått på offshoring till hög-, medel- och låginkomstländer. Vi konstruerar sedan mått på utbudsförbättringar i robotkapacitet genom att matcha kategorier av kommersiellt tillgängliga robotar till yrken som utför liknande uppgifter. Detta gör det möjligt för oss att konstruera 'shift-share" instrument på företagsnivå på exponering mot industriroboter. Våra resultat indikerar att företag som är mer exponerade för industriroboter ökar sin offshoring till alla länder, särskilt till länder med låg inkomst och medelinkomst. Slutligen finner vi att endast de låg- och medelinkomstländer som redan hade en stående affärsrelation gynnas av ökningen av offshoring.

Contents

Introduction

This thesis consists of three chapters that attempt to improve our understanding of international trade and multinational production. All three chapters are quantitative micro-based studies. Chapter one and two consider different ways a firm can produce in another country. The first chapter considers foreign direct investment. In particular, we study the question whether local firms perceive productivity spillovers from foreign firms and how the intensity depends on the investment strategy of multinational companies (MNC). Javorcik (2004) introduced a new perspective to the literature by pointing out that spillovers mainly occur between foreign firms and local suppliers and. We argue that this interaction between the firms depends on the on the investment structure of the multinational company. In case the MNC is vertically integrated and has invested in industries that are connected by the value chain, they will likely source inputs within the boundaries of the group and interact less with local suppliers. Our results indicate that productivity spillovers to local suppliers only occur if the foreign affiliate does not belong to a MNC that is vertically integrated in the industry of the local firm. This result can be used to make an important policy recommendation. Governments invest in costly policies to attract foreign direct investment and subsidies are often given on case to case basis. If the effect on local firms is a determinant in the decision, our study would suggest that governments should analyse the investment structure of the MNC to increase potential productivity spillovers.

The second chapter is not considering foreign direct investment as a way to produce in another country, but offshoring of products the firm produces in the home country. We analyse how the value of offshoring to both high income and low and middle income countries changes with a firms‘ exposure to industrial robots. The model we use combines two key frameworks from recent literature: firm heterogeneity (Melitz (2003)) and a task based framework building upon Acemoglu and Restrepo (2018) but we include the option to offshore in addition to the option to automate. Our results show that robot exposure leads firms to increase offshoring to both high income and low and middle income countries, with an even greater increase for the latter. However, the increase to low and middle income countries only occurs for countries that are existing offshoring destinations. The policy recommendation that can be drawn from this study is not focused on the offshoring country itself but other countries that receive offshoring and can use the increase in demand for development. Our results would suggest that automation appears to have a positive impact on offshoring and less developed countries might benefit by establishing business links with additional partner countries.

While the focus of the second chapter is to analyze a firms‘ value of offshoring, the third chapter studies how international trade changes the demand for skilled labor and training of workers. Previous studies have identified that firms that are engaged in international trade increase the skill intensity (Bustos, 2011). Our study analyzes how an increase in the trading activity affects the share of high skilled workers in a firm and we also answer the question whether workers‘ participate in adult education and training. We build on the framework of Hummels et al. (2014) and our results indicate that importing and offshoring increase the skill-intensity of a firm and that exporting and importing increase the probability that workers start vocational courses.

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Chapter 1 - Vertically Integrated Multinationals and Productivity Spillovers

Vertically Integrated Multinationals and Productivity Spillovers

Friedrich Bergmann* and Federico Clementi†

Abstract

How does the activity of foreign multinationals affect the competitiveness of local companies in the host country? Previous studies have identified positive productivity spillovers from foreign companies to their local suppliers. However, those backward spillovers are not automatic. In this paper, we study how spillovers are affected by the investment strategy of foreign multinationals. Our analysis is based on firm-level data of European manufacturing companies and shows that local suppliers perceive productivity spillovers only if the foreign multinational is not vertically integrated in their industry.

*Copenhagen Business School Department of Economics

†Copenhagen Business School Department of Economics

1 Introduction

Governments invest in costly policies to attract foreign direct investments (FDI). These policies are driven by the belief that foreign direct investment will bring additional know-how and technologies to the their country that can boost the productivity and competitiveness of the local economy. An important question in the discussion about benefits from FDI is whether local companies gain from foreign presence. The interaction with a foreign company can influence the production of the local company and a productivity spillover might occur. The literature has typically focused on the existence of productivity spillovers but pays little attention to the multinational company behind the foreign affiliate. Another branch of the literature has focused on the strategy and motives of multinational companies (MNC) when investing abroad. One strategy is the so called "vertical integration", that is an investment in firms in different industries that are connected by the value chain. One motive of that strategy is to produce goods that can be used as inputs for production activities within the MNC's network.

In this paper we combine both these two fields of the literature and analyze how the strategy of vertical integration affects productivity spillovers to local firms. We argue that foreign affiliates of vertically integrated MNCs will likely source inputs within the boundaries of the group and source less from local suppliers. This decrease in interactions with local firms reduces the potential for productivity spillovers. We therefore expect that local firms receive a lower productivity spillover from foreign firms of vertically integrated MNCs compared to spillovers arising from interactions with non-integrated MNCs. We test our hypothesis using a rich firm-level panel data set of European manufacturing companies that allows us to identify each affiliate of a MNC. We construct two new measures of foreign presence that account for vertical integration of MNCs and relate them to the productivity of local firms. Our results indicate that productivity spillovers to local suppliers only occur if the foreign affiliate does not belong to a MNC that is vertically integrated in the industry of the local firm.

The existing literature on productivity spillovers usually considers two types, horizontal spillovers and backward spillovers. Horizontal spillovers can occur between local firms and foreign firms in the same industry, but the empirical evidence on this is inconclusive. The second type, backwards spillovers, refers to productivity spillovers from foreign firms to local firms in supplying industries and has been confirmed by numerous studies (Javorcik 2004; Blitzer et al. 2011; Aitken 1999). Such spillovers most likely occur through direct interactions between both firms, i.e. when a the local firm supplies inputs to the foreign firm. The literature offers several explanations of how such an interaction can increase the productivity of the local firm. It can be a deliberate knowledge transfer to the supplier to insure that the quality of inputs meet their production needs (Moran 2001). The direct interaction with the foreign firm may also increase the incentive to invest in research and upgrade management and technology. But even local firms that are not supplying the foreign firm can receive a productivity spillover through an indirect increase in competition among suppliers (Crespo and Fontoura 2007). Most of the literature in the field is identifying productivity spillovers by relating a measure of foreign presence to the productivity of all local firms. This approach can not distinguish between local firms that are actually supplying the foreign firm and those that are not. Testing whether the direct interaction is necessary to receive productivity spillovers would require transactional data. One exception in the field is Barrios et al. 2011. While not observing transactions, their data allow the authors to identify local firms that supply foreign affiliates. Their results indicate that productivity spillovers only occur between interacting firms. This result is essential for the hypothesis. We argue that foreign affiliates of integrated MNCs are less likely to interact with local suppliers due to input sourcing within the boundaries of the group and therefore should receive a smaller spillover.

There is vast body of theoretical and empirical literature that analyzes the organization of production of MNCs. The decision between purchasing inputs and producing them within the group is influenced by multiple factors, such as the industry and productivity of the firm, the substitutability and complementarity of inputs, the distance from final consumption, the elasticity of demand and the existence of trade costs (Antras 2003, 2005, Antras and Helpman 2004; Antras and Chor 2013; Alfaro et al 2016). One empirical paper has analyzed the degree of vertical integration pursued by MNCs. Alfaro and Charlton (2009) studied American MNCs and conclude that most foreign affiliates represent vertical investments and that the industries are closely interconnected by the value chain. This investment strategy suggests that MNCs focus on buying suppliers to source inputs within the boundaries of the group instead of interacting with unaffiliated suppliers. Identifying the real extent of intra-group sourcing requires transactional data for all affiliates within a MNC. The paper of Ramondo et al (2016) is using a firm-level data set of American MNCs that includes the value of sales to the parent of the group and other affiliates. Their results indicate that intra-group sourcing might not be the only motivation for vertical investments since the average affiliate sells 27% of total sales to other affiliates.

To summarize, the spillover literature indicates that local firms receive a productivity spillover when supplying a foreign firm. The literature on the organization of production within MNCs indicates that vertical integration is a common strategy and that affiliates of the group source a share of their inputs internally rather than locally entirely out-sourcing them. Both facts support our hypothesis, that the productivity spillover from foreign affiliates of a vertically integrated MNCs should be lower compared to non-integrated MNCs.

The remainder of the paper is organized as follows. In section 2 we presents our empirical strategy. We explain how we measure the presence of foreign firms and how we estimate the productivity of local firms. Section 3 describes our data set. In section 4 we present the regression results and in section 5 we present suggestive evidence for intra-group sourcing. The last section concludes and discusses the implications of our results.

2 Empirical Strategy

In this section we describe our empirical strategy and the measures we construct for foreign presence and vertical integration.

We identify spillovers by relating the productivity of a local firm to the presence of foreign firms. In theory, we expect that the intensity of productivity spillovers increases with the extent of foreign presence. We use a panel data set of local firms and estimate a fixed effect regressions. Our baseline model for a local firm i in industry j and country c in year t is:

$$tfp_{ijct} = \alpha_i + \alpha_1 Vertical_{jct-1} + \alpha_2 Horizontal_{jct-1} + \alpha_X X_{it} + \delta_t + \delta_{ct} + \delta_{st} + \epsilon_{it} \quad (1)$$

where tfp_{ijct} is an estimate of the total factor productivity of the local firm. $Horizontal_{jct}$ is an industry-country-time specific measure for the presence of foreign firms in the same industry as the local firm and is intended to capture horizontal productivity spillovers. $Vertical_{jct}$ is a set of various measures for the presence of foreign firms in downstream industries and is intended to capture backward productivity spillovers. Specific specifications of the measures in $Vertical_{jct}$ will capture vertical integration of MNCs. We assume that productivity spillovers are not immediate, since the local firm needs time to react to interactions with foreign firms. X_{it} is set of control variables that may affect the productivity of the local firm. We include a set of time δ_t, country-time δ_{ct} and sector[1]-time δ_{st} dummies to control for differences and trends in productivity across sectors and countries over time. To summarize, our empirical strategy is using changes in foreign presence in jct and relate them to explain changes in the local firms‘ productivity.

2.1 FDI horizontal and vertical penetration indexes

In this section we describe how we measure the presence of foreign firms and how we account for vertical integration of multinational business groups.

[1]industries j are defined on the four digit level and sectors s are defined on the three digit level

Our measures of foreign presence are related to the ones in Javorcik (2004) but we use a different definition of foreign firms and we modify them to account for vertical integration. At first, we define the *generic* measure and disregard other investments of the MNC.

The horizontal penetration index HP_{jct} measures the presence of foreign firms in the industry of the local firm. For each industry j in country c at time t, HP_{jct} is defined as,

$$HP_{jct} = \frac{\sum_{i=1,\text{ in } jct}^{N} SALES_{it} * FDI_{it}}{\sum_{i=1 \text{ in } jct}^{N} SALES_{it}} \tag{2}$$

where FDI_{it} is a dummy equal to one if firm i is a foreign affiliate in year t. Holding all else equal, the value of HP_{jct} increases with the output of foreign firms. The index varies across time t, countries c and industries j but is identical for all local firms in a given jct.

The vertical penetration index VP_{jct} captures the potential for backward productivity spillovers between local suppliers and foreign firms. It measures the presence of foreign firms in all industries $k \neq j$ that are supplied by industry j. The index VP_{jct} is defined as,

$$VP_{jct} = \sum_{k=1, \neq j \text{ in } ct}^{N} \alpha_{jk} HP_{kct} \tag{3}$$

where α_{jk} is the proportion of industry js output of intermediates supplied to industry k. We calculate α_{jk} using the American input-output matrix provided by the Bureau of Economics Activity. All else equal, an increase in VP_{jct} reflects a weighted (α_{jk}) increase in foreign presence in a sector k that is supplied by sector j. Similar to the horizontal penetration index, VP_{jct} varies across industries j, countries c and time t but is identical for local firms in a given jct.

We modify the *generic* vertical penetration index to account for vertical integration of multinational business groups. Our hypothesis is that affiliates of MNCs are likely to source inputs within the boundaries of the group and therefore interact less with local firms. Consider a local firm in industry j that is supplying a specific industry k. Consider further that there is foreign affiliate in industry k that belongs to a business group that *has another affiliate* in the industry of the local firm (j). We expect that the foreign affiliate in industry k will primarily rely on the other affiliate of the business group when sourcing inputs from industry j and is less likely to interact with the local firm in industry j. To account for the vertical integration, we separate the total presence of foreign firms in downstream industries (VP_{jct}) into two components. VP_{jct}^{j} measures the presence of foreign firms belonging to business groups that have at least one affiliate in industry j and VP_{jct}^{-j} measures the presence of foreign firms belonging to business groups that are not vertically integrated in j.

We define a new dummy variable for foreign affiliates depending on other investments of the group. In the following we use industry j as the reference industry. FDI_{kit}^{j} is equal to one if the foreign affiliate

i in industry k at time t belongs to a business group that has at least one more affiliate in industry j. FDI_{kit}^{-j} equals one if the foreign affiliate in industry k belongs to business group that is not vertically integrated in industry j. Our dummy variables are not restricted on countries since we want to allow for intra-group sourcing across borders. The horizontal penetration in each industry k in country c at time t becomes,

$$
\begin{aligned}
HP_{kct}^{j} &= \frac{\sum_{i=1 \text{ in } kct}^{N} SALES_{it} * FDI_{kit}^{j}}{\sum_{i=1 \text{ in } kct}^{N} SALES_{it}} \\
HP_{kct}^{-j} &= \frac{\sum_{i=1 \text{ in } kct}^{N} SALES_{it} * FDI_{kit}^{-j}}{\sum_{i=1 \text{ in } kct}^{N} SALES_{it}}
\end{aligned} \tag{4}
$$

In a specific kct, HP_{kct}^{j} measures the share of sales of foreign affiliates that belong to business groups that control other affiliates in industry j. As before, we calculate the total presence of foreign firms in all downstream industries of j by,

$$
\begin{aligned}
VP_{jct}^{j} &= \sum_{k=1,\neq j \text{ in } ct}^{N} \alpha_{jk} HP_{kct}^{j} \\
VP_{jct}^{-j} &= \sum_{k=1,\neq j \text{ in } ct}^{N} \alpha_{jk} HP_{kct}^{-j}
\end{aligned} \tag{5}
$$

VP_{jct}^{j} measures the weighted shares of sales in all downstream industries ($k \neq j$) of foreign affiliates that belong to a business group that *also* has a affiliate in industry j. Both measures vary across time t, industries j and countries c but are identical for local firms in jct.

There several channels that can effect the value of VP_{jct}^{j}. First, a non-vertically integrated business group that has an affiliate in a downstream industry k in country c acquires an affiliate in industry j. Keeping all else equal, this change in the status of vertical integration would decrease VP_{jct}^{-j} and increase VP_{jct}^{j}. A local firm in industry j might see its opportunity of interaction with foreign affiliates reduced, since the business group could source inputs internally.

Second, a business group that is already vertically integrated in j, acquires a previously unaffiliated firm in a downstream industry k in country c. Keeping all else equal, this change would increase VP_{jct}^{j} while keeping VP_{jct}^{-j} constant.

Since the majority of MNCs invest in multiple industries, the populations of FDIs used to compute HP_{kct}^{-j} and HP_{kct}^{j} overlap across industries. Multinational groups that do not invest in industry j are likely integrated in a different industry. Therefore, the HPs and VPs consist of groups of foreign affiliates that are alike in several dimensions.

Applying the same input-output table to all countries is a compromise. Cross-industry flows in an input-output table are influenced by the production technology and factor prices. Since the countries in our sample are all integrated in the European Market we expect a high degree of correlation across country specific input-output tables. The main advantage of applying one table only is that the definition of vertical linkages across industries is identical for all countries. This is especially useful in the context of multinational companies.

2.2 Total Factor Productivity estimation

In this section we describe how we estimate the production function parameters and firms' productivity. Once we identify the production coefficients, we can retrieve the productivity as a residual.
Consider the following log transformation of a generic gross-output production function,

$$q_{it} = f(m_{it}, l_{it}, k_{it}; \beta) + \omega_{it} + \epsilon_{it} \tag{6}$$

The lower cases represent the natural logarithms of the production variables. Thus, q_{it} is the log of gross output, l_{it} log of labour, m_{it} the log of intermediate inputs, k_{it} is the log of capital. The production coefficients (and a constant term) are grouped in the vector (β). The element ω_{it} is the output shock observed by the firm but not by the researcher, finally ϵ_{it} represents the measurement error and idiosyncratic unexpected productivity shock, unobserved by both the econometrician and the company.

Arguably, the production function of multinational firms and local companies may be very different. Using a sample of local companies and MNCs' affiliates would imply the assumption that the two types of firms share a common production function. This might cause a bias in the estimation of production function coefficients of local companies and, as a consequence, of their productivity. Therefore, we estimate the production functions separately for each country-sector pair excluding the multinational firms from the sample. This allows for possible differences in the productions functions of local companies active in different sectors and countries. For each group we estimate productivities assuming two specification of production function, namely the Cobb-Douglas and the Translog. The first is the standard specification adopted in the literature, while the second offers the advantage of making the production functions more flexible as these are approximated using a polynomial of higher (second) degree. We estimate production functions for all country-sector pairs with at least 100 observations. This allows us to use a substantial sample for each estimation and allows us to achieve reliable estimates of production functions' coefficients and of firms' productivities.

To control for endogeneity of input usage when estimating the inputs' coefficients of the production function, we closely follow the two-step procedure developed in Ackerberg et al (2015) (hereafter ACF). As De Loecker (2013) discusses, if one expects economic variables to affect the productivity of firms, then it is theoretically consistent to include them in the law of motion of tfp. The law of motion indeed identifies which elements *may* have an impact on productivity. The author shows that the exclusion of relevant variables from the law of motion may lead to a bias in the estimation of production functions and, as a consequence, of the estimated total factor productivity. We follow that intuition of De Loecker and al (2016) that both firms' characteristics and aggregate variables - export behaviour and trade tariffs in their application - can affect firms' competitiveness and should therefore be included in the tfp law of motion.

In order to estimate the vector of production function paramenters (β) we implement the ACF procedure and define moments based on the innovation shock ξ_{it} in the evolution of productivity. We consider an endogenous law of motion of productivity that evolves over time according to a Markov process. We *allow* the evolution of productivity to depend on the characteristics of the business group-g to which firm-i is affiliated - whether it invests in multiple industries (MI_{gt}), the number of its affiliates (Nf_{gt}) and the relative importance of industry-j for the group ($rank_{jgt}$) - and on the activity of foreign affiliates in industry-j (HP_{jt}) and downstream industries (VP_{jt}).[2]

Formally, we consider a law of motion defined as follows:

$$\begin{aligned}\omega_{it} &= g(\omega_{it-1}, MI_{gt-1}, rank_{jgt-1}, Nf_{gt-1}, HP_{jt-1}, VP_{jt-1}) + \xi_{it} \\ &= \alpha_1\omega_{it-1} + \alpha_2\omega_{it-1}^2 + \alpha_3\omega_{it-1}^3 + \beta_1 MI_{gt-1} + \beta_{12} rank_{jgt-1} + \beta_3 Nf_{gt-1} + \gamma_1 HP_{jt-1} + \gamma_2 VP_{jt-1} + \xi_{it}\end{aligned} \tag{7}$$

The characteristics of firm-i's business group and the measured presences of FDI are included in the law of motion to account for the fact that these elements *may* affect productivity. Indeed, the affiliation of firms to a (vertically integrated) business group is likely associated with specific business strategies and transfer of technologies that may affect and improve the productivity of the single affiliates.

The presence of foreign-owned companies in the economy is expected to affect the competitiveness of local firms through multiple channels. Previous research on productivity spillovers has shown that the activity of FDI in the same or in downstream industries can induce changes in the productivity of local firms (e.g. Javorcik 2004, Carluccio and Fally 2013). For instance, local firms can imitate foreign competitors and adopt efficient management practices or acquire advanced know-how by hiring managers with a working experience in foreign affiliates. Moreover, the interaction of local companies with foreign-owned clients may allow them to learn new and more efficient technologies or it might induce them to directly invest in R&D to meet the clients' quality and timing requirements and improve their own competitiveness.

[2] For *unaffiliated* firms the variables Nf_{gt} and $rank_{jgt}$ are constant and equal to one, whereas the groups-specific variable MI_{gt} becomes firm-specific (MI_{gt}=MI_{it}), measuring how many industries the single firm is active in.

We emphasize again that in this specification these variables are *allowed* to impact productivity, but this does not mean that they will necessarily nor mechanically have an effect.[3]

In the first step of the ACF procedure, we estimate $\hat{\phi}_{it}$ and $\hat{\epsilon}_{it}$ in

$$q_{it} = \phi_{it} + \epsilon_{it} \tag{8}$$

where $\phi_{it} = f_{it}(m_{it}, l_{it}, k_{it}) + h(m_{it}, l_{it}, k_{it}, z_{it}, \delta_t)$, with h(.) representing the inverse material demand function that we use to proxy the unobserved productivity term. The estimate of the polynomial expansion ϕ_{it} measures the output net of the unexpected output shock and measurement error ϵ_{it} in eq.(8). We collect in z_{it} all the elements - other than expenditures in input variables - that affect firm-i residual demand and consequently its optimal consumption of intermediates.

These are $\{upVI_{jgt}, rank_{jgt}, BG_{gt}, HP_{jt}, VP_{jt}\}$. In section we have shown that the firms' consumption of intermediates varies with the level of upstream vertical integration ($upVI_{jgt}$) in their industry of the business group their are affiliated to and with the relative importance of their line of business for the group ($rank_{jgt}$). Due to reasons of technological complementarity and specific inputs needs, companies affiliated to a (vertically integrated) business group (BG_{gt}) are more likely to coordinate with related firms and comply with the strategy of the business group. Finally, through competitive pressure and technological spillovers, the activity of foreign affiliates may modify the residual demand of local firms affecting their the productivity and demand of materials. For example, foreign competitors may steal market shares from local companies. At the same time, foreign-owned companies compete also on the inputs markets with domestic companies. These latter would not be able to exploit economies of scale and would modify their demand of inputs. In order to meet the quality requirements of foreign clients, local firms may be have to change their sourcing strategy, purchasing inputs of higher quality or importing inputs endowed with foreign technologies.

To recover the innovation shock $\xi_{it}(\beta)$ for any value of β, we define productivity $\omega_{it}(\beta)$ as $\hat{\phi}_{it} - f_{it}(X_{it}, \beta)$ and we non-parametrically regress it on the third order polynomial of its lag and the first lags of the other elements included in the productivity law of motion defined in eq. (7).

In the second step, the production function coefficients are estimated through GMM, using as valid instruments the inputs orthogonal to the unexpected productivity shock. The moments that identify the production parameters are:

$$E[\xi_{it}(\beta) I_{it}] = 0 \tag{9}$$

where $I'_{it} \equiv (1, l_{it-1}, m_{it-1}, k_{it}, l^2_{it-1}, m^2_{it-1}, k^2_{it}, l_{it-1}m_{it-1}, l_{it-1}, k_{it}, m_{t-1}k_{it}, l_{it-1}m_{it-1}k_{it})$ is the vector

[3] As a robustness check we exclude all additional elements z_{it} from the law of motion. The results remain consistent (see Appendix D).

of instruments under the assumption of Translog production function. In the Cobb-Douglas specification this system becomes computationally much simpler as the vector of parameters β is reduced to $\beta = (\beta_0, \beta_l, \beta_m, \beta_k)$ and $I'_{it} = (1, l_{it-1}, m_{it-1}, k_{it})$. These instruments are all orthogonal to the unexpected innovation component of the productivity as they all are decided before the productivity shock is realized. We can now estimate the revenue-based total factor productivity as $\varphi_{it} = \hat{\phi}_{it} - f(X_{it}, \hat{\beta})$. We provide in Appendix C summary statistics of the production function coefficients.

Since we do not observe quantities and prices of the output and inputs used by the firm, we have to rely on deflated sales and input costs to proxy the physical output and inputs.[4] We are able to estimate revenue-based productivity (TFPR) that we use as a proxy of firms physical productivity (TFPQ). In the rest of the paper we will refer to the estimated TFPR as productivity. As formally discussed by De Loecker and Goldberg (2013), revenue-based productivity measures physical productivity and a combination of output and inputs' price deviations from industry price indexes. As these differences vary with firms' market power, the effects of FDI activity on local firms that we measure in the next section may partly capture the impact of foreign companies on local firms' markups rather than on their physical efficiency. The impact of FDI on local firm's markups does not have to be the same as the impact on their physical efficiency. Hence, the sign of the bias in our estimations is, at least, not clear. The reader should interpret our results heeding these considerations.

3 Data

To test our hypothesis, we use the *Amadeus* database provided by the Bureau van Dijk's and combine balance-sheet data and ownership data from eight different releases. Our sample consists of domestic and foreign-owned firms active in 35 European[5] in the period 2001-2008.

We restrict our sample to firms that have their main activity in a manufacturing industry according to NACE Revision 1 *and* NAICS 2007 classification. Manufacturing industries correspond to sectors 15-36 in the NACE Rev.1 classification and sectors 31-33 in the NAICS 2007 classification. Our empirical analysis is primarily based on the NAICS industry classification on a 4-digit level. We retrieve yearly, unconsolidated balance sheet data on revenues (S_{it}), tangible fixed assets (K_{it}), costs of materials (M_{it}), number of employees (L_{it}) and total wage bill (W_{it}), and ownership of the company. To identify all NACE and NAICS industries in which single firms are active in, we combine the information on primary and secondary industry codes. The main activity of a firm is classified as the

[4]Klette and Griliches (1996) argue that the use of industry-wide indexes might create a bias in our production function estimations.

[5]We provide a list of the countries in our sample in Appendix A.

industry in which the firm produces the largest total value added. The *Amadeus* data set provides information on the owner of a firm. The ultimate owner is the legal entity that directly or indirectly controls least 50% of the firm's shares.

Not all firms in our data set report complete financial information. Although information on one or more of the production variables may be missing, we know that the firm is operating in an industry and we want to use this information. Therefore, we consider all companies in our sample when we map the set of industries in which the groups invest.

In order to limit the loss of observations, we interpolate production variables for 9% of the firms in our sample. If the ownership information is missing, we assume that the firm is still controlled by the owner of the previous year. We deflate sales and materials using the appropriate 2-digit NACE Producer Price Index. Capital is deflated by using the country-average of the PPI deflators of five sectors that produce the bulk of capital inputs used in manufacturing.[6]
We trim our firm sample in several ways. First, we exclude firm observations with zero or negative values of production variables. Second, we eliminate outliers using ratios of production function variables and their growth rates. We drop firms at bottom and top 1% of the distribution on a year-sector-country level. Finally, we keep only observations with at least two consecutive years.[7]

This leaves us with an unbalanced panel of 2,024,899 firm-year observations, of which 3,13% are multinational companies.

3.1 Firm characteristics

In this section, we illustrate the extend of vertical integration of multinational companies and present summary characteristics of the firms in our sample.

A good example for a vertically integrated MNCs in our sample is the Siemens AG. Siemens is an integrated technology company that operates in the industry of electronics and electrical engineering and the head quater is located in Munich, Germany. The *core* business in Germany *core*[8] is *Engine, Turbine, and Power Transmission Manufacturing* (NAICS code 3336). The Siemens Business group controls 174 manufacturing subsidiaries of which 136 are located abroad. Only 8 of these foreign affiliates are horizontal FDI that operate in the industry of the Siemens' *core* business. The vast majority of the affiliates represents vertical FDI. Along the supply chain, Siemens invests most heavily in the

[6]Like in Javorcik (2004), these sectors are: machinery and equipment; office, accounting and computing machinery and apparatus; motor vehicles, trailers, and semi-trailers; other transport equipment.

[7]We refer the reader to Appendix A for a detailed description of the raw data, the interpolation strategy and the trimming procedure.

[8]The *core business* is the industry that has the highest value of sales within the BG in a country-c at time-t.

following industries: *Navigational, Measuring, Electromedical, and Control Instruments Manufacturing* (NAICS code 3345), *Electrical Equipment Manufacturing* (NAICS code 3353), *Other Electrical Equipment and Component Manufacturing* (NAICS code 3359) and *Other Fabricated Metal Product Manufacturing* (NAICS code 3329).

All of these industries are highly interdependent. For example a foreign affiliate producing *Electrical Equipment* could supply the *core* business *Engine, Turbine, and Power Transmission Manufacturing* and could also supply other foreign affiliates in *Navigational, Measuring, Electromedical, and Control Instruments Manufacturing.* Siemens' production network seems to be vertically integrated and has the potential for intra-group sourcing.

To analyze the degree of vertical integration we construct a simple dummy variable *Multi-industry* MI_{gt} that takes value one if the BG-g controls firms in more than one industry. Furthermore, we follow Acemoglu et al (2009) and compute an index of vertical integration in upstream industries. The index $upVI_{jgt}$ is specific for each BG-g and industry-j and is defined as:

$$upVI_{jgt} = \sum_{k \neq j} dr_{kj} \mathbb{1}(INV_{kgt} = 1) \tag{10}$$

The coefficient dr_{kj} is the *direct requirement* and measures the dollar value of industry-k's output that is required to produce a dollars worth of goods in industry-j. The coefficients are based on inter-industry trade in goods reported in the 2007 I/O Tables. The indicator $\mathbb{1}(INV_{kgt} = 1)$ takes value one if the business group-g controls at least one firm in industry-k at time-t.
The index $upVI_{jgt}$ measures the dollar value of inputs produced by industries in which the BG invests that is needed to produce one dollar worth in a given industry-j. The value of $upVI_{jgt}$is monotonically increasing in the number of industries the BG invests in *and* in the relevance of these industries for the specific industry j. Hence, the higher the value the larger the scope for intra-group sourcing. We first compute the index for each group-g and industry-j and then we assign the values to the affiliates according to their primary industry's code.

In Table 1, we report the summary statistics of firms distinguishing by type of affiliation, namely unaffiliated firms, companies affiliated to domestic business groups and firms controlled by multinational companies. We present the statistics of the degree of groups' vertical integration, the number of industries, countries and firms in which firms and business groups invest.

As it appears from the Table 1, companies affiliated to business groups are much larger than unaffiliated ones in every dimension.[9] They are bigger in terms of size (no. employees L_{it} and sales S_{it}) and endowment of capital. Both local and multinational business groups invest in several

[9]Financial variables are reported in thousands Euro

industries, but on average multinationals control more affiliates and invests in more industries than local business groups. The index of upstream vertical integration ($upVI_{jgt}$) is also higher for MNCs' affiliates than for firms that belong to local business groups. On average MNCs produce internally 8 cents worth of inputs for one dollar worth of their affiliates' output, local BGs produce only 1 cent worth of inputs. This statistic suggests that the average affiliate of MNCs is more likely to belong to a business group that owns companies in its supplying sectors than a firm controlled by a domestic BG.[10]

[10] Appendix E provides a test of equality for selected sumary variables.

Table 1: Summary statistics

		Mean	p10	p50	p90	sd
Unaffiliated firms	S_{it}	3629.24	71.00	682.40	6384.21	30511.26
	L_{it}	31.69	2.00	9.00	56.00	150.97
	M_{it}	1947.04	19.00	253.00	3187.00	20003.16
	K_{it}	799.08	6.07	90.13	1389.06	6971.03
	$upVI_{jgt}$	0.00	0.00	0.00	0.01	0.02
	MI_{gt}	0.24	0.00	0.00	1.00	0.43
	$\#\ industries_{it}$	1.49	1.00	1.00	2.00	1.31
	$\#\ industries_{gt}$	1.49	1.00	1.00	2.00	1.31
	# countries	1.00	1.00	1.00	1.00	0.00
	# firms	1.00	1.00	1.00	1.00	0.00
	FDI_{it}	0.00	0.00	0.00	0.00	0.00
Observations				1,799,586		
Domestic Business groups	S_{it}	15930.48	474.64	3577.98	28829.82	134544.29
	L_{it}	106.73	5.00	30.00	204.00	703.07
	M_{it}	8778.05	119.00	1454.00	15335.00	91038.65
	K_{it}	3091.78	25.77	437.30	5778.93	22939.52
	$upVI_{jgt}$	0.01	0.00	0.00	0.03	0.04
	MI_{gt}	0.49	0.00	0.00	1.00	0.50
	$\#\ industries_{it}$	1.39	1.00	1.00	2.00	0.95
	$\#\ industries_{gt}$	2.23	1.00	1.00	4.00	2.50
	# countries	1.00	1.00	1.00	1.00	0.00
	# firms	2.55	1.00	2.00	4.00	4.09
	FDI_{it}	0.00	0.00	0.00	0.00	0.00
Observations				134,121		
Multinationals	S_{it}	109716.75	2477.08	20527.70	171301.83	908671.06
	L_{it}	350.90	15.00	108.00	700.00	1653.98
	M_{it}	62503.16	832.00	9686.00	89818.00	647862.61
	K_{it}	17029.31	123.67	2852.45	30781.21	94556.42
	$upVI_{jgt}$	0.08	0.00	0.03	0.25	0.11
	MI_{gt}	0.90	0.00	1.00	1.00	0.30
	$\#\ industries_{it}$	1.51	1.00	1.00	3.00	1.13
	$\#\ industries_{gt}$	10.08	1.00	6.00	24.00	10.09
	# countries	6.55	2.00	4.00	15.00	5.68
	# firms	28.95	2.00	11.00	76.00	50.53
	FDI_{it}	0.69	0.00	1.00	1.00	0.46
Observations				91,192		

Table 2: FDI Indexes

	Mean	p10	p50	p90	sd
HP_{jct}	0.17	0.01	0.10	0.40	0.17
VP_{jct}	0.09	0.00	0.06	0.21	0.10
VP_{jct}^{-j}	0.06	0.00	0.04	0.13	0.06
VP_{jct}^{j}	0.03	0.00	0.02	0.08	0.06
			Correlations		
	HP_{jct}	VP_{jct}	VP_{jct}^{-j}	VP_{jct}^{j}	
HP_{jct}	1				
VP_{jct}	0.35	1			
VP_{jct}^{-j}	0.28	0.81	1		
VP_{jct}^{j}	0.27	0.78	0.26	1	
Observations			2,024,899		

Table 2 summarizes the measures of foreign presence that we defined in section 2.1. On average 17% of sales within an industry are made by foreign affiliates. The *generic* index of downstream penetration (VP_{jct}) is on average 9%. The two *specific* indexes of vertical penetration that account for vertical integration must be smaller than VP_{jct} since they measure the presence of specific subgroups. The average presence in downstream industries of foreign affiliates belonging to business groups that also control companies in industry j (VP_{jct}^{j}) is 3%, while VP_{jct}^{-j} is 6%.

4 Results

In this section we present the results of our empirical analysis.

We estimate different versions of the baseline specification described in section 2 and our results are reported in table 3. We estimate the fixed effect model under the assumption of Cobb-Douglas and Translog production function separately. In line with our specification of the productivity's law of motion defined in equation 7, the activity of foreign firms is allowed to affect the productivity of local firms after a one-year period. In each regression we control for the log capital intensity of the firm and the Herfindhal index HHI_{jct}. These controls limit concerns about a potential bias in the estimated effects of FDI activity, due to the endogeneity of foreign investments. We cluster the error terms at year-industry-country level, as this is the dimension at which the measures of foreign presence vary (Moulton 1990).

As a first step, we estimate the effect of foreign presence in downstream industries on the productivity of local firms without anticipating vertical integration of MNCs. This exercise is primarily aimed at testing whether, overall, local firms benefit from the presence of foreign clients. The results of the regressions are reported in column (1) and (5) of table 3. The coefficients of VP_{jct} are positive and highly significant indicating that the productivity of local firms increases with the presence of foreign firms in downstream industries.

Next, we include the indexes VP^{j}_{jct} and VP^{-j}_{jct} that account for vertical integration of MNCs. As presented in section 2.1, VP^{j}_{jct} measures the presence of foreign firms in downstream industries that belong to business groups that also control affiliates in industry j. The index VP^{-j}_{jct} measures the presence of foreign firms in downstream industries belonging to business groups that are not vertically integrated in sector j. We first include the two indexes separately (second and third column in each specification) and then together (fourth column). To test whether the intensities of productivity spillovers are different for the two groups, we perform a F-test of equality of the estimated coefficients. The results are displayed in columns (2)-(4) and (6)-(8) of table 3.

We find that only the coefficient of VP^{-j}_{jct-1} is positive and significant, whereas the coefficient VP^{j}_{jct-1} is always insignificant. Under the assumption of either production function's specification the F-test rejects the hypothesis of equality of coefficients. Our results show that the strategy of vertical integration of MNCs does in fact matter. Local firms receive productivity spillovers *only* from affiliates of MNCs that *do not* invest in their industry.

Our results for horizontal spillovers are only significant for the Cobb-Douglas production function. The coefficients of HP_{jct-1} suggests a positive productivity spillover from foreign firms to local firms in the same industry. Local firms may be pushed by stiffer competitive pressure or might be learning from foreign competitors. The coefficients of capital intensity indicate that the more a company invest in capital, the more efficient they become. The coefficient of the Herfindhal index is never significant indicating that there is no relation between the intensity of competition and the evolution of a firms' productivity.

As a robustness check, we implement the estimation of production functions and productivities of local companies imposing an exogenous law of motion. The regression results can be found in table D. Our results are consistent with the ones in table 3 leaving the estimation qualitatively unchanged.

Table 3: Productivity spillovers

$\mathbf{F(X,}\beta)$	Cobb-Douglas				Translog			
Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VP_{jct}	0.072***				0.056***			
	(0.020)				(0.019)			
VP^{j}_{jct}		-0.018		0.014		-0.029		-0.001
		(0.021)		(0.023)		(0.021)		(0.023)
VP^{-j}_{jct}			0.130***	0.134***			0.118***	0.118***
			(0.026)	(0.026)			(0.022)	(0.023)
HP_{jct}	0.012**	0.013**	0.012**	0.012**	0.006	0.006	0.006	0.006
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
$ln(K/L)_{it}$	0.014***	0.014***	0.014***	0.014***	0.001***	0.001***	0.001***	0.001***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
HHI_{jct}	0.014	0.014	0.013	0.013	0.000	-0.001	-0.001	-0.001
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
δ_t	YES	YES	YES	YES	YES	YES	YES	YES
δ_{ct}	YES	YES	YES	YES	YES	YES	YES	YES
δ_{st}	YES	YES	YES	YES	YES	YES	YES	YES
N.obs.	1,291,934	1,291,934	1,291,934	1,291,934	1,291,934	1,291,934	1,291,934	1,291,934
R2	.34	.34	.34	.34	.66	.66	.66	.66
$VP^{j}_{jct} = VP^{-j}_{jct}$				.00014				.000022

,,*** Statistically significant at 10, 5, 1%, respectively.

S.e. clustered by industry-year-country.

5 Evidence intra-group sourcing

In this section we provide suggestive evidence for intra-group sourcing.

The hypothesis that vertical integration decreases productivity spillovers is based on intra-group sourcing of MNCs. Due to the lack of transactional data we can not test for sourcing patterns directly. Instead, we want to present two facts that suggest internal sourcing. If internal sourcing was an important driver of the MNCs' decisions to invest abroad in a vertically-integrated manner, we should find that multinationals invest in industries that intensely trade intermediates and control affiliates that are geographically clustered to reduce shipment costs.

In line with Alfaro and Charlton (2009) and Antras et al (2012), we measure the intensity of industries' integration in the supply chain using two indexes. These are *direct requirement* (dr_{jk}) and *proximity* ($proximity_{jk}$). Both are based on the coefficients of inter-industry trade in goods between each pair of industries j and k reported in the 2007 I/O Tables provided by the Bureau of Economics Activity (BEA). The BEA Tables are provided at 6-digit code level, we reduce the level of detail to 4-digit as this is the level of aggregation in our data.

The higher the values of these indexes the more interdependent the two industries are in the supply chain. *Direct requirement* (dr_{jk}) is the value of goods from industry-k that industry-j needs to produce one dollar of its own output. This first index measures how important the products of industry-k are as inputs in industry-j's production. The index *proximity* ($proximity_{jk}$) is constructed as the share of output of industry-k directly purchased by industry-j over industry-j's total use of industry-k's products. It measures how much of industry-k's output is directly used as an input by industry-j and not as a component embodied in other inputs. Similarly to *direct requirement*, the higher its value closer the two industries are on integrated over the supply chain.

Besides the input/output relationships between the industries of affiliates we also look at their geographical location. We use the measures of geographical distance computed in Meyer and Zignano (2011).[11]

These data is provided by CEPII. Several measures of intra-country distances are available. The results of the estimations we present are based on simple distances[12].

To analyze the dispersion of investments and relate it to the I/O connections between industries, we follow Ramondo et al (2016) and aggregate the single MNCs investments at the country-industry level. Hence, the country-industry pairs become our unit of observation.

[11]Specifically, we use the measures of pairwise geographical distances between the capital cities of the countries and the same measures weighted by population densities within each country.

[12]The results are robust to the use of the alternative measures of geographical distances.

We match each industry-country pair $\{j0, c0\}$ with all possible industry-country $\{j1, c1\}$ pairs. For each year, our sample consists of 35x35 countries and 78x78 possible industry pairs, for a total of 7,452,900 combinations or quartets {j0,c0,j1,c1} with full information on relevant variables. We consider only primary industries of each firm. To avoid double counting, we keep in $\{j0, c0\}$ only core business of their MNCs, while we keep all investments when we pair the observations with all possible $\{j1, c1\}$ combinations. Given the large amount of combinations that we create and use in our estimations, we restrict our sample to one single year (2006) in order to make computations feasible.We exclude from the analysis same industry combinations ($z = x$, 92,820 observations, with 13,253 of investments), while we keep combinations of industries in the same country ($c0 = c1$). The number of possible quartets therefore becomes equal to 7,357,350 (=35x35x78x77). In 63,498 of them we observe realized investments, 92.2% of which (58,506 observations) involve multinational production ($c0 \neq c1$).

We estimate the following OLS models:

$$D(INV_{j0j1c0c1}) = \alpha_1 geod_{C0C1} + \alpha_2 dr_{01} + \alpha_3 dr_{10} + \alpha_4 geod * dr_{01} + \alpha_5 geod * dr_{10} + \delta + \epsilon_{j0j1c0c1} \quad (11)$$

and

$$ln(Nf_{j0j1c0c1}) = \beta_1 geod_{C0C1} + \beta_2 dr_{01} + \beta_{23} dr_{10} + \beta_4 geod_{C0C1} * dr_{01} + \beta_5 geod_{C0C1} * dr_{10} + \delta + \upsilon_{j0j1c0c1} \quad (12)$$

D($INV_{j0j1c0c1}$) in eq. (11) is a dummy that equals one if we observe at least one MNC that controls firms in *both* industry-*j0* in country-*c0* *and* in industry-*j1* in country-*c1*. In equation (12) we use the total number of firms in $\{j0, c0\}$ and in $\{j1, c1\}$ controlled by the same MNCs. The variable dr_{xz} is the direct requirement of goods from the affiliate-x's industry for production of the affiliate-z's industry. The variable $geod_{C0C1}$ is the log of geographical distances between the countries $c0$ and $c1$. In order to control for features of industries and for the characteristics of countries that could affect the decision of FDI location, we include a set of industries and country dummies δ $(\delta_{j0}, \delta_{C0}, \delta_{j1}, \delta_{C1})$. Error terms are clustered by $\{j0, c0\}$.

Table 4 and Table 5 below display the results of the estimation of eq.(11) and of eq.(12), respectively. For the sake of presentation, we limit the discussion to the estimation of eq.(11).
The estimated coefficient for the number of investments in eq.(12) are consistent and provide a similar evidence. Similarly, when we replace direct requirement indexes with proximities the results remain virtually unchanged.
The coefficients $\alpha_1, \alpha_2, \alpha_3$ in the first and second columns are highly significant and show that MNCs are likely to invest in close locations and in industries that are highly interconnected. Similar to the

results of Alfaro and Charlton (2009), MNCs tend to own firms in supplier and client industries of the one in which they establish their core business.

The use of the interactions terms between the indexes of interconnections and geographic distances provides a novel result to the literature on multinational production. The coefficients are negative and significant. The more interdependent are the industries in which MNCs invest, the closer the affiliates are located. This evidence is consistent with the existence of a prominent vertical integration strategy among MNCs and intra-group trade of intermediate goods.

Table 4: Investments

Variable	$INV_{j0j1c0c1}$	$INV_{j0j1c0c1}$	$INV_{j0j1c0c1}$	$INV_{j0j1c0c1}$	$INV_{j0j1c0c1}$
$geod_{C0C1}$	-0.004***	-0.004***	-0.004***	-0.003***	-0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
dr_{01}		0.268***		1.198***	
		(0.020)		(0.167)	
dr_{10}		0.268***		1.066***	
		(0.014)		(0.087)	
$prox_{01}$			0.016***		0.071***
			(0.001)		(0.006)
$prox_{10}$			0.017***		0.080***
			(0.001)		(0.005)
$geod_{C0C1} * dr_{01}$				-0.133***	
				(0.022)	
$geod_{C0C1} * dr_{10}$				-0.114***	
				(0.012)	
$geod_{C0C1} * prox_{01}$					-0.008***
					(0.001)
$geod_{C0C1} * prox_{10}$					-0.009***
					(0.001)
δ_{C0}	YES	YES	YES	YES	YES
δ_{C1}	YES	YES	YES	YES	YES
δ_{n0}	YES	YES	YES	YES	YES
δ_{n1}	YES	YES	YES	YES	YES
N.Obs	7,357,350	7,357,350	7,357,350	7,357,350	7,357,350
R2	.013	.017	.017	.018	.017

,,*** Statistically significant at 10, 5, 1%, respectively.

Robust standard errors clustered at $\{j0, c0\}$ level.

Table 5: # Firms

Variable	$ln(Nf)$	$ln(Nf)$	$ln(Nf)$	$ln(Nf)$	$ln(Nf)$
$geod_{C0C1}$	-0.115***	-0.116***	-0.116***	-0.113***	-0.093***
	(0.008)	(0.008)	(0.008)	(0.009)	(0.008)
dr_{01}		1.443***		2.400**	
		(0.139)		(1.178)	
dr_{10}		1.426***		1.999***	
		(0.094)		(0.720)	
$prox_{01}$			0.179***		0.436***
			(0.015)		(0.122)
$prox_{10}$			0.146***		0.325***
			(0.012)		(0.084)
$geod_{C0C1} * dr_{01}$				-0.142	
				(0.166)	
$geod_{C0C1} * dr_{10}$				-0.084	
				(0.102)	
$geod_{C0C1} * prox_{01}$					-0.038**
					(0.018)
$geod_{C0C1} * prox_{10}$					-0.026**
					(0.012)
δ_{C0}	YES	YES	YES	YES	YES
δ_{C1}	YES	YES	YES	YES	YES
δ_{n0}	YES	YES	YES	YES	YES
δ_{n1}	YES	YES	YES	YES	YES
N.Obs	63,498	63,498	63,498	63,498	63,498
R2	.12	.13	.13	.13	.13

,,*** Statistically significant at 10, 5, 1%, respectively.

Robust standard errors clustered at $\{j0, c0\}$ level.

6 Conclusions

Previous literature has shown that backward productivity spillovers from FDI to domestic firms occur if the domestic companies supply intermediates to the foreign clients. In this study we relate the intensity of backward spillovers to the organization of multinational production in which foreign affiliates are involved. We argue that backward spillovers from FDI are not automatic and crucially depend on the make-or-buy decisions of foreign multinationals. Foreign affiliates of vertically integrated MNCs will likely primarily purchase their inputs from related companies within the boundaries of their business group. Therefore, the likelihood and intensity of interactions with local suppliers are lower for companies that are vertically integrated in their industry. This results in a reduced potential for productivity spillovers. Relevant productivity spillovers should instead arise from the activity of foreign companies that do not control affiliates in the industry of local suppliers. q We empirically test our theory using a firm-level panel data set of European manufacturing companies. The results provide evidence that productivity spillovers to local companies come *only* from the activity of foreign clients whose multinational business groups do not invest in the industry of the local firms, whereas the presence of foreign clients that control affiliates in their industries does not seem to affect the competitiveness of domestic suppliers.

Our results have important policy implications. Governments and policy makers in advanced and developing economies have been heavily investing to attract foreign multinationals in their countries. These policies were led by the belief that MNCs would introduce advanced know-how that local companies, and especially domestic suppliers, may acquire and use to improve their own competitiveness (i.e. the presence of FDI would be associated to productivity spillovers). However, our analysis shows that backward spillovers are not automatic and arise with stronger intensity when foreign affiliates are not vertically integrated in the industries of local suppliers.
If productivity spillover to local firms are the main objective of these investments, then policy makers should design incentive schemes to attract mainly companies that do not pursue strategies of vertical integration . These firms will more likely start collaborations with local suppliers that can benefit from these interactions acquiring new technologies and know-how.

As every empirical study, our analysis has limitations. Certainly, the most relevant is the lack of transaction data. Ideally, if we had information on commercial deals and partnerships, we could identify the interactions between local and foreign companies. This would expand the range of research questions one might answer to and allow for a finer analysis of the impact of heterogeneous MNCs on the competitiveness of local companies. We consider these as promising lines of research.

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Appendices

A The Dataset

The main source of information on firms' unconsolidated accounting data and ownership information is the commercial database *Amadeus* compiled by *Bureau van Dijk*, a consulting company. For each company we retrieved yearly information on financial variables, the NACE REV.1 and REV.2 and NAICS 2002 and 2007 codes of the primary and secondary industries each firm operates in and ownership information. This latter consists of an index of independence of the company, the ultimate owner's BvD identifier, its name and country. Each Amadeus release reports only latest available information on ownership and industry of operations. Therefore we created the panel dataset of financial data for the entire sample period using the 2010 release and used several issues of the database (2003-2010) to keep track of changes of firms' ownership and industry of activity. The use of early vintages of the database also allowed us to include in our sample companies that are not in the 2010 version of the database and recreate the time-series of their financial data. In a few cases the BvD identifiers (BvD-ID) assigned to single companies change over time. Before merging the data from different issues, we used conversion tables we received from BvD to replace old BvD-IDs with the new ones. When information on ownership and industrial codes was missing we assumed it did not change from the most recent previous year we have information for. In a minority of cases, we had information from different releases for the same year. In these cases, we used the most complete information available and gave priority to the oldest releases when the information was conflicting (few cases). For both variables, we observe limited variation over time. Hence, the structures of (multinational) business groups remain fairly stable.

After a careful analysis, we decided to use the 2007 NAICS industry codes as the 2007 Tables compiled by the Bureau of Economic Analysis (BEA) are more detailed that the 2002 versions. We converted firms' industry NAICS 2002 codes that we retrieved from early releases of the database (2001-2006) to the corresponding NAICS 2007 ones using official BEA conversion tables. The vast majority of codes did not change, while we observe a unique conversion for almost all codes that were modified. The BEA IO Tables report information the 6-digit level. We aggregate the figures to the 4-digit level as this is the level of aggregation we adopt to identify relevant industries. This is indeed the level that has been used in the literature to study industries' interconnections and MNEs' vertical integration (e.g. Alfaro and Charlton 2009). [13]

[13] Since inter-industry relationships may be different across countries and may change over time, it would be ideal to

We dropped single observations if we had no information on the identity of the ultimate or direct owners, but we knew that 50% or more of the shares of the firm were controlled by some different entity. When we had no information on ultimate owner of the company in a given year (or the previous ones) and we knew it was independent (or the independence index was missing) we assumed that the companies were local and unaffiliated. This left us with a dataset of 6,921,984 firm-year observations with (imputed) ownership information. This original sample corresponds to 959,886 firms in 78 industries. Unaffiliated companies represent the vast majority of cases: these are 863,378. We indentify 109,086 BGs of which 16,813 are MNCs that control 37,798 foreign affiliates. Our observations are limited to investments in Europe. Therefore, extra-European investments (including extra-European Head Quarters) of MNCs fall out of our sample. Moreover, most of the HQs report only consolidated data and are excluded from our analysis to avoid double counting. While we use this dataset to reconstruct the structure of (multinational) business groups, most of the observations miss information on one or more of the production variables.
After interpolating production variables (see next section), we can work with a sub-sample of 3,694,096 that report information on sales - that we use to compute HPs - and a sub-sample 2,024,899 firm-year observations with full information on all the relevant variables we need in order to perform our analysis, in particular the production functions' estimations and final regressions.

Bureau van Dijk gathers firm-level information from different local data providers (private organization or official national bodies) and makes the information standard and comparable across countries. The data providers in different countries apply different rules on the type of information that firms have to communicate. In some countries firms are not required to report information on all production variables. In particular, reporting cost of material inputs is not always mandatory. Therefore the groups of companies in these countries completely or partly (complete information is still available for some firms) fall out of our sample as we cannot estimate production functions and tfp spillovers. However, we still have information on their ownership and location. Therefore, we can make use of this information when we reconstruct the MNCs' group structure and identify the industries in which they invest. Table 6 provides a list of the countries and of local information providers included in our analysis of MNCs structure and for the estimation of production functions and the measurement of spillovers.

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use country-year specific tables. Unfortunately, IO tables at this level of disaggregation are available only for the USA. The reader should bear in mind this caveat in interpreting our results.

Table 6: Country coverage

Country	MNC structure	TFP & Spillovers	Info Provider
Austria	✓	✓	Creditreform Austria
Belgium	✓	✓	National Bank of Belgium
Bosnia and Herzegovina	✓	✓	Creditreform Belgrade
Bulgaria	✓	✓	Creditreform Bulgaria
Croatia	✓	✓	Creditreform Croatia
Czech Republic	✓	✓	Credit Czech Republic, s.r.o.
Denmark	✓		Købmandstandens Oplysningsbureau
Estonia	✓	✓	Krediinfo
Finland	✓	✓	Suomen Asiakastieto
France	✓	✓	Coface SCRL
Germany	✓	✓	Verband der Vereine Creditreform
Greece	✓		ICAP
Hungary	✓	✓	Creditreform-Interinfo
Iceland	✓		CreditInform Group
Ireland	✓		Jordans
Italy	✓	✓	Honyvem
Latvia	✓		Creditreform Latvia
Lithuania	✓		Creditreform Lietuva UAB
Luxembourg	✓		BvD
Macedonia	✓		Creditreform
Moldova	✓		SeeNews
Netherlands	✓		LexisNexis
Norway	✓	✓	CreditInform Group
Poland	✓	✓	InfoCredit
Portugal	✓	✓	Coface MOPE
Romania	✓	✓	Chamber of Commerce and Industry of Romania
Russia	✓		Creditreform St.Petersburg
Serbia	✓	✓	Creditreform Belgrade
Slovakia	✓	✓	CreditInform Slovakia, s.r.o.
Slovenia	✓	✓	Coface Slovenia
Spain	✓	✓	Informa
Sweden	✓	✓	UC
Switzerland	✓		Worldbox
Ukraine	✓	✓	Creditreform Bulgaria
United Kingdom	✓		Jordans

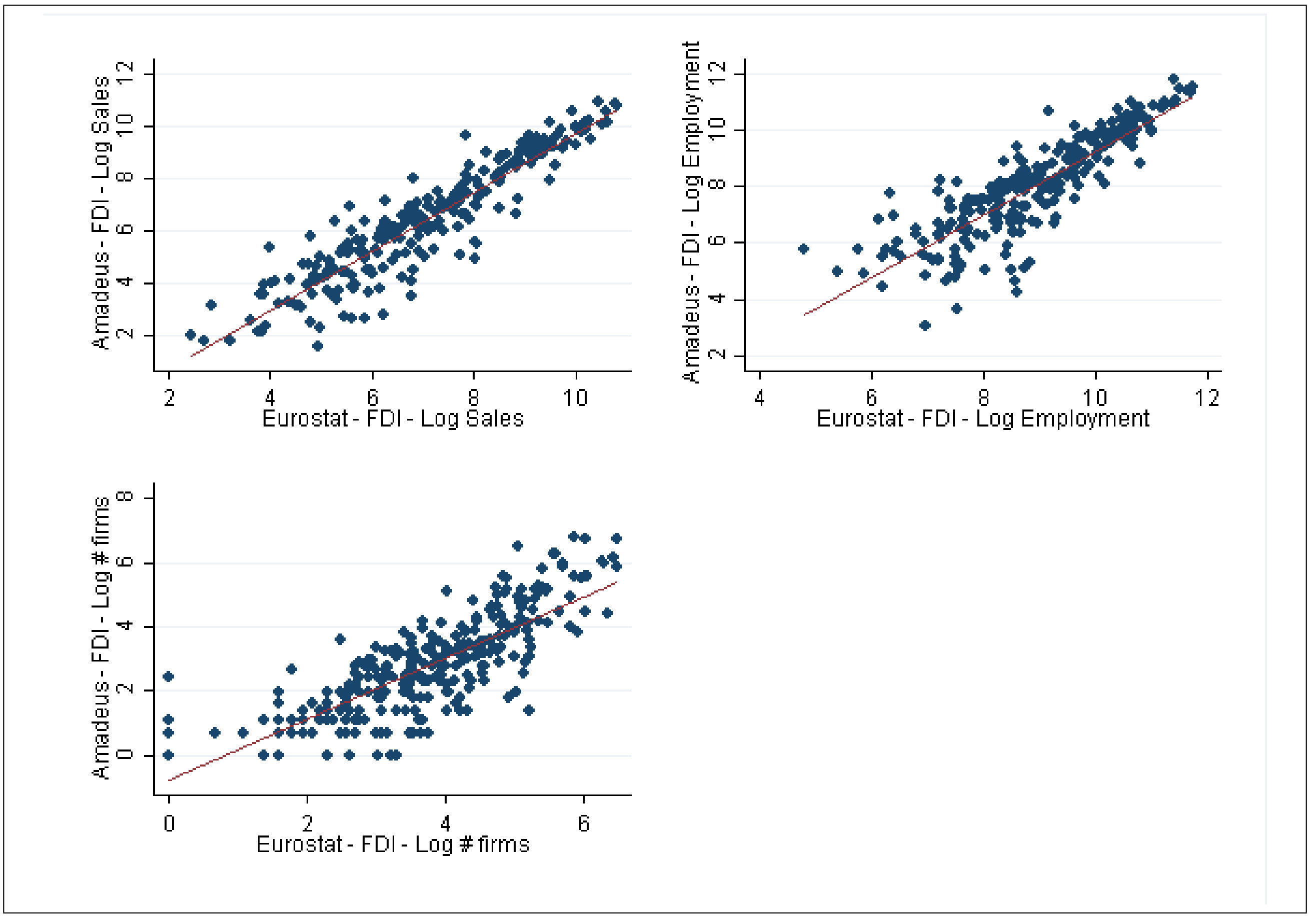


Figure 1: Sample validation

A.1 Sample validation

To give a sense of the coverage of the Amadeus dataset, we compare relevant statistics we compute using our firm-level sample with Eurostat's official *Structural Business Statistics* on *inward FATS*. These latter are available at country-sectoral level. Therefore, we aggregate our observations at the same level in order to calculate the total value of sales of FDI, their total number of employees and their number. In Figure 1 we plot the values we obtain from our sample against the official Eurostat statistics in 2006. The country-specific correlations are sticking, suggesting that the distribution of FDI across countries and sectors in our dataset well matches the one in Eurostat.[14]

[14]In order to validate our sample, we use the NACE REV.1 classification of sector as this is the classification adopted by the European Commission and Eurostat. In this subsection, we refer to NACE REV.1 2-digit codes as sectors.

B Data management

B.1 Interpolation of production variables

As we mentioned in the previous section an extensive data management had to be done. One of the issues we faced was that in many cases we missed information on one or more of the production variables (S_{it}, K_{it}, L_{it}, M_{it}). In particular material inputs were often missing. In order to address this issue and keep in our sample as many observations as possible we interpolate production variables. To do so, we modify the raw data and fill in observations. We replace missing and non-positive values of each variable with the value predicted with a linear trend. In practice, we use the *STATA* commands *tsfill* and *ipolate*. This latter generates a linear interpolation of missing variables over time.[15] We report in Table 7 here below the information on the number of interpolated variables for the sample of local companies that we use to estimate production functions and tfp spillovers. Over 90% of observations have no interpolated variable. Hence, the interpolation procedure is unlikely to affect the results of our estimations.

Table 7: Interpolated variables

# interpolated variables	Freq.	Percentage	Cumulated
0	1,847,042	91.20	91.20
1	134,689	6.65	97.87
2	4,855	0.24	98.11
3	3,857	0.19	98.30
4	34,456	1.70	100
N. firm-year Obs.		2,024,899	

B.2 Data Trimming

In order to identify and eliminate outliers we trim the data in several dimensions. First, we eliminate outliers *before* the estimation of production functions using ratios of production function variables and their growth rates. Second, we drop extreme values of estimated productivities and of productivity growth over time. In both steps we first identify all outliers and then drop them. Because we limit the estimation production functions and productivities to local companies, in the second step of the data trimming we only use the sample of domestic companies for which we can estimate productivity. As the ACF procedure requires complete information on production variables for at least two consecutive

[15] Notice that we neither generate a balanced dataset nor extrapolate new values of relevant variables. Therefore, the panel dataset remains unbalanced, but we limit the number of gaps in the panel.

years, we keep in the sample only firm-year observations that have non-missing information on all variables at time-*t* and time-*t-1*.

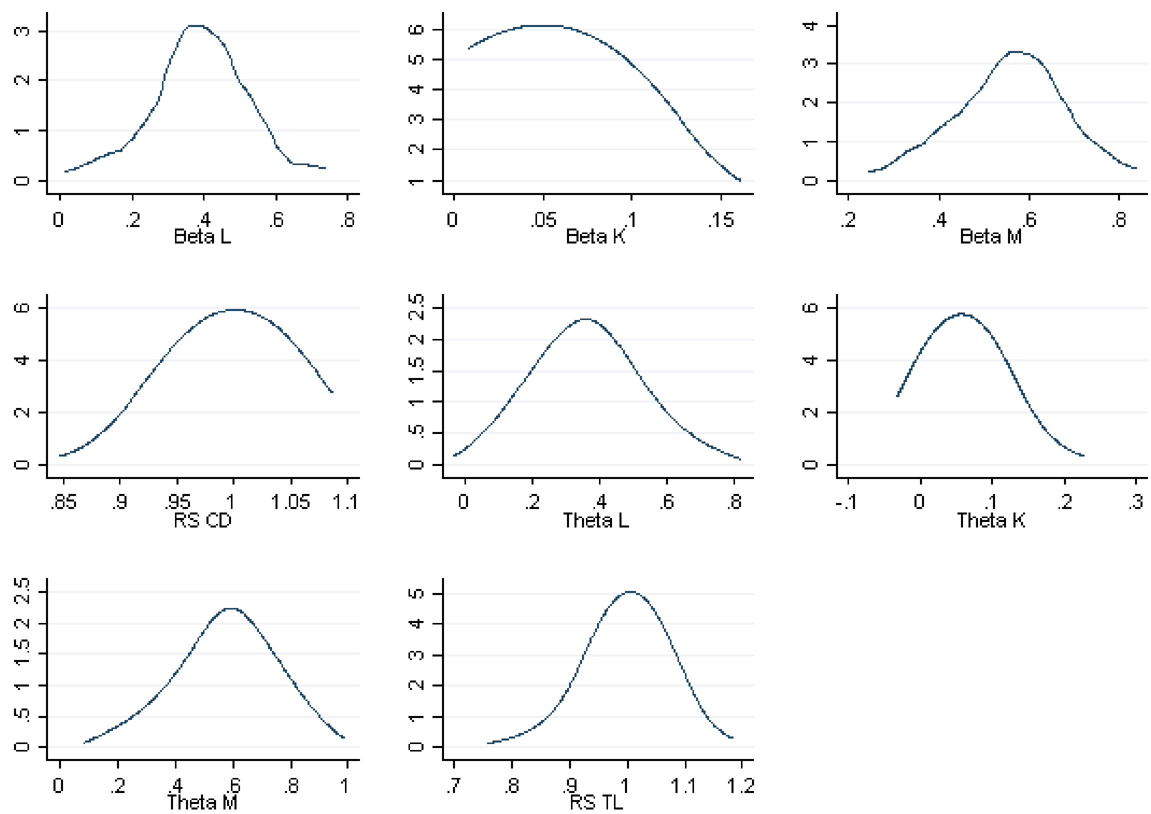
In both steps we define the relevant distributions of the variables within their year-country-sector triplets.

- *Before* production functions' estimation
  - We identify as outliers the top and bottom 1% of the following variables: capital per employee (capital intensity), sales per employee (labour productivity), material inputs over total sales (materials' revenue share)
  - We identify as outliers observations with extreme growth rates (the top and bottom 1%) of the following variables in two consecutive years: sales, number of employees, material inputs, capital.
  - We drop outliers
- *After* production functions' estimation
  - We identify as outliers top and bottom 1% of productivities under each specification of the production function
  - We identify as outliers observations with extreme growth rates (the top and bottom 1%) of tfp in two consecutive years under either assumption of production function
  - We eliminate all observations in sector-country bins for which we estimate one (or more) negative coefficient of the Cobb-Douglas production
  - We drop outliers

C Production function coefficients

Table 8: Production function coefficients

F(X,β)	Coeff.	Mean	p10	p25	p50	p75	p90	sd
Cobb-Douglas	β_L	0.39	0.20	0.32	0.38	0.49	0.54	0.14
	β_K	0.05	0.02	0.03	0.04	0.06	0.11	0.04
	β_M	0.56	0.38	0.48	0.56	0.62	0.71	0.14
	RS	1.00	0.95	0.97	1.00	1.02	1.05	0.08
Translog	θ_L	0.36	0.14	0.24	0.36	0.47	0.59	0.18
	θ_K	0.06	0.01	0.03	0.05	0.08	0.12	0.05
	θ_M	0.58	0.33	0.46	0.58	0.70	0.81	0.19
	RS	1.00	0.91	0.97	1.00	1.04	1.08	0.08
Observations					1,291,934			



Note: Extreme values in the bottom and top 1% are excluded from the graphs

Figure 2: Distribution of production function coefficients

D Robustness

As a robustness check, we implement the estimation of production functions and productivities of local companies imposing an exogenous law of motion. Therefore, it is defined as follows:

$$\omega_{it} = g(\omega_{it-1}) + \xi_{it} = \alpha_1 \omega_{it-1} + \alpha_2 \omega_{it-1}^2 + \alpha_3 \omega_{it-1}^3 + \xi_{it} \tag{13}$$

These results, that we show in in Table 9, provide an evidence consistent with the one presented in the section 4, leaving the estimation qualitatively unchanged.

Table 9: Productivity spillovers, with exogenous tfp law of motion

F(X,β)	Cobb-Douglas				Translog			
Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VP_{jct}	0.078***				0.051**			
	(0.019)				(0.021)			
VP_{jct}^{j}		0.019		0.046**		-0.050**		-0.020
		(0.021)		(0.023)		(0.023)		(0.025)
VP_{jct}^{j}			0.102***	0.113***			0.132***	0.127***
			(0.025)	(0.025)			(0.028)	(0.029)
HP_{jct}	0.009	0.009	0.009	0.009	0.006	0.007	0.006	0.006
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
$ln(K/L)_{it}$	0.014***	0.014***	0.014***	0.014***	0.005***	0.005***	0.005***	0.005***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
HHI_{jct}	-0.012	-0.012	-0.013	-0.012	-0.027***	-0.028***	-0.028***	-0.029***
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
δ_t	YES	YES	YES	YES	YES	YES	YES	YES
δ_{ct}	YES	YES	YES	YES	YES	YES	YES	YES
δ_{st}	YES	YES	YES	YES	YES	YES	YES	YES
N.obs.	1,230,329	1,230,329	1,230,329	1,230,329	1,230,329	1,230,329	1,230,329	1,230,329
R2	.31	.31	.31	.31	.61	.61	.61	.61
VP_{jct}^{j}=VP_{jct}^{-j}				.022				.000027

,,*** Statistically significant at 10, 5, 1%, respectively.

S.e. clustered by industry-year-country.

E Summary Statistics Test for Equality

To test whether the differences between firms that we presented in Table 1 are statistically and economically significant, we estimate a set of OLS regressions based on the model of Bernard and

Jensen (1999):

$$lnY_{it} = \beta_0 + \beta_1 DOM\ BG_{it} + \beta_2 MNC_{it} + \beta_3 l_{it} + \delta_{ntc} + \epsilon_{it} \quad (14)$$

where Y_{it} is the variable of interest for firm i active in industry-n, country-c in a given year-t. The vector Y_{it} consists of number of employees L_{it}, value of sales S_{it}, intermediate goods M_{it}, capital K_{it} and total wage bill W_{it}. As all the dependent variables are expressed in natural logarithms, the βs measure the premia associated to each status of firms in percentage terms compared to unaffiliated firms in the same country, industry and year.

We present the results of our estimation in Table 10. As expected, firms that are affiliated to BGs are larger than *unaffiliated* companies in every dimension. Furthermore, firms that belong to MNCs have higher premia than local BGs. In the last row of the Table we report the p-values of the F-tests of equality. The null hypothesis is always rejected.

Table 10: Companies' affiliation

Variable	lnL_{it}	lnS_{it}	lnM_{it}	lnK_{it}	lnW_{it}
$DOM\ BG_{it}$	1.179***	0.234***	0.280***	0.163***	0.060***
	(0.008)	(0.004)	(0.006)	(0.007)	(0.002)
MNC_{it}	1.984***	0.510***	0.595***	0.407***	0.168***
	(0.012)	(0.005)	(0.008)	(0.009)	(0.003)
l_{it}	NO	YES	YES	YES	YES
δ_{nyc}	YES	YES	YES	YES	YES
N.obs.	2,024,199	2,024,199	2,024,199	2,024,199	2,011,516
R2	.32	.87	.77	.7	.87
F-Test ($DOM\ BG = MNC$)	0.00	0.00	0.00	0.00	0.00

,,*** Statistically significant at 10, 5, 1%, respectively.

Robust standard errors clustered at firm-level.

Chapter 2 - Technology and Global Value Chains: Evidence from Denmark

Technology and Global Value Chains: Evidence from Denmark*

Friedrich Bergmann

Copenhagen Business School

Katherine Stapleton

University of Oxford

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Abstract

There is a growing debate over whether the path of manufacturing-led development will remain viable for developing countries, or whether the advanced capabilities of robots will render labour cost differentials obsolete, leading to a decline in offshoring to developing countries or 'reshoring' of manufacturing production. To date, there is relatively little empirical evidence on this question. In this paper we shed new light on the relationship between automation and offshoring using data on the universe of Danish firms, employees and trade transactions. Exploiting supply side improvements in the capabilities of robots, we show that robot exposure leads firms to increase offshoring to both high income and low and middle income countries, with an even greater increase for the latter. However, the increase to low and middle income countries only occurs for countries that are existing offshoring destinations, while for high income countries firms start offshoring to new countries as well.

Keywords: offshoring, robots, development, automation, firms, trade, global value chains

*Bergmann email: fbe.eco@cbs.dk. Stapleton email: katherine.stapleton@economics.ox.ac.uk

1. Introduction

Recent technical advances in robotics and machine intelligence, along with the accelerated growth in the deployment of robots, have sparked a new wave of concern about the consequences of automation. The debate and literature so far has typically focused on advanced countries, where adoption rates of industrial robots have been highest (e.g. Acemoglu and Restrepo (2018) Graetz and Michaels (2018)). A more recent, emerging discussion has started to consider the impact on less developed countries.

There is an extensive literature showing that the integration of low and middle income countries into global value chains has been an important force for productivity growth, employment creation and poverty reduction. The offshoring of low-skilled labour intensive manufacturing production from high-income countries in the past few decades has enabled a well-trodden growth path of manufacturing-led development. The recent advances in automation are now fuelling concern that automation technologies might substitute for low-skilled labour in developing countries, leading to 'reshoring' or generally reducing the future scope for manufacturing-led development in parts of the world that have yet to industrialise.

The literature evaluating this research question is still nascent and so far inconclusive. A few recent papers have studied the impact of automation in high income countries on trade flows between high income and low and middle income countries using industry or regional level trade data. Artuc et al. (2018) use global country-industry panel data on robot penetration and trade, finding a positive relationship between robot intensity in own production and imports sourced from less developed countries. Likewise, Hallward-Driemeier and Nayyar (2019) also show that the intensity of robot use in high-income countries has a positive impact on foreign direct investment growth from high-income countries to low- and middle-income countries.

There has been relatively little work on this topic to date using firm-level data, perhaps due to the scarcity of firm level data with detailed information on offshoring, combined with the challenge of finding firm data detailed enough for studying technology adoption. An exception has been Stapleton and Webb (2020), which uses data on Spanish manufacturing firms to study the relationship between automation and offshoring, finding that automation causally increased imports from less developed countries.

In this paper we shed new light on this topic at the firm level by studying the employment and offshoring decisions of Danish firms. We combine a matched worker-firm dataset of the universe of Danish firms with transactional trade data on the universe of each firm's import transactions. We use the transactional trade data to construct firm level measures of narrow offshoring from high, middle and low-income countries. We then construct measures of supply-side improvements in the capabilities of robots in a similar vain to Graetz and Michaels (2018) by mapping categories of commercially available robots, as recorded by the International Federation of Robotics (IFR), to occupations conducting similar tasks. This allows us to construct firm-level shift-share instruments for industrial robot exposure.

We show that exposure to advances in the commercial availability of industrial robots had a positive impact on offshoring to all countries and particularly to low and middle income countries between 2001 and 2009. A 1% increase in robot exposure increased aggregate offshoring by 0.05%, with a 0.04% effect for high income countries and 0.07% for low and middle income countries, nearly twice as high. During this period offshoring from Danish firms to low and middle income countries in fact doubled, despite a concurrent increase in industrial robot use. We further find that the impact of robot exposure on offshoring to low and middle income countries only occurs at the intensive margin and not the extensive margin, suggesting that only the subset of low and middle income countries that are already offshoring destinations for Denmark benefit from the increase in offshoring. For high income countries, on the other hand, exposure to robots also leads to an increase in the extensive margin of offshoring, with more exposed firms starting to offshore to new countries. For all countries the increase in offshoring operates through an increase in the number of products offshored, but the increase in the number of products is particularly apparent for offshoring to low and middle income countries.

We show that this impact of automation holds even after controlling for other exogenous factors that could increase offshoring. Following Hummels et al. (2014) we use the growth in the aggregate export supply of countries offshored to by Denmark to the rest of the world excluding Denmark as a measure of exogenous shocks that could increase Danish offshoring. We find that this instrument has a positive impact on offshoring, but including it only strengthens our results for the impact of robot exposure.

This research contributes to the small but growing literature examining how automation in high-income countries affects trade with developing ones. Our findings support the results in Artuc et al. (2018) and Stapleton and Webb (2020), that automation, in fact, increases imports from, or multinational activity with, developing countries. Our findings might also offer an explanation for why increased robot penetration in the US decreased exports from Mexico to the US. We show that, at the firm level, exposure to robots increased offshoring to the low and middle income countries that were already offshoring destinations for Danish firms, but firms only sought out new offshoring locations amongst high income countries. It is plausible then that new firms entering the market, without existing offshoring relationships with low and middle income countries, might start offshoring only to high income countries, meaning that at the industry level, over time, automation could shift the composition of offshoring away from low and middle income countries.

This paper is also related to an emerging literature studying the effects of automation on outcomes at the firm level (Acemoglu et al. (2020) Aghion et al. (2020),Humlum, Anders (2019), Bessen et al. (2019)). It is also related to a wider literature on the impact of robots on labour markets and more broadly to a substantial literature studying computerisation and skill-biased technological change (Acemoglu and Restrepo (2019); Acemoglu and Autor (2011); Webb (2019); Dauth et al. (2017)). Finally, it also contributes to a growing literature studying how different technologies affect trade and global supply chains ((Fort, 2017); Baldwin and Forslid (2020); Brynjolfsson et al. (2019); Freund et al. (2019)). In what follows, Section 2 outlines the model we are using followed by the empirical strategy in Section 3. In Section 4 we describe our data set and present some stylized facts about the offshoring patterns of Danish firms. Section 5 presents the estimation results of robot exposure on both margins of offshoring. Section 6 provides robustness checks and Section 7 then concludes.

2. Model

We consider a setup that closely follows the model in Stapleton and Webb (2020), but we focus on a different type of advance in automation[1]. The model combines two key frameworks from recent literature: firm heterogeneity, as in Melitz (2003) and a task based framework building upon Acemoglu and Restrepo (2018) but including the option to offshore in addition to the option to automate.

2.1 Model setup

We consider one monopolistically competitive industry where firms produce differentiated products under increasing returns to scale. Firms are heterogeneous in productivity as in Melitz (2003), each firm produces a single variety ω and there is free market entry. The heterogeneity of firms is reflected by differing 'baseline' marginal costs of production $\varphi(\omega)$. To enter into production, firms pay a fixed entry cost of f_e units of labour. They then draw their productivity from a known Pareto cumulative distribution function $G(\varphi) = 1 - \varphi^{-k}$ with $k > 1$. After observing their productivity firms decide whether to exit the market or start producing.

Following Acemoglu and Restrepo (2018) we assume that production is characterised by combining a unit measure of tasks according to a constant elasticity of substitution aggregator. The production of variety ω involves performing tasks $x \in [0, 1]$. The output of firm ω is then:

$$q(\omega) = \varphi(\omega)\left(\int_0^1 q(\omega, x)^{\frac{\sigma-1}{\sigma}} dx\right)^{\frac{\sigma}{\sigma-1}} \tag{1}$$

where $q(\omega, x)$ is the output of task x for firm ω and σ is the elasticity of substitution between tasks.

[1] We refer the reader to their paper for a full exposition of the model.

2.2 Automating and offshoring tasks

We assume that tasks can be performed by either labour at home $l_H(x)$, offshore labour $l_O(x)$ or automated machines $m(x)$. Assume the tasks are ordered by the productivity of home labour in completing them, $\gamma_{LH}(x)$. Only a subset of tasks $x \in [0, I^O]$ are possible to offshore because there are certain activities that cannot be performed at a distance and these are the tasks that home labour is the most productive in performing. The tasks that are possible to offshore can be performed by labour at home or offshore labour, but performing a task with offshore labour involves an iceberg transport cost τ and performing any tasks with offshore labour involves paying a one-off upfront fixed cost f_O.

Over time a subset of tasks $x \in [0, I^M]$ become technically feasible to automate using industrial robots. We assume that this subset of tasks is more limited than the subset that can be offshored $I^M < I^O$, since certain tasks are not yet technically feasible to automate. Tasks $x \in [0, I^M]$ can be performed by either labour at home, offshore labour or machines. Performing any tasks with machines involves paying a one-off fixed upfront cost f_M representing the initial investment. The output of a task x can expressed:

$$q(\omega,x) = \begin{cases} 1[H=1]\gamma_{LH}(x)l_H(\omega,x) + 1[O=1]\frac{\gamma_{LO}(x)l_O(\omega,x)}{\tau} + 1[M=1]\gamma_M(x)m(\omega,x) & \text{if } x \in [0, I^M] \\ 1[H=1]\gamma_{LH}(x)l_H(\omega,x) + 1[O=1]\frac{\gamma_{LO}(x)l_O(\omega,x)}{\tau} & \text{if } x \in [I^M, I^O] \\ \gamma_{LH}(x)l_H(\omega,x) & \text{if } x \in [I^O, 1] \end{cases}$$

where $\gamma_{LH}(x)$ is the productivity of home labour in task x, assumed to be increasing in x, $\gamma_{LO}(x)$ is the productivity of offshore labour in task x, $\gamma_M(x)$ is the productivity of machines in performing task *x*, $1[H=1]$ indicates that the firm chooses to conduct the task at home and $1[O=1]$ indicates that the firm chooses to conduct the task offshore and $1[M=1]$ is an indicator function denoting that the firm chooses to automate that task. We assume that $\gamma_{LH}(x)/\gamma_M(x)$ and $\gamma_{LO}(x)/\gamma_M(x)$ are increasing in x so labour at home and abroad has a comparative advantage relative to machines in higher-indexed tasks and $\gamma_{LH}(x)/\gamma_{LO}(x)$ is increasing in x so labour has a comparative advantage relative to offshore labour in higher-indexed tasks. We assume that for each task, labour in the home country, labour in the offshore country and machines are perfect substitutes.

2.3 Preferences

Preferences across varieties have the standard constant elasticity of substitution format, with $\sigma = 1/(1-\rho) > 1$. These preferences lead to demand function $q(\omega) = EP^{\sigma-1}[p(\omega)]^{-\sigma}$ for every variety ω , where $p(\omega)$ is the price of each variety, $P = [\int_0^M p(\omega)^{1-\sigma} d\omega]^{\frac{1}{1-\sigma}}$ is the price index of the industry, M is the number (measure) of existing varieties and E is the aggregate level of spending in the country.

2.4 Profit maximisation

The profit maximising price is a constant markup over marginal costs. We consider the scenario where the unit cost of offshore labour is lower than the unit cost of home labour for tasks that are feasible to offshore. This implies that for the marginal task I^O we have that $\frac{\tau w_O}{\gamma_{LO}(I^O)} < \frac{w_H}{\gamma_{LH}(I^O)}$. We further assume that the unit cost of machines is lower than the unit cost of offshore labour and the unit cost of home labour. This implies that for the marginal task I^M we have that $\frac{r}{\gamma_M(I^M)} < \frac{\tau w_O}{\gamma_{LO}(I^M)}$. In the absence of fixed costs, all firms would therefore automate all tasks that are technically feasible to automate, offshore the remainder that are feasible to offshore and produce the remaining tasks at home. In the presence of fixed costs, firms that choose to automate will automate all of the tasks that can be automated and firms that offshore will offshore all of the tasks that can be offshored.

Firms that have not chosen to automate or offshore therefore charge the highest price, while firms that both automate and offshore charge the lowest price. The marginal costs if the firm offshores and automates, MC^{OM}, only automates MC^M, only offshores MC^O or produces at home, MC, can be expressed as:

$$MC^{OM}(\omega) = \frac{\beta}{\varphi(\omega)} \qquad \text{and} \qquad MC^M(\omega) = \frac{\delta}{\varphi(\omega)} \tag{2}$$

$$MC^O(\omega) = \frac{\alpha}{\varphi(\omega)} \qquad \text{and} \qquad MC(\omega) = \frac{1}{\varphi(\omega)} \tag{3}$$

where $\alpha < 1$ given our assumption that offshoring involves a marginal cost saving relative to using home labour. Our assumption that automation involves a marginal cost reduction relative to offshoring implies that $\beta < \alpha < 1$, while we also have that $\beta < \delta$ and $\delta < 1$. The rank of α relative to δ, on the other hand, depends on the task subset that is feasible to automate, I^M relative to the subset feasible to offshore, I^O and the rental rate r relative to the cost of offshore labour w_O. We assume for now that I^M/I^O is sufficiently high, or r/w_O sufficiently low that $\delta < \alpha$.

To make the decision of whether to conduct tasks using only home labour, offshore labour, machines, or both offshore labour and machines, firms compare the profits under each option. Their profit functions if they offshore, $\pi^O(\varphi(\omega))$, if they produce at home, $\pi(\varphi(\omega))$ if they automate, $\pi^M(\varphi(\omega))$, or if they offshore and automate, $\pi^{OM}(\varphi(\omega))$ can be expressed as follows:

$$\pi^M(\varphi(\omega)) = (1-\rho)EP^{\frac{\rho}{1-\rho}}\left[\frac{1}{\rho}MC^M\right]^{\frac{-\rho}{1-\rho}} - F_M - F_e \tag{4}$$

$$\pi^{OM}(\varphi(\omega)) = (1-\rho)EP^{\frac{\rho}{1-\rho}}\left[\frac{1}{\rho}MC^{OM}\right]^{\frac{-\rho}{1-\rho}} - F_M - F_O - F_e \tag{5}$$

$$\pi^O(\varphi(\omega)) = (1-\rho)EP^{\frac{\rho}{1-\rho}}\left[\frac{1}{\rho}MC^O\right]^{\frac{-\rho}{1-\rho}} - F_O - F_e \tag{6}$$

$$\pi(\varphi(\omega)) = (1-\rho)EP^{\frac{\rho}{1-\rho}}\left[\frac{1}{\rho}MC\right]^{\frac{-\rho}{1-\rho}} - F_e \tag{7}$$

There are hence three productivity cutoffs associated with automating only φ^{M*}, offshoring only φ^{O*} and both automating and offshoring φ^{OM*}. Firms sort into groups depending on their productivity. The lowest productivity firms produce but do not automate or offshore, those with medium productivity do one or the other and the most productive firms both automate and offshore. The benefit of automating and offshoring is firms earn higher revenues, because consumer demand is elastic ($\sigma > 1$), after having payed the additional fixed cost. The benefits of automating or offshoring are increasing in firm productivity.

2.5 Advances in automation

There are several types of exogenous technological progress in automation that can be considered in this framework:

1. The extensive margin of automation: an increase in the subset of tasks feasible to automate I^M.

2. The intensive margin of automation: an increase in the productivity of machines in performing tasks, $\gamma_M(x)$ or a decrease in the rental rate r.

3. The fixed cost of automation: a decrease in f_M.

In this paper we hypothesise that the most relevant changes are changes to the intensive margin of automation or to the upfront fixed costs. For industrial robots, we find that the majority of the categories of robots by 'application' in the data of the IFR were already commercially available at the beginning of our sample period. Only a few new types of robots in terms of these applications were introduced in the 1990s and 2000s. What changed substantially in this period, however, was the number of robots being purchased in these existing categories around the world. This suggests that either existing types of robots were falling in price, increasing in productivity or becoming easier to procure or integrate, while the subset of automatable tasks I^M did not change by much. Our model would predict that changes to the intensive margin or the fixed cost of automation would have the following effects.

2.5.1 Firm level implications

Advances in the intensive margin: At the firm level, holding all else fixed, an increase in the intensive margin of automation, γ_M or a decrease in the rental rate r has the following effect:

- **Firms that are already automating** will face a positive productivity effect as their marginal costs decrease and so they can increase revenues and expand. There is no additional labour displacement effect of automation.

- **Firms that are induced to automate** because of the larger marginal cost reduction of automating those firms will have a labour displacement effect as they switch a whole subset of tasks $x \in [0, I^M]$ away from home labour or offshore labour and towards machines and also a positive productivity effect as their marginal costs have decreased so they can charge lower prices and expand.

- **Firms that do not automate** decrease output, home employment and offshoring if they have offshored. They face no labour displacement but a negative *productivity* effect.

A decline in fixed costs: At the firm level, holding all else constant, a fall in the fixed cost of automating f_e has the following effect:

- **Firms that are already automating** have already paid the associated fixed cost. Those firms will experience no productivity or displacement effect.

- **Firms that are induced to automate** because of the fixed cost reduction of automating will have a displacement effect as they switch a whole subset of tasks $x \in [0, I^M]$ away from home labour or offshore labour and towards machines and also a positive productivity effect since their marginal costs have decreased allowing them to charge lower prices and expand.

- **Firms that do not automate** decrease output, home employment and offshoring if they have offshored. They face no displacement but a negative productivity effect.

2.5.2 Industry level implications

All potential improvements in automation reduce the productivity cutoff associated with automating and so raise automation on the industry level. In turn this raises the survival cutoff, meaning that firms that cannot automate are forced to exit and the surviving non-automating firms reduce their output, employment and offshoring. In a world with more automation, the expected productivity level of surviving firms is therefore higher than in a world without automation and the per period expected profits of surviving firms are higher.

3. Empirical strategy

In this section we outline our empirical strategy. We begin by describing our baseline estimation specification, then describe our measure of exposure to industrial robots and finally we describe our trade variables. In evaluating the impact of automation on offshoring, the central identification issue is that firms do not randomly select into automation, but automation is a function of firm characteristics such as employment and productivity. In addition, the direction of causality is not clear. While having the option to automate could reduce offshoring, offshoring could, in turn, affect firm choices on technology adoption and innovation in Denmark. Therefore we make use of the shift-share instrument approach, by combining industry growth in the deployment of industrial robots in the rest of the world, with firm specific exposure to robots based upon their occupational composition in the base year.

We use a panel data set of Danish manufacturing firms to identify how robot exposure effects offshoring. Both, the measure of automation exposure and the control for the trading environment are firm-year specific. Our baseline specification for the panel regression is:

$$\begin{aligned} \mathrm{X}_{it} =& \alpha + \beta \text{robot exposure}_{it} + \tau \text{industry-year}_{it} + \phi \text{region-year}_{it} \\ &+ \text{controls}_{it} + \delta_t + \upsilon_i + \epsilon_{it} \end{aligned} \tag{8}$$

where X_{it} is outcome of interest for firm i at time t, robot exposure$_{it}$ is the firm's exposure to industrial robots, and industry-year$_{it}$ and region-year$_{it}$[2] are industry-year and region-year fixed effects. While firm fixed effects soak up unobserved time-invariant firm characteristics, we additionally add industry-year and region-year fixed effects to control for time varying shocks to different industries and policy changes that might have differentially affected regions in different time periods.

Our main control variable, control$_{it}$ aims to account for exogenous changes to global trade that shifted the cost of offshoring from Danish firms. We follows the method of Hummels et al. (2014) in accounting for supply side changes in global trade patterns that affected the ability of Danish firms to offshore production. Our primary outcome of inter-

[2] We distinguish between three regions: Copenhagen, other major cities and rural areas.

est is the firm's offshoring to low- and middle income countries. This specification hence means that our regressions make use of the variation in robot exposure and offshoring over time, within a firm.

3.1 Measuring exposure to industrial robots

We derive the firm-year specific measure for robot exposure using data from the International Federation of Robotics (IFR). The IFR provides global sales and operational stock of industrial robots by 'application', where applications are activities like 'metal casting' or 'plastic moulding' or 'arc welding'. This lends itself well to mapping these applications to the occupations conducting similar tasks and measuring the extent to which different occupations are exposed to these robot types. In a similar vain to Graetz and Michaels (2018) we hand match these robot applications to ISCO occupation codes. In contrast to Graetz and Michaels (2018), however, we use the dates of when sales of robot applications switched to be non-zero to include a time dimension.

Our procedure is the following: in each time period we define a 4 digit occupation code as 'automatable' using industrial robots if its title or formal description contains any of the words included in the application titles of the IFR data and if the IFR global operational stock of robots for that application is non-zero in that year. Examples of matched occupations are 'Metal casters', which maps to 'Metal casting' as an application in the IFR data or the occupation 'Machine tool operators' matching to the 'Handling operations at machine tools' IFR application. [3]

After we have identified occupation-years that relate to the capabilities of industrial robots, we calculate the $automatableshare$ for each firm. That is the share of workers that could potentially be replaced by an industrial robot by a given year. For firm i in base year t_{base} the automation share is then:

$$\text{automatable share}_{it_{base}} = \frac{\sum_{o=1}^{n} \text{automatable}_{ot} \times \text{empl}_{oit_{base}}}{\sum_{o=1}^{n} \text{empl}_{oit_{base}}} \tag{9}$$

where $automatable_{ot}$ is a dummy variable with value 1 if occupation code o is replaceable by

[3]Table A2 in the appendix provides the full list of ISCO 68 occupations that could be automated according to our hand matching.

industrial robots in year t and $empl_{oit_{base}}$ is the number of employees of occupation o in firm i in t_{base}. Allowing the $automatable_{ot}$ dummy to be time dependent enables us to account for the availability of new industrial robots that only became commercially available at some point in our sample period. In the next step we make use of industry-year specific global stock of industrial robots global robot stock$_{jt}$ provided by the IFR. For firm i in industry j the final measure of time varying 'robot exposure' becomes,

$$\text{robot exposure}_{ijt} = \text{automatable share}_{it_{base}} \times \text{global robot stock}_{jt} \tag{10}$$

Table A1 illustrates the mean automation share of firms in the base year and the stock of industrial robots reported by the International Federation of Robotics. Our handmatching procedure between occupation codes and robot tasks appears to performs well, since the industries with the highest automation potential are also the industries with the highest stock of industrial robots. Given we are using a fixed effects specification, within a firm, the variation in robot exposure across years is driven by industry-year specific sales of industrial robots. The variation in robot exposure across firms is coming from several sources: the share of automatable employment in the base year, the availability of new types of robots over time and industry specific sales.

3.2 Measuring offshoring and shocks to the global trading environment

The literature has suggested several ways to measure the relocation of production activities to foreign countries using import data. We are interested in the value of imported inputs that can substitute for employment in the firm in Denmark and hence want to exclude imports of raw materials used in the production process. Therefore we apply the definition of narrow offshoring as outlined in Hummels et al. (2014) by calculating the total value of imported HS4 products that the firm also sells domestically and/ or exports.

In the following, we outline how we control for changes in the global trading environment that affect Danish firms. The most important high income offshoring partner country of Danish manufacturing firms in our sample is Germany. The machinery industry is particularly interlinked with Germany. If we take, for example, the HS6 product 848340 – ”gears and gearing” that is offshored to Germany, an idiosyncratic shock to the supply of gears of German manufacturers exporting to the world market will affect the subset of Danish firms that offshored gears to Germany. This change in the trading environment is exogenous for the Danish offshorer and product-by-partner country specific. To separate the effect of automation on offshoring from the effect of trade shocks on offshoring we include a control for the trading environment in baseline specification8.

To control for firm-year specific trade shocks we use the instrument introduced to the literature by Hummels et al. (2014). At first we calculate the World Exports Supply (WES). The WES, I_{cpt} is country c's export of HS6 product p to the world market at time t minus its supply to Denmark. Then we calculate the shares s_{icp} of each country x product combination cp on total offshoring in the pre-sample year of firm i. The final measure for changes in the trading environment, C_{it} for firm i in year t is the sum over country x product specific WES, I_{cpt} weighted by the firm‘s country x product specific pre-sample shares s_{icp}.

$$C_{it} = \sum_{cp} s_{icp} I_{cpt} \tag{11}$$

Since we are interested in offshoring overall, and offshoring to high income and low and middle income countries separately, we calculate three different control variables for shocks in the trading environment for each of these groups.

4. Data

4.1 Danish Register Data

Our primary data source is Danish administrative data on the universe of firms, workers and trade transactions. We create a matched worker-firm panel by combining several registers provided by Statistics Denmark for the years 2001-2009. The *firm* register covers the universe of Danish firms and provides annual data for total employment, industry, region, wage bill and firm ownership. Industries are recorded with NACE codes and we focus on private-sector, manufacturing firms on a 2 digit level. Annual trade flows are recorded in the register of Danish Foreign Trade Statistics *Uhdi*. Products are reported on a 8-digit level according to the Harmonized System (HS) and trade-flows are disaggregated by partner country.

To measure offshoring we use domestic sales from the Sales Register *Vars* by year and product. We aggregate trade-flows and domestic sales to six digit HS product to match the level of digits in the Comtrade data base. *Firm*, *Uhdi* and *Vars* use the same firm identifier. The worker data is taken from the Integrated Database for Labor Market research *Ida*. The register provides socioeconomic characteristics, such as labor market participation, wages, gender, age and detailed occupation codes for the entire Danish population on an annual level. Denmark Statistics uses DISCO codes, an adaption of the International Standard Classification of Occupations (ISCO88). We focus on full-time workers aged between 18 and 65. To connect firm and worker identifiers and create a matched panel we use the Firm-Integrated Database for Labor Market Research *Fida*.

4.2 International Federation of Robotics Data

The IFR measures global shipments of industrial robots, which they define using the International Organization for Standardization (ISO) 8373 definition of "An automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which may be either fixed in place or mobile for use in industrial automation applications". The IFR data includes shipments delivered to each country by industry and application for the time period 1993-2016. We map IFR industries to two digit-NACE industry codes to combine IFR with our firm-worker panel. Typical applications of industrial robots include assembling, dispensing, handling, processing (e.g. cutting), and welding, all of which are prevalent in manufacturing industries, as well as harvesting (in agriculture) and inspecting of equipment and structures (common in power plants). The data are compiled by surveying global robot suppliers.

4.3 World Bank Income Groups

To separate countries by development status we use the Income Classification provided by the World Bank Group. Gross National Income (GNI) per capita is calculated using the

Atlas Method and countries are separated into low, lower-middle, upper-middle, and high income countries. For our analysis we combine low, lower-middle, upper-middle countries in one group and compare them to high income countries. The thresholds between the groups are updated on an annual bases. For example, in the beginning of our sample period (2000) high income countries had a GNI per capita above 9.200 United States Dollar (USD) and in 2010 above 12.200 USD.

4.4 UN Comtrade Data

We use data from UN Comtrade to construct the controls for changes in the global trading environment. The data base provides annual export values for all countries in the world. Exports are reported by 6-digit product (HS) and partner country, allowing us to identify exports to the world market and exports to Denmark. Values are reported in USD and we convert them to Danish Kroners (DKK).

We deflate all financial values using a Danish GDP deflator and trim the final sample in several ways. First, we only consider firms that are active in manufacturing industries across the entire period to avoid special characteristics of firms changing in and out of manufacturing. Second, we exclude firms with fewer than 20 employees. Purchasing industrial robots and training workers to operate them is an investment small firms are unlikely to undertake. Third, we exclude firms where the reported number of total employees in *Firm* deviates by more than 15% from the number of observed workers in *Ida*. Our identification strategy is relying on the occupational composition of the workforce and missing worker information would result in an inaccurate measure of robot exposure. Our final sample has about 1.400 manufacturing firms and 8.100 firm-year observations.

4.5 Sample Description

Table 1 provides summary statistics for the key firm-level variables. The manufacturing firms in our sample have a mean log employment of 4.3 (about 75 employees) and an annual gross output of 18.3 (about 88.6 mio. DKK[4]). The mean share of high-skilled workers

[4]Equivalent to about 13.8 million USD

Table 1: Summary Statistics

	Obs.	Mean	SD
Firm-level domestic outcomes			
log employment	8,156	4.32	1.01
log gross output	8,156	18.31	1.16
log capital per worker	8,127	12.33	1.06
log avg. wage bill per worker	8,156	12.70	0.18
log accounting profits	6,176	15.43	1.77
high-skill share	8,156	0.19	0.13
automation share t_{base}	1,441	0.36	0.28
Firm-level trade outcomes			
log imports	8,147	15.98	2.30
imports / gross output	8,156	0.22	0.22
log offshoring	7,622	15.39	2.60
offshoring / gross output	7,622	0.16	0.20
log exports	8,136	16.95	2.13
exports / gross output	8,156	0.41	0.34

Notes: The table reports summary statistics for all firm-year observations. For each variable we report means and the standard deviation across all observations.

is 19%[5]. The significant share of low-skill employment is reassuring us that the main focus of the firms in the sample is the production of goods rather than product design and product development. The logged value of annual offshoring is 15.3 (about 4.8 mio DKK[6] and the standard deviation indicates that the value varies significantly across firm-years. As we would as expect from the literature, the offshoring firms in our sample are heavily embedded in global production. Almost all the firms import and export products simultaneously and the share of exports on gross output (0.41) illustrates that the international market is nearly as important as the local market. The mean automation share in the base year, calculated as described in section 3 is 36% and its standard deviation is mainly driven by industry differential as illustrated in table A1.

4.6 Stylised facts about offshoring

The firms in our sample offshore 4,812 different HS-6 products to a total of 126 countries between 2001-2009. Table 2 summarizes offshoring by development status of the partner

[5]We classify the skill level of a worker according to the International Standard Classification of Education. A high-skilled worker has a first stage tertiary education or second stage tertiary education.

[6]Equivalent to about 0.76 million USD)

country. We have 7.622 firm-year offshoring observations. Nearly all firms offshore to high income countries in any given year (7,411 firm-year obs), while half of them offshore to low- and middle income countries (4,101 firm-year obs) simultaneously. At the extensive and intensive margin, offshoring to low- and middle income countries is less prevalent than offshoring to high income countries. The mean of logged offshoring to low- and middle income is 13.33 (0.6 million DKK) and 15.1 (3.6 million DKK) to high income countries . While firms only offshore 5.8 products to 3.5 low- and middle income countries, on average, they offshore 11.8 products to 7.9 high income countries.

Table A3 illustrates the partner countries the firms in our sample offshore to, sorted by shares in total offshoring. The most important low- and middle income partner countries are China, Thailand, Brazil, Malaysia, India and Turkey, accounting together for 78% of total offshoring within that income group. The most important high income partner countries are mainly neighbors of Denmark: Germany, Sweden, United Kingdom, United States and the Netherlands jointly accounted for 78% of offshoring within that group.

However, during our sample period, offshoring to low- and middle income countries has been gaining in importance. Between 2000-2009 the value of offshoring to low- and middle income countries more than doubled while the value of offshoring to high income increased only by around 70%[7]. Also the number of products offshored to low and middle income countries increased more than for high income countries.

5. Results

5.1 Intensive Margin of Offshoring

In this section we report our regression results. We run separate regression for offshoring to all countries, to low- and middle income countries and high income countries. To ensure that a change in the value of offshoring is not driven by changes in the income status of the partner countries we have to exclude those countries that move from low- and middle income to high income status during the sample period.[8] We tested our results

[7]Figure A1 illustrates the total value of offshoring by development status over time.

[8]While this restriction excludes 6.4 percent of total offshoring across firms and years, we consider the restriction necessary to estimate precise coefficients for each income group.

Table 2: Offshoring by Development Status

	Mean	SD	Obs.
Offshoring to all Countries			
Log Value	15.39	2.60	7,622
Number Products	12.91	22.42	7,622
Number Countries	10.05	9.12	7,622
Offshoring to Low- and Middle Income Countries			
Log Value	13.33	2.91	4,101
Number Products	5.86	10.38	4,101
Number Countries	3.56	4.14	4,101
Offshoring to High Income Countries			
Log Value	15.17	2.66	7,411
Number Products	11.81	20.54	7,411
Number Countries	7.91	5.98	7,411

Notes: The table reports firm-year observations. For each variable we report means and the standard deviation across all observations. Products refer to 6-digit HS codes.

by running regressions without this exclusion and by instead using the income status of the partner country according to its status in the pre-sample year, finding that the magnitude of estimated effects changed very slightly but our results remained qualitatively unchanged by this element of the analysis.

Table 3 reports the baseline regression results. Overall, we find a positive and significant effect of robot exposure on the value of offshoring. In column (1) we estimate the effect on offshoring to all countries. An exogenous increase in robot exposure by 1% increases the firms' offshoring value by 0.041%. Columns (3) and (5) separate offshoring by the development status of the partner country. We find that an increase in robot exposure significantly increases the value of offshoring to low and middle income countries as well as to high income countries. However, the magnitude of that effect is about 50% higher for low- and middle income countries, although the coefficients are more significant for high income countries. A 1% increase in robot exposure increases the value of offshoring to low- and middle income countries by 0.065% but only by 0.041% to high income countries. Columns (2), (4) and (6) report the result when adding the offshoring control for world export supply. A positive supply shock for offshored products in the partner countries increases the value of offshoring to all countries by 0.041% and by 0.033% for offshoring to high income countries, although its significance drops when we disaggregate the sample. Including this control in fact increases the coefficients for robot exposure, suggesting that

Table 3: Offshoring by Development Status

	Dep variable: Log Offshoring					
	All Countries		Low & Middle Income		High Income	
	(1)	(2)	(3)	(4)	(5)	(6)
Log robot exposure	0.0413***	0.0450***	0.0649**	0.0662**	0.0407***	0.0434***
	(0.000)	(0.000)	(0.027)	(0.030)	(0.000)	(0.000)
Log offshoring control		0.0413**		0.0482		0.0328*
		(0.035)		(0.139)		(0.061)
Constant	16.18***	17.86***	11.59***	10.36***	15.93***	16.64***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Observations	7,622	7,518	3,789	3,386	7,441	7,329
F	13.62	14.57	18.20	14.74	8.710	8.944

Notes: p-values in parentheses. Standard errors two-way clustered by firm and year. All specifications include industry-year, region-year and firm fixed effects. *** significant at the 1 percent level, ** significant at the 5 percent level, * significant at the 10 percent level.

excluding it leads us to underestimate the impact of automation.

5.2 Extensive margin of offshoring

After analyzing the effect of robot exposure on the intensive margin of offshoring we focus on the extensive margin of offshoring next. In section 4.5 we have established that the number of offshored products as well as the number of partner countries has increased between 2001-2009. In a similar vain to the regressions in Table 3 we now relate changes in robot exposure to changes in the number of offshored products and number of countries a firm offshores to.

Table 4 and Table 5 report the results. A 1% increase in robot exposure significantly increases the number of offshored products by 0.014% for all partner countries. The increase in offshored products is larger for low- and middle income countries. While a 1% increase of robot exposure leads to an increase of offshored products by 0.026% for low- and middle income countries the increase in offshored products to high income countries is 0.015%. The results for the number of countries a firm offshores to in response to an

Table 4: Products offshored

	Dep variable: Log Number of Products					
	All		Low & Middle Income		High Income	
	(1)	(2)	(3)	(4)	(5)	(6)
Log robot exposure	0.0146**	0.0147**	0.0249**	0.0262**	0.0148**	0.0148**
	(0.026)	(0.029)	(0.025)	(0.024)	(0.024)	(0.025)
Log offshoring control		0.0175**		0.0036*		0.0085
		(0.041)		(0.075)		(0.128)
Constant	1.888***	2.257***	0.871***	0.957* **	1.835***	2.021***
	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)
Observations	7,622	7,518	3,789	3,386	7,441	7,329
F	4.139	4.612	8.471	8.968	3.994	3.429

Notes: p-values in parentheses. Standard errors two-way clustered by firm and year. All specifications include industry-year, region-year and firm fixed effects. *** significant at the 1 percent level, ** significant at the 5 percent level, * significant at the 10 percent level.

increase in robot exposure vary across these groups. Overall, a 1% increase in robot exposure increases the number of countries by 0,009% but that increase is one-sided. While we find a significant increase of 0.009% for the number of high income countries we do not find any effect on the number of low- and middle income countries.

6. Robustness

One potential concern with the results presented in section 5 is that we use the 'exposure' of firms to industrial robots based upon their occupational composition, which may not necessarily reflect actual robot adoption. In the following we present two approaches to evaluate the extent to which this measure is correlated with other proxies for robot adoption on the firm-level.

The first one relates to the changes in labor demand that might be expected to occur due to the adoption of industrial robots. Our model predicts that industrial robots have a labor displacing effect for occupations that perform similar tasks. We would in turn

Table 5: Countries offshored to

	Dep variable: Log Number of Countries					
	All		Low & Middle Income		High Income	
	(1)	(2)	(3)	(4)	(5)	(6)
Log robot exposure	0.0091***	0.0093***	0.0056	0.0049	0.0086***	0.0089***
	(0.005)	(0.006)	(0.204)	(0.260)	(0.004)	(0.005)
Log offshoring control		0.0215*		0.0044		0.0191*
		(0.078)		(0.160)		(0.093)
Constant	2.095***	2.545***	0.877***	0.891***	1.978***	2.383***
	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)
Observations	7,622	7,518	3,789	3,536	7,441	7,329
F	8.096	8.256	7.410	6.855	5.775	5.314

Notes: p-values in parentheses. Standard errors two-way clustered by firm and year. All specifications include industry-year, region-year and firm fixed effects. *** significant at the 1 percent level, ** significant at the 5 percent level, * significant at the 10 percent level.

expect that this decrease in labor demand would be counteracted by an increase in the demand for tech workers, such as skilled technicians, engineers and researchers that operate, maintain and program industrial robots. In a recent paper, Humlum, Anders (2019) uses a survey of robot adoption finding that industrial robots account for 25% of the decrease in labor demand for production workers and account for 8% of the increase in labor demand for tech workers. Building on that result we define a group of 4 digit occupation codes that we would expect to be in higher demand if a firm is indeed investing in industrial robots. We focus on three types of workers; plant and machine operators (automated assembly-line operators and industrial robot operators), engineering professionals (electrical engineers) and technicians (electrical technicians, computer equipment controller and industrial robot programmers)[9]. In total we consider 7 occupation codes and calculate the total employment in that group for each firm-year.

The second proxy for the adoption of industrial robots is the import of machinery. The main global producers of industrial robots are located in Germany, Japan, the US and South Korea. For firms in smaller countries that are more likely to be reliant on import-

[9]A list of the considered occupation codes can be found in table A4

Table 6: Comparison of robot exposure with other firm metrics

	Log Imports Machinery		Log Robot-related Employment	
	(1)	(2)	(3)	(4)
Log robot exposure	0.130***	0.0445	0.0231***	0.00668**
	(0.000)	(0.177)	(0.000)	(0.043)
Constant	9.112***	4.894***	1.581***	0.658***
	(0.000)	(0.000)	(0.000)	(0.000)
Firm FE	No	Yes	No	Yes
Observations	8,156	8,156	8,156	8,156
F	67.15	2.791	56.30	3.500

Notes: Robot related employment refers to the total employment in a group of 7 occupations related to the operation, maintenance and programming of industrial robots. Standard errors two-way clustered at the firm and year level. All regressions include region-year and industry-year fixed effects. p-values in parentheses. *** significant at the 1 percent level, ** significant at the 5 percent level, * significant at the 10 percent level.

ing industrial robots, one option is therefore to measure industrial robot deployment at the firm level with transactional trade data using imports of machinery and mechanical appliances on the four digit level[10] (see, for example, Acemoglu and Restrepo (2019)). This method is not without its limitations, however: it is well documented that industrial robot purchases often rely on hiring a robotics 'integrator' to customise and install the robots and, even even if this is not the case, there is the additional likelihood that firms purchase industrial robots from retailers or middlemen rather than importing them directly themselves. Accordingly, we do not use this is a main indicator of robot use but verify whether this measure is correlated with robot exposure. We use the Danish customs records to identify total imports, total exports and domestic sales of HS code 8479 at the firm-year level.

We explore the correlation between our robot exposure measure and these two proxies for robot adoption by regressing our measure of robot exposure on robot related employment and imports of machinery and mechanical appliances. Table 6 reports the regression results. Columns (1) and (3) report the results without including firm fixed effects, while columns (2) and (4) report the results including firm fixed effects.

[10]HS code 8479 includes the 6-digit product "847950 Industrial Robots".

These results indicate that there is a strong relationship between robot exposure and the employment of robot-related employment, and some evidence of a relationship between robot exposure and imports, although that relationship doesn't hold after adding firm fixed effects. In specification 1, a 1% increase in robot exposure is associated with an increase in the imports of machinery by around 0.13%. However, while the coefficient is positive we can not identify a significant effect when using firm fixed effects additionally. Imports in machinery are extremely lumpy and 72,56% of the firms in our sample import in a single year only. Due to the limited within-firm, across-year variation of imports in machinery the panel regression is not our preferred setting.

The results in columns (3) and (4) indicate that a 1% increase in robot exposure is associated with an increase in the firm's employment in occupations that operate, maintain and program industrial robot of 0.006%. In general, these results show suggestive evidence that the measure of robot exposure is associated with firm outcomes that we would expect to observe if a firm did start deploying industrial robots. As firm exposure increases, so does employment of occupations that would likely be required to operate, maintain and program industrial robots and there is some evidence that the exposure measure is correlated positively with imports of industrial robots.

7. Conclusions

In this paper we shed new light on the firm-level impacts of automation on offshoring to less developed countries. We combine a matched worker-firm dataset of the universe of Danish firms with transactional trade data on the universe of each firm's import transactions. We use the transactional trade data to construct firm level measures of narrow offshoring from high, middle and low-income countries. We then exploit supply-side improvements in the capabilities of robots in a similar vain to Graetz and Michaels (2018) by mapping categories of commercially available robots, to occupations conducting similar tasks.

We show that firms that were more *ex ante* exposed to industrial robots increased their offshoring to all countries and particularly to low and middle income countries between 2001 and 2009. A 1% increase in robot exposure increased aggregate offshoring by 0.06%, with a 0.05% effect for high income countries and 0.07% for low and middle income countries. During this period, offshoring from Danish firms to low and middle income countries in fact doubled, despite a concurrent increase in industrial robot use.

We further find that the impact of robot exposure on offshoring to low and middle income countries only occurs at the intensive margin and not the extensive margin, suggesting that only the subset of low and middle income countries that are already offshoring destinations for Denmark benefit from the increase in offshoring. For high income countries, on the other hand, exposure to robots also leads to an increase in the extensive margin of offshoring, with more exposed firms starting to offshore to new countries. For all countries the increase in offshoring operates through an increase in the number of products offshored, but the increase in the number of products is particularly apparent for offshoring to low and middle income countries.

We show that this impact of automation holds even after controlling for other exogenous factors that could increase offshoring. Following Hummels et al. (2014) we use the growth in the aggregate export supply of countries offshored to by Denmark to the rest of the world, excluding Denmark, as a measure of exogenous shocks that could increase Danish offshoring. We find that this instrument has a positive impact on offshoring, but including it only strengthens our results for the impact of robot exposure.

These conclusions suggest that the fears of automation's consequences for offshoring or the prospect of 'reshoring' have perhaps been overblown. Our results are generally supportive of the findings in Artuc et al. (2018), Hallward-Driemeier and Nayyar (2019) and **?** that automation appears, in fact, to have a positive impact on offshoring to less developed countries. In the context of our modelling framework, these results also suggest that the 'productivity' effect of automation outweighs the 'displacement' effect on offshoring.

On the other hand, however, the extensive margin results could suggest negative implications for countries that were not initial offshoring destinations for high-income countries, such as Denmark, as increases in offshoring have been concentrated in existing offshoring destinations. In this paper we have not considered how automation affects the product composition of offshoring. One possibility is that the increase in offshoring caused by automation is concentrated in higher-skill intensive, or more complex products and that traditional low-skilled labour intensive offshoring destinations, such as China, have shifted production away from labour intensive products in response to the falling scope or expanded scope for automation. An alternative possibility is that the production process in existing offshoring destinations has also become more capital intensive. These are both important avenues for further research on this topic.

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Appendix

Table A1: Robot exposure and IFR global robot stock by industry

	Mean robot exposure	IFR robot stock	Obs.
All manufacturing	0.36	66.278	8153
Electronics	0.29	47.412	1004
Food and Beverages	0.08	17,735	687
Furniture and Others	0.36	23,094	856
Machinery	0.59	145,596	1855
Metals	0.55	98,340	1120
Oil, Chemical, Rubber, Plastic	0.21	29,251	1148
Paper, Graphics	0.09	8,735	363
Stone, Clay, Glass	0.23	37,421	276
Textiles & Leather	0.07	13,987	340
Logistic	0.56	98,251	242
Wood Products	0.12	10,934	262

Notes: Robot exposure is our derived measure of the share of employment in the base year that could potentially be replaced by robots. IFR robot stock is the IFR global operational stock of industrial robots.

Figure A1: Total Value of Offshoring by Development Status

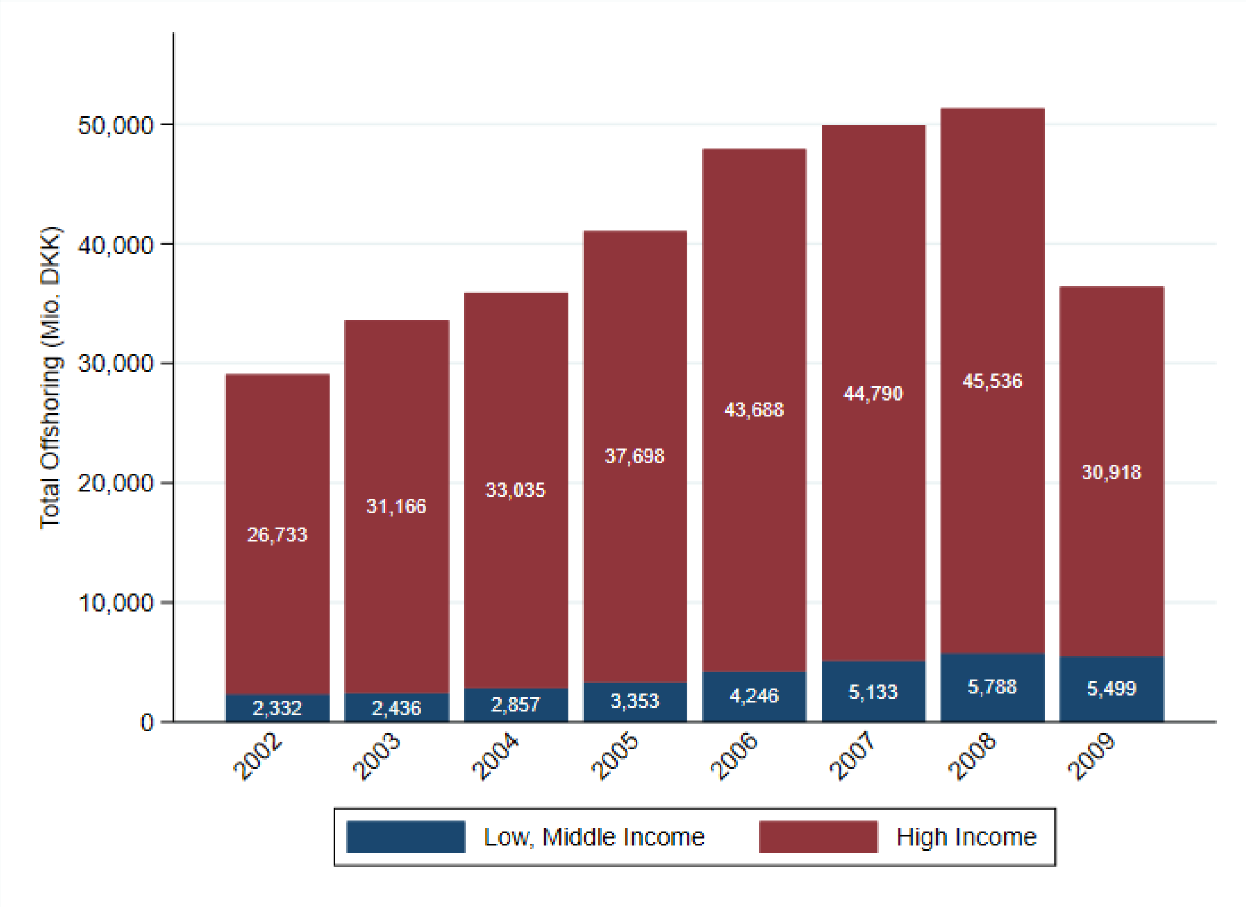

Table A2: Automatable Occupation Codes

ISCO68	Description
72	Metal Processers
72-1	Metal smelting, converting and refining furnacemen
72-2	Metal rolling-mill workers
72-3	Metal melters and reheaters
72-4	Metal casters
72-5	Metal moulders and coremakers
72-6	Metal annealers, temperers and case-hardeners
72-7	Metal drawers and extruders
72-8	Metal platers and coaters
72-9	Metal processers not elsewhere classified
73	Wood Preparation Workers and Paper Makers
73-1	Wood treaters
73-2	Sawyers, plywood makers and related wood-processing workers
73-3	Paper pulp preparers
73-4	Paper makers
74	Chemical Processers and Related Workers
74-1	Crushers, grinders and mixers
74-2	Cookers, roasters and related heat-treaters
74-3	Filter and separator operators
74-4	Still and reactor operators
74-5	Petroleum-refining workers
74-9	Chemical processers and related workers not elsewhere classified
83	Blacksmiths, Toolmakers and Machine-Tool Operators
83-1	Blacksmiths, hammersmiths and forging-press operators
83-2	Toolmakers, metal patternmakers and metal markers
83-3	Machine-tool setter-operators
83-4	Machine-tool operators
83-5	Metal grinders, polishers and tool sharpeners
83-9	Blacksmiths, toolmakers and machine-tool operators not elsewhere classified
84	Machinery Fitters, Machine Assemblers and Precision Instrument Makers (except Electrical)
84-1	machinery fitters and machine assemblers
84-2	Watch, clock and precision instrument makers
84-3	Motor vehicle mechanics
84-4	Aircraft engine mechanics
84-9	Machinery fitters, machine assemblers and precision instrument makers (except electrical) not elsewhere classified
85	Electrical Fitters and Related Electrical and Electronics Workers
85-1	Electrical fitters
85-2	Electronics fitters
85-3	Electrical and electronics equipment assemblers
85-4	Radio and television repairmen
85-5	Electrical wiremen
85-6	Telephone and telegraph installers
85-7	Electric linemen and cable jointers
85-9	Electrical fitters and related electrical and electronics workers not elsewhere classified
87	Plumbers, Welders, Sheet Metal and Structural Metal Preparers and Erectors
87-1	Plumbers and pipe fitters
87-2	Welders and flame-cutters
87-3	Sheet-metal workers
87-4	Structural metal preparers and erectors
93	Application of Paint
93-1	Painters, construction
93-9	Painters not elsewhere classified

Notes: This table displays the occupations that are matched with an application in the IFr data and hence have a dummy variable of 1, in some year in the sample, indicating that these occupations are potentially 'automatable' using industrial robots.

Table A3: Offshoring Partner Countries

	Av. growth rate in products	Av growth rate in offshoring	Share of offshoring within group	Cumulativeshare within group
Low and Middle Income Countries				
China	0.120	0.266	0.492	0.492
Thailand	0.073	0.262	0.078	0.569
Brazil	0.031	0.405	0.067	0.636
Malaysia	0.056	-0.057	0.054	0.690
India	0.097	0.063	0.048	0.738
Turkey	0.076	0.233	0.042	0.780
Ukraine	0.111	0.225	0.037	0.817
Mexico	0.046	0.018	0.035	0.852
Philippines	0.046	0.062	0.028	0.880
Vietnam	0.303	0.573	0.018	0.898
Total	0.073	0.144		
High Income Countries				
Germany	0.013	0.085	0.304	0.304
Sweden	0.005	0.008	0.127	0.431
United Kingdom	0.003	0.063	0.078	0.509
Unites States	0.020	0.049	0.060	0.570
Netherlands	0.016	0.056	0.060	0.630
Belgium	0.029	0.137	0.054	0.683
Norway	-0.014	0.077	0.050	0.734
France	0.003	0.044	0.049	0.782
Italy	0.012	0.069	0.048	0.830
Finland	0.001	0.028	0.030	0.860
Spain	0.025	0.102	0.020	0.880
Switzerland	-0.009	-0.059	0.020	0.900
Total	0.002	0.054		

Notes: Reported values exclude partner countries that changed income groups between 2001-2009.

Table A4: Robot-related Occupation Codes

ISCO 88	Description
8	**Plant and Machine Operators**
81	Stationary plant and related operators
817	Automated assembly
8171	Automated assembly-line operators
8172	Industrial robot operators
2	**Professionals**
21	Physical, mathematical and engineering science professionals
214	Engineers and related professionals
2143	Electrical engineers
3	**Technicians and Associated Professionals**
31	Physical science and engineering associate professionals
311	Physical science and engineering technicians
3113	Electrical engineering technicians
3115	Mechanical engineering technicians
312	Computer associated professionals
3122	Computer equipment
3123	Industrial robot

Notes: This table displays the occupation codes we identified as plausibly reflecting a firm starting to use industrial robots. These were used in the analysis in section 6.

Chapter 3 - Firm Upskilling in Response to Trade Shocks: Evidence from Denmark

Firm Upskilling in Response to Trade Shocks: Evidence from Denmark *

Friedrich Bergmann
Copenhagen Business School

Ben Kett
University of Oxford

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Abstract

This paper investigates how firms change their skill composition in response to exporting, importing and offshoring shocks. Uniquely detailed Danish administrative data allows us to explore both skill upgrading of workers through individual-level training responses, and changes in the firm employment composition by hiring and firing workers. We find that importing and offshoring increase the skill-intensity of a firm and importing increases the proportion of workers undertaking some form of training. At the worker level our main results indicate that both exporting and importing increase the probability that workers start vocational courses. For importing we find a different effect depending on the education of the worker, with unskilled workers being more likely to start vocational courses than skilled workers.

Keywords: trade shocks, upskilling, labour demand, training, labour reallocation

*Bergmann e-mail: fbe.eco@cbs.dk. Kett e-mail: ben.kett@economics.ox.ac.uk. We thank seminar participants at Oxford for their comments.

1. Introduction

Firm and worker responses to globalization have received significant attention in economic research. It is well understood that, while trade may lead to aggregate gains at the national level, there will be winners and losers from globalization. The Heckscher-Ohlin trade model, for example, identifies that a country's relatively abundant factors will see an increase in their returns whilst the relatively less abundant factors will see a fall. In the context of a high-income country like Denmark, where high-skill workers are relatively abundant, we might expect that globalization affects low skill workers negatively and increases their incentive for training.

If offshoring and exporting increase a firm‘s skill intensity in production, workers might need to adapt their skill sets to meet the new demands. In this paper we want to analyze whether an increase in the trading activity of the firm increases the workers‘ participation in adult education and training. To address this question, we use a highly detailed matched employer-employee dataset of Danish manufacturing firms over the period 2001-2013. This data includes comprehensive individual-level information on government-subsidised training. Our empirical strategy is based on Hummels et al. (2014), we identify exogenous changes in the firms' trading activity using World Import Demand, World Export Supply and transport costs to instrument for exporting, importing and offshoring respectively. We then examine training responses to these shocks at the firm- and worker-level. Our results indicate that importing and offshoring increases the skill-intensity of firms and that importing increases the proportion of workers undertaking some form of training. At the worker level our main results indicate that exporting and importing increase the probability that workers start vocational courses. Furthermore, the importing effect depends on the education of the worker, with unskilled workers being more likely to start vocational courses than skilled workers.

Our paper relates to a rich literature about international trade and skill upgrading on the firm-level. Bustos (2011) analyses the demand for skilled labor of exporters in response to the drop in Brazilian import tariffs. She finds that this reduction induces Argentinean firms below median size to downgrade skill, while firms above median size upgrade skill. She also concludes that the increase in the relative demand of skilled labor does not come from labor reallocation across sectors or firms, but from skill upgrading within firms. Our study builds on her work by including disaggregated individual-level training data and by considering importing, offshoring and exporting shocks. In addition, Hummels et al. (2014) uses Danish firm-level and finds that exogenous shocks in exporting and offshoring increase the share of high skilled workers, although they do not include analysis at the worker-level or investigate the heterogeneity of their results. We provide nuanced worker-level results broken by worker age, worker education, and firm size to better understand the training responses to these shocks.

Another group of related literature focuses on upskilling of the individual worker. A recent paper by Costa et al. (2019) exploits a trade shock caused by the sharp sterling depreciation in the 24 hours after Brexit vote to investigate the impact on worker training. They find that 'job related education and training' fell for workers employed in sectors that faced a shock due to an increase in their intermediate import prices. The authors make use of a yes-no training question from in the UK Labour Force Survey and are limited by an inability to link workers to firms. Our work is closely related to Hummels et al. (2012), who study how individual workers' training is affected by changes in trading opportunities in Denmark. They identify training take-ups before, during, and after worker a mass-layoff. Their identification strategy compares displaced to staying workers, and employers that immediately increased offshoring directly after the layoff (offshorers) to employers that did not (nonoffshorers). Their results indicate that displaced workers from offshorers had higher training take-up rates than displaced non-offshorers. Despite similarities, our paper is using a more rigorous specification by instrumenting for changes in both importing (offshoring) and exports rather than limiting the analysis to mass layoff events.

Bernard et al. (2019) provide evidence that offshoring firms offshore low quality varieties, freeing up domestic resources for higher quality varieties to be produced at home. Importantly, they also show that labour is reallocated from production to innovation and technology occupations in response to offshoring. Given that these reallocations require changes in skill sets, it is likely that this would be accompanied by increased training but the authors to not explore this angle.

In terms of heterogeneity, we consider worker age, education, and firm size. Regarding age, we might consider that older workers have a lower net lifetime benefit of training as well as being further from education and hence less learning oriented. However, this may also mean that they require more training to adapt to changes in globalization that their younger colleagues. Simonsen and Skipper (2008) provides mixed evidence will could imply that these competing explanations balance out in practise. Specifically Simonsen and Skipper (2008) provide an analysis of adult training in Denmark without focusing on the relationship to changes in international trade. They find evidence of considerable lifelong learning with regards to enrolment in basic and vocational training, whereas post-secondary training enrolment usually takes place early in life with a smooth decline over the working life cycle.

For heterogeneity by education level, high skill workers already have significant training and hence might be less likely to undertake courses in response to trade shocks. This is particularly true of vocational courses which make up the majority of the courses in our sample. Upskilling by its nature is therefore likely to affect lower skill workers more intensely. Finally, Bustos (2011) finds that propensity to train is higher for above median sized firms although this is over the whole distribution of firm sizes. Since we focus on firms that already both import and export, this prediction is less clear. We may expect larger firms to do more in-house training which is not included in our dataset, whereas smaller firms will be more reliant on government training support. This said, if larger firms are more skill intensive they may also require more training.

The rest of the paper proceeds as follows. Section 2 provides more background context on the Danish approach to adult education and training. Section 3 presents the data, whilst Section 4 explains the empirical strategy. Section presents the results and discussion followed by the conclusion in Section 6.

2. Institutional Framework and Adult Education

In this section we briefly describe the Danish training programs.

Denmark has one of the highest participation rates in adult learning in the European Union. According to the Continuing Vocational Training Survey, 29.2% of employees aged 25-64 years participated in continuing vocational training in 2006 compared to 9.6% in EU-28 countries. The average Dane is expected to spend 1,000 hours in vocational training over a 40 year working life cycle (OECD, 2007).

Adult education and training can be divided into three groups basic, vocational, and further. Basic education consists of courses at the primary or secondary educational level. These courses aim to provide or improve fundamental skills and to prepare individuals for higher education. Subjects include, for example: writing skills, math, languages, social sciences, and natural sciences.

Vocational training is provided for low- and high-skilled adults and is mainly targeted at workers that are in employment. The purpose of vocational training is to upgrade or adjust the skill set of workers in accordance with the needs of the labor market. The content of the courses is revised on a yearly basis to adjust for recent developments. The courses cover general topics (e.g. "Information and communications technology"), job-specific and sector specific skills (e.g. "knowledge of materials"), and labour management skills (e.g. "Organization and Management"). Post-secondary training, or 'further training' targets workers that have completed the upper secondary education and that have a minimum of two years of relevant work experience, and can be a further specialization within the field of study or an introduction to a complementary field (e.g."knowledge of materials")

Adult education and training can be provided by either a public or private institution but, in general, the courses are subsidized by the Danish government. In 2006, around 5,250 DKK million (approximately 710 million Euros) were invested with the highest share of 19% being dedicated to subsidize vocational courses. This total equates to 0.5 percent of Danish GDP each year (equal to the country's expenses on ordinary post-secondary education).

The distribution of course costs varies by course type and field. While basic courses are fully covered by the subsidy, vocational courses[1] and post-secondary courses are only partly publicly financed and require a contribution from the employer or worker.

The course fees are between 500 DKK and 700 DKK (3,700 to 5,200 Euro) per week and are usually paid by the employer. To compensate workers/employers for wage losses during the time of the training, participants/employers are entitled to a fixed allowance equal

[1]Some fields are excluded from worker/ employer contributions, e.g. courses in the social and health service, in the pedagogical field, individual competence assessment

to the maximum unemployment benefit rate.[2]

The Danish employment system operates under the so called "flexicurity" model. This system combines low firing/ hiring costs and comprehensive unemployment benefits, with the idea of maximising the country's adaptability to shocks.Danish Agency for Labour Market and Recruitment (n.d.) This makes Denmark a particularly interesting case study as it allows us to understand how firms and workers, when presented with such flexibility, choose to adapt their behaviour optimally.

3. Data

To test our hypotheses we use a matched worker-firm panel data set for the years 2001 to 2013. The majority of the data is provided by Statistics Denmark, the national statistics agency, and the relevant information must be aggregated from several registers using individual and firm identifiers.

The main source for firm variables is the Firm Statistics Register (FIRM). It covers the universe of Danish firms and provides general information such as the number of full-time employees, six digit industry codes (NACE), firm-output, ownership, region and wage bill. We supplement the firm database with accounting statistics available in the FIRE-register. While this survey data restricts the number of firms in the final sample, it provides detailed information about assets, investments, value added and raw materials used in the production. To construct the exporting and importing/offshoring instrument used in the regression, we use the Danish foreign trade statistics register (UHDI), the register of industry sales (VARS), and the United Nations Comtrade Database. The foreign trade statistics provide firm-specific imports and exports disaggregated by HS8 code and country of origin/destination at the yearly level. In addition to the value of the traded product in Danish Kroners, its weight in kilograms is also reported. The industry sales register reports quarterly data on firm- and product-specific domestic sales. To measure bilateral, product-specific trade flows between Denmark and all countries of the world, we merge the Comtrade Database to the Danish register data. Since Comtrade measures products at the HS6 level, we aggregate domestic sales, imports and exports of a firm accordingly. We

[2]https://asemlllhub.org/wp-content/uploads/attachments/Denmark.pdf

measure the distance between ISO-codes by using the GeoDist provided by CEII.

Our worker data is mainly extracted from the Integrated Database for Labor Market Research (IDA). It provides socio-economic characteristics for the entire Danish population aged between 15-74. Each person is identified with a unique number and can be tracked across years. IDA records annual data about labor market participation, age, gender, tenure within a firm, work experience, wage and hours worked. To determine the education of an employee, we use the Education register (UDDA). We are able to identify the highest level of completed education and the field the education was taken in. We categorize employees into two groups: high-skilled and low-skilled, where an employee is considered high-skilled if they have at least tertiary education. To distinguish between full-time and part-time employees and to obtain occupation codes, we complement the data with information from the Workforce register (RAS). Our training data comes from the Adult and Continued Education Database (VEUV) which covers the entire Danish population. VEUV provides annual data about the type, field and length of the training undertaken by an individual.

After merging the different registers for firm and worker data separately, we use the FIDA-key to link firm identifiers and worker identifiers. The final data set is an unbalanced panel of matched worker-firm information on a yearly level.

While our panel data covers the entire universe of danish firms and workers, some required variables are only available for selection of firms and it is necessary to trim the data in various ways leaving us with a subset of firms and workers in the estimation sample.

We restrict our data sample to privately-owned manufacturing firms and exclude firms that switch into or out of manufacturing within the sample period.[3] Since small firms tend to have imputed accounting information and missing trade data, we drop all firms with fewer than 50 employees and less than 0.6 million DKK (approxmiately 67,500 Euros) in imports. To estimate the instrumental variable strategy it is necessary to restrict the samples to firms which both import and export (see section 4.3).

On the worker side, we restrict the sample to employees aged 20-68 working in a full-time position. Furthermore, we only include worker-firm matches if the position is re-

[3]We define manufacturing industries by using two-digit NACE codes. In total we separate the economy in eleven industries.

ported to be the primary working position of the year to make sure that observed worker training is associated with the matched firm.

Our analysis looks at both the effect of importing on skill intensity and that of offshoring. Following Hummels et al. (2014) we define offshoring to be imports of products that are in the same HS4 category as the products that are either exported or sold domestically by the firm.

3.1 Summary Statistics

In this chapter we provide summary statistics of the main variables.

Table 3.1 provides summary statistics of the main variables used in the regression. Our final sample consists of 7,887 firm-year observations and has 1,219.654 firm-year-worker observations. The average firm in our sample has 140 employees and a gross output of 183 million Danish Kroners (20 million Euro). On average 20% of the workforce are considered high-skilled workers and 19% receive training across the years. Our sample consists of firms that are significantly engaged in international trade, on average they import 24 million DDK (2.7 million Euros) worth of products and export 60 million (6.7 million Euros). Offshoring is by definition a subsample of importing and the average value is about 14 million (1.6 million Euros). The standard deviation of the trading variables is sizeable leaving us with variation for the estimation. Our sample represents between 40-50% of total annual manufacturing employment and total manufacturing output in Denmark.

Table 2 provides summary statistics for the course variables. Around 90% of the courses in our sample are vocational courses, followed by 6% further courses and 4% basic courses. Vocational courses cover a range of subjects and the two most important fields provide more than 50% of all course observations: *Technology, Engineering* and *Office Services*. Course titles in those fields include, for example, "mechanical engineering and production", "automotive and marine mechanics" , "power and electronics", and "Office, Trade and Business Service".

The most important fields within basic courses are "primary school courses for adults" followed by "Danish language classes"and within further courses the most important field is "Social Science Business'". The most important course in further education is "Economics Mercantile". It is striking that the absolute majority of courses are business and engineering related.

Table 3 separates courses by type and relates them to the trading activity of the firms. We defined two groups for each trading type and separated them by the median of the distribution. The resulting picture is quite clear. The more a firm is trading the more it is training the workforce. The differences in training between trading types are not

Table 1: Firm and workers summary statistics

	Observations	Mean	SD
Firm-level data			
log employment	7,887	4.95	0.92
log gross output	7,887	19.03	1.08
log capital per worker	7,887	12.51	0.99
log average wage bill per worker	6.337	12.74	0.18
log accounting profits	6.926	9.31	1.72
high-skill share	7,887	0.20	0.13
low-skill share	7,887	0.80	0.13
training share	7,887	0.19	0.20
Firm Level trade data			
log imports	7,887	17.01	1.53
imports / gross output	7,887	0.22	0.19
imports, log deviation from firm mean	6.337	0.38	0.39
log narrow offshoring	7,887	16.47	2.11
narrow offshoring / gross output	6.337	0.16	0.22
narrow Offshoring, log deviation from firm mean	6.109	0.72	1.00
log (exports)	7,887	17.91	1.82
exports / gross output	7,887	0.52	0.35
exports, log deviation from firm mean	6.337	0.40	0.62
Worker-firm data			
hourly wage	1,219.654	212.89	105.04
log hourly wage	1,219.648	5.15	0.32
log gross output	1,219.654	20.74	1.78
log employment	1,219.654	6.50	1.53
log capital per worker	1,219.654	12.84	0.90
high skill	1,219.654	0.26	0.44
age	1,219.654	43.15	9.82
work experience	1,219.654	18.05	7.66

Notes: The data used for the last panel titled "Worker-firm data" has worker-firm-year observations, and the data used for the other panels has firm-year observations. For each variable we report its mean and standard deviation across all observations.

Table 2: Training summary statistics, by field

Type	Observations	Percentage
Basic Courses	16.601	
Danish Language Courses	3.430	20.66
High School Courses	588	3.54
Primary School Courses	12.579	75.77
Other	4	0.02
Vocational Courses	361.746	
Agriculture	2.455	0.68
Health	1.589	0.44
Construction	22.793	6.30
Food	12.184	3.37
Office Services	63.177	17.46
Technology, Engineering	146.322	40.45
Technology, Other	34.165	9.44
Transport	49.559	13.70
Other	29.502	8.16
Post Secondary Courses	19.448	
Agriculture	53	0.3
Education	202	1.0
Food	335	1.7
Health	481	2.5
Humanities	661	3.4
Media	1.255	6.5
Social Science, Buisness	13.312	68.4
Social Science, Other	946	4.9
Technical Science	1.733	8.9
Other	470	2.4

Notes: The number of observations presented counts worker-firm-year observations, and percentages are relative to the total of the particular training type. Basic Courses refer to the lower secondary level, Vocational Courses refer to upper secondary courses, Further courses refer to tertiary courses.

Table 3: Summary Statistics Training by Trading Intensity

	Imports		Offshoring		Exports		
	Low	High	Low	High	Low	Hig	Obs/ Mean
At least one Course started	45.812	233.872	41.419	238.265	45.959	233.725	279.684
Basic Course	2.639	12.147	2.507	12.279	2.672	12.114	14.786
Vocational Course	42.078	214.222	37.898	218.402	42.431	213.869	256.300
Further Course	2.173	14.179	1.978	14.374	1.953	14.399	16.352
Course started / Total Employment	0.189	0.239	0.190	0.238	0.201	0.236	0.229
Basic Course	0.011	0.012	0.012	0.012	0.012	0.012	0.012
Vocational Course	0.173	0.219	0.174	0.218	0.186	0.216	0.210
Further Course	0.009	0.015	0.009	0.014	0.009	0.015	0.013
Mean Number of Course a year	1.114	1.125	1.114	1.124	1.138	1.119	1.123
Basic Course	1.114	1.125	1.114	1.124	1.138	1.119	1.123
Vocational Course	1.409	1.412	1.393	1.415	1.375	1.419	1.411
Further Course	1.162	1.194	1.161	1.193	1.168	1.192	1.189
Mean length course in days	4.573	5.242	4.616	5.225	4.215	5.314	5.133
Basic Course	14.975	15.653	15.311	15.574	16.459	15.310	15.527
Vocational Course	1.252	1.162	1.312	1.153	1.091	1.194	1.177
Further Course	43.022	45.796	42.516	45.827	41.631	45.941	45.427

Notes: The number of observations presented counts worker-firm-year observations in each category, percentages are relative to the total number of observations, the number of courses and course length are averaged across worker-firm-year observations. Basic Courses refer to the lower secondary level, Vocational Courses refer to upper secondary courses, Further courses refer to tertiary courses. The low-high imports/offshoring/exports cutoff is at the median value.

4. Empirical Strategy

In this section we explain the empirical strategy used to estimate the effect of international trade on training outcomes at the firm and worker level.

4.1 Baseline firm-level specification

We use the following baseline model at the firm-level:

$$firmoutcome_{jt} = \beta_1 \widehat{ln(X_{jt})} + \beta_2 \widehat{ln(M_{jt})} + \gamma_j + \gamma_t + \epsilon_{jt} \tag{1}$$

where $firmoutcome_{jt}$ includes the following firm-level outcomes: training intensity, log employment, log gross output, log accounting profits, log capital per worker, log wage bill per worker, log material inputs, log domestic material inputs, share of high-skilled workers, share of worker upskilling, materials/ output, and domestic materials/output. The fitted value of the log exports X_{jt} and either imports or offshoring M_{jt} are included using the instruments described below. We include firm j, year t fixed effects to account for time-invariant differences between firms and global time-trends common to all firms.

4.2 Baseline worker-level regressions

We use the following baseline model at the firm-level:

$$workertraining_{it} = \delta_1 \widehat{ln(X_{j,t-1})} + \delta_2 \widehat{ln(M_{j,t-1})} + \alpha_i + \alpha_j + \gamma_{ind \times year} + \gamma_r + \epsilon_{ijt} \tag{2}$$

where $workertraining_{it}$ includes various measures of the intensity of training undergone by worker i at time t. As above, the values of the log of both exports and imports are instrumented. We include worker i, firm j, industry-year $indxyear$, region r and fixed effects. We lag both the instrmuments and the trading variables by one period since we expect that workers and firms need time to adjust and agree on training. We also therefore only include workers that are employed in the firm at the time of the shock.

4.3 Instruments

The instrumental variables approach used in this paper follows the strategy used by Hummels et al. (2014). The primary concern is that the trade behaviour of the firms and our outcome variables may both be driven by unobserved time-varying firm-level shocks. For example a positive demand or productivity shock observed by the firm can lead to both an increase in imported inputs and an increase in worker training to maximise profits. To avoid this problem in the identification strategy we use instruments that are correlated with the value of imports and exports at the firm-year level but are uncorrelated with firm-level shocks that would bias our results. The solution proposed by Hummels et al. (2014) is to calculate World Export Supply, to instrument for imports, and World Import Demand, to instrument for exports. These instruments are supplemented by transport cost instruments that exploit variations in fuel prices over time.

World export supply WES_{ckt} is defined as country c's total supply of product k to the world market, minus its supply to Denmark, in period t. The world export supply can be interpreted as the changes in the countries' comparative advantage for exporting that specific product to the world market and changes in WES_{ckt} reflect changes in production prices, product quality or consumer taste in other countries. World import demand WID_{ckt} is defined as country c's total purchases of product k from the world market, less its purchases from Denmark, in period t. Similarly to the world export supply, changes in WID_{ckt} can be attributed to a changes in the comparative advantage of the country in the specific product.

Furthermore, we construct a instrument for transport costs tc. Changes in transport costs are intended to capture shocks to the delivered price of inputs purchased by the firm. We use annual crude oil prices and calculate a simple interaction of unit weight, oil price index and distance for each product-country-year. The source of variation of the transport costs within a given a worker-firm pair is determined by the oil price. During our sample period, the oil price increased from 37.4 per barrel to 67.1 USD per barrel.

As mentioned in section 3, we use bilateral trade flows on HS6 product-level from the Comtrade Database to construct world export supply and world import demand.[4] The

[4]To account for gaps in the data we interpolate bilateral trade flows if the total amount of gap-years is smaller than 20% of total observations

constructed instruments have country-product-time variation [5]. To obtain a single value for a firm-year observation, the instruments are weighted with pre-sample shares. In more detail, the instrument of importing firm j at time t (I_{jt}) is the sum over country-product-year export instruments (WES_{ckt}) weighted by firm j's share of $c-k$-imports on total imports in the pre-sample year[6]. The same approach is used for the offshoring and export instruments respectively. Using constant pre-sample shares avoids potential endogeneity due to the firm changing its product composition in response to global shocks. The firms in our sample have persistent product-country-relationships relative to the pre-sample year. 40%-70% of total imports and 60%-90% of total exports are continued product-country-relationships from the pre-sample year[7].

To summarize, we have two instruments for each of the three endogenous variables: importing, offshoring and exporting. We instrument for exporting (offshoring, imports) using the weighted average of import demand (export supply, export supply) and the corresponding transport costs.

Taking the example of a specific country c that supplies product k to firm j in Denmark, and experiences a change in production cost, product variety or quality resulting in a lower export supply to the world market. This change will be exogenous and specific to the firm j since product k is weighted by the firm-product-country specific pre-sample share. Even firms in the same industry, importing the same product from the country will experience a different trade shock.

5. Results

In this section we present the results of the regressions at the firm-level and worker-level.

5.1 Baseline firm-level specification

Table 4 presents the results of our main firm-level estimation.[8] Columns (7), (8) illustrate the results for log(offshoring) and log(exports) when they are jointly included in the in-

[5] See figure A1 and figure A2 in the appendix for the development of WID and WES over time
[6] $I_{jt} = \sum_{c,k} s_{jck} I_{ckt}$ with $I \in (tc, WES_{ckt})$,
[7] See figure A4 and figure A3 in the appendix.
[8] Table A1 presents the first-stage regression results.

strument variable regression.

Beginning with offshorers in column (7), we find negative and significant employment coefficient indicating that a 1% increase in offshoring decreases employment by 0.7%. Furthermore we find a negative effect on their usage of domestic materials and materials/output and a positive effect on gross output and wages. Therefore offshorers decrease their input usage (employment, materials) but increase output and wages. This result might be explained by explained Bernard et al. (2019) who argue that firms offshore low quality products to free up resources for higher quality products at home.

Most importantly we find strong evidence that an trade shock leads to an upskilling of the workforce. The coefficient for skill share indicates that a 1% increase in offshoring increases the skill intensity of offshorers by 0.17 percentage points. Since offshorers reduce employment and do not do any training, this indicates that the increase in skill intensity is likely due to a reduction in employment of low-skill workers.

Exporters are displayed in column (8) and (10). The employment coefficient is positive but insignificant in column (8) but slightly significant at the 10% when regressed with importing. Furthermore, we found a positive effect on materials input, local materials, gross output and profit. While those results indicate that a trade shock allows exporters to expand, we find no evidence for upskilling or training of workers at the firm level.

Importers (column (9)) decrease their employment when facing a trade shock. The coefficient indicates that a 1% increase in importing decreases employment by 0.82%. Furthermore, we find a trade shock significantly increases output, wage bill and domestically sourced inputs. Most importantly we find that an exogenous trade shock increases upskilling by skill intensity as well as training. This result is related to Grossman and Rossi-Hansberg (2008) who show that firms can import the labor intensive stages of their production process and thus increase their domestic demand for skilled labor.

To summarize the firm-level regressions, exporters expand their production but we do not find evidence for upskilling. While offshorers upskill by firing low skill workers, and importers upskill both by training their workforce and firing low skill workers.

Table 4: Baseline firm-level results

	FIRM & YEAR FE			FIRM & YEAR FE, PREDICTED VALUES			FIRM & YEAR FE, PREDICTED OFFSHORING & EXPORTS		FIRM & YEAR FE, PREDICTED IMPORTS & EXPORTS	
	log(offshoring) (1)	log(imports) (2)	log(exports) (3)	log(offshoring) (4)	log(imports) (5)	log(exports) (6)	log(offshoring) (7)	log(exports) (8)	log(imports) (9)	log(exports) (10)
log(employment)	0.0373***	0.178***	0.119***	-0.912***	-1.020***	-0.0571	-0.749***	0.515	-0.824***	0.294*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.486)	(0.000)	(0.120)	(0.000)	(0.095)
log(gross output)	0.0615***	0.276***	0.149***	0.0578	0.0659	0.613***	0.130*	0.348**	0.159**	0.270**
	(0.000)	(0.000)	(0.000)	(0.294)	(0.242)	(0.000)	(0.057)	(0.021)	(0.024)	(0.014)
log(accounting profits)	0.0731***	0.323***	0.175***	0.00450	0.0562	0.910***	-0.211	0.997*	-0.444	1.370***
	(0.000)	(0.000)	(0.000)	(0.973)	(0.721)	(0.001)	(0.443)	(0.062)	(0.151)	(0.009)
log(capital per worker)	0.00161	0.0193	-0.00660	0.0205	-0.192*	-0.0234	0.0768	0.0521	-0.129	0.301**
	(0.802)	(0.172)	(0.507)	(0.835)	(0.060)	(0.863)	(0.573)	(0.814)	(0.317)	(0.050)
log(wage bill per worker)	0.00495***	0.0122***	0.00242	0.662***	0.740***	0.303***	0.612***	-0.253	0.657***	-0.0574
	(0.000)	(0.000)	(0.269)	(0.000)	(0.000)	(0.001)	(0.000)	(0.333)	(0.000)	(0.458)
log(material inputs)	0.0815***	0.345***	0.162***	-0.162	-0.167	0.817***	-0.0973	0.760***	-0.0376	0.428**
	(0.000)	(0.000)	(0.000)	(0.215)	(0.154)	(0.002)	(0.460)	(0.006)	(0.777)	(0.036)
log(domestic material inputs)	0.0103	0.0468**	0.123***	-0.718***	-0.731***	0.413**	-0.589***	0.832**	-1.157***	1.374***
	(0.203)	(0.013)	(0.000)	(0.003)	(0.000)	(0.023)	(0.008)	(0.019)	(0.000)	(0.003)
Share of high-skilled workers	0.000905**	-0.000894	-0.00239***	0.183***	0.200***	0.0666**	0.171***	-0.0967	0.178***	-0.0209
	(0.049)	(0.515)	(0.004)	(0.000)	(0.000)	(0.019)	(0.000)	(0.197)	(0.000)	(0.424)
Share of worker upskilling	0.00332*	-0.00141	0.00349	0.0545*	0.0712**	0.0200	0.0514	-0.0127	0.0766**	-0.00742
	(0.056)	(0.721)	(0.204)	(0.083)	(0.034)	(0.616)	(0.126)	(0.833)	(0.013)	(0.819)
Materials/output	0.00710***	0.0249***	0.00828***	-0.0583**	-0.0540**	0.0305	-0.0580**	0.0950*	-0.0496**	0.0273
	(0.000)	(0.000)	(0.000)	(0.030)	(0.011)	(0.325)	(0.033)	(0.056)	(0.017)	(0.275)
Domestic materials/output	-0.0110***	-0.0506***	-0.00285	-0.141***	-0.152***	-0.0151	-0.135***	0.114*	-0.204***	0.157***
	(0.000)	(0.000)	(0.171)	(0.000)	(0.000)	(0.513)	(0.001)	(0.061)	(0.000)	(0.004)
Observations	7,887	7,887	7,887	7,887	7,887	7,887	7,887	7,887	7,887	7,887

Notes: The cells are coefficient estimates of various regressions, whose dependent variables are down the rows and regressors are along the columns. For example, column 1 shows that when we regress log(employment) on log(offshoring), we get a coefficient of 0.0373 (significant). The samples use only the firm-years that have positive offshoring/importing/exporting values. P-values in parentheses, robust standard errors used. Columns (1)-(6) include one trade regressor in each regression, whereas columns (7) & (8) represent the coefficients. from one joint regression, as do columns (9) & (10). *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

5.2 Baseline worker-level regressions

In this section we focus on the worker-level regressions.

As described in equation 2, our estimation strategy relates changes in a worker‘s training to changes changes in importing and exporting activity of the firm. This identification strategy is based on the variation of trading activity within a firm and over time. We estimate a linear probability model and control for worker, firm, region and industry-year fixed effects and cluster the standard errors on the worker level to allow for serial correlation. We consider the four training categories described in 3.1: any course, basic course, vocational course and further course started. All variables are zero-one dummies indicating whether at least one course in the category has been started in that year.

We execute two sets of regressions for each course category. The first jointly includes the firms' importing and exporting, the second includes offshoring and exporting. We include the full set of instruments for each of the endogenous variables and our first stage consists of a total of four distinct regressions.[9]

Table 5 presents the results of the main worker-level regression. The first panel displays the results using $log(imports_{t-1})$ and $log(exports_{t-1})$, and the second panel displays the $log(offshoring_{t-1})$ and $log(exports_{t-1})$.

Our results indicate that an exogenous change in exporting or importing increases the probability of workers undertaking any training (Column 1). In detail, an exogenous increase in importing of 1% in the previous period increases the probability of undertaking any course by 0.12 percentage points in this period. The coefficient for exporting is positive and significant but the magnitude of the effect varies across the panels. Once we control for log imports, the positive coefficient of log exports from the bottom panel reduces to 0.0328 and imports now explains a sizeable share of the variation. This may be because log(imports) is more positively correlated with log exports than with log offshoring is, and hence log exports in the bottom panel is also capturing changes in log imports. It is possible that firms that export also tend to import a lot due to global values chains/connection with international markets.

Column (2) presents the results for basic courses. We find a positive and significant

[9] Table A2 provides the regression results of the first stage.

Table 5: Worker-Level Training Regressions

	Any course	Basic courses	Vocational courses	Further courses
	(1)	(2)	(3)	(4)
Imports and Exports				
log imports$_{(t-1)}$	0.119***	0.00141	0.118***	0.00125
	(0.0107)	(0.00255)	(0.0105)	(0.00275)
log exports$_{(t-1)}$	0.0328***	-0.00697**	0.0368***	-0.00407
	(0.0110)	(0.00301)	(0.0110)	(0.00272)
Obs.	1,216,972	1,216,972	1,216,972	1,216,972
Exports and Offshoring				
log offshoring$_{(t-1)}$	0.00531	-0.00460	-0.000783	0.00396
	(0.0150)	(0.00295)	(0.0147)	(0.00325)
log exports$_{(t-1)}$	0.279***	0.0133*	0.284***	-0.0118
	(0.0406)	(0.00750)	(0.0400)	(0.00778)
Obs.	1,197,550	1,197,550	1,197,550	1,197,550

Notes: Table 2 presents the results from linear probability regressions using binary variables for *course started* as dependent variables. All specifications include worker, firm, industry-year and regional fixed effects. Log imports, log offshoring and log exports in the previous period are instrumented using transport costs, world export supply and world import demand in the previous period. Standard errors clustered at worker levels. Standard errors in parentheses.
*** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

effect of exporting in panel one but a negative and significant effect in panel two. Those mixed results might be explained by the low number of observations in this training category[10] and some degree of correlation between the regressors.

The results for vocational courses are highly significant and positive for imports and exporting, with similar magnitudes to those seen for any course (reflecting the importance of these courses in overall training). A 1% increase in the firms‘ importing last period increases the probability that a worker starts a vocational course in this period by 0.118 percentage points. Column (4) indicates that a change in the trading activity of the firm does not affect the probability that workers start a further course in general.

Overall, we find evidence that upskilling of workers is indeed related to the firms‘ trading activity. The results indicate that vocational courses are the main driver for worker training, and our results for offshorers and importers reflect the results from the firm-level regressions.

5.3 Worker-level education, age, firm sized analysis

In this section we want to test heterogeneity of our results by the key margins of worker age, education, and firm size.

We would expect that the interaction with education allows us to capture the access criteria of courses. While every worker could start a *basic course*, *further courses* are aimed at workers with upper secondary education. Not separating into groups will result in an imprecise estimate.

We define three dummies. *high-skilled* equals one if a worker has tertiary education. To analyze the effect of age we define the dummy *age high* that equals one if the worker is older than 40 years.[11] To analyze the heterogeneity by size we define the dummy *large firm* to be one if the firm is above the median in total employment.[12]

We interact each dummy variable with the full set of instruments and endogenous variables and estimate the linear probability model as described in Section 4. We estimate export (export) and offshoring (import) jointly. For each of these regressions we end up with

[10] See table 2.
[11] Approximately the median age in our sample.
[12] In our sample the median employment is 108 workers.

four endogenous variables and eight instruments. The results of the interacted regressions for the *any course started*[13] variables are presented in Table 6.

Table 6: Worker-level training; education, age and firm size Interactions

Any course started$_{(t)}$	log imports$_{(t-1)}$ (1)	log imports$_{(t-1)}$ x (RowVar)$_{(t-1)}$ (2)	log exports$_{(t-1)}$ (3)	log exports$_{(t-1)}$ x (RowVar)$_{(t-1)}$ (4)	Obs
high skilled$_{(t-1)}$	0.130***	-0.0474**	0.0376***	0.0318*	1,216,972
	(0.0114)	(0.0193)	(0.0110)	(0.0186)	
age high$_{(t-1)}$	0.114***	0.00822	0.0438***	-0.0143	1,216,972
	(0.0139)	(0.0122)	(0.0147)	(0.0114	
large firm$_{(t-1)}$	0.131**	-0.0186	0.0713	-0.0288	1,216,972
	(0.0622)	(0.0598)	(0.0442)	(0.0441)	

Any course started$_{(t)}$	log offshor$_{(t-1)}$ (6)	log offshor$_{(t-1)}$ x (RowVar)$_{(t-1)}$ (7)	log exports$_{(t-1)}$ (8)	log exports$_{(t-1)}$ x (RowVar)$_{(t-1)}$ (9)	Obs
high skilled$_{(t-1)}$	0.00929	0.0127	0.268***	-0.0247*	1,197,550
	(0.0151)	(0.0135)	(0.0410)	(0.0136)	
age high$_{(t-1)}$	-0.00931	0.0418***	0.222***	-0.0544***	1,197,550
	(0.0183)	(0.0134)	(0.0363)	(0.0168)	
large firm$_{(t-1)}$	0.169***	-0.0966***	-0.0839***	0.165***	1,197,550
	(0.0216)	(0.0195)	(0.0272)	(0.0301)	

Notes: Table 6 presents the results from six separate linear probability regressions along. Dependent variable is *Any course started.* Columns 2, 4, 7, 8 are coefficients for interactions with one of three dummies in the rows. *high-skilled* equals one if at least tertiary education. *age high* equals one if worker is older than 40 years. *large firm* equals one if firm is larger than median firm in the sample. Columns 1,3,6,8 are none-interacted coefficients. Log imports, log offshoring, log exports and their interactions with one of the in the previous period are instrumented using transport costs, world export supply and world import demand interacted in the previous period. Standard errors clustered at worker levels. Standard errors in parentheses.
*** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

The coefficients for importing in column (1) and (2) indicate that a 1% increase in importing increases the probability to start any course by 0.13 percentage points for unskilled workers. The increase is around 40% smaller for skilled workers, since their probability to start any course increases by only 0.08 percentage points This is consistent with the initial high level of skilled workers meaning that they have less need to undertake more training, whereas low skill workers benefit more from training. This is supported by that fact that the majority of training included in the dataset is vocational and hence arguably more suitably designed for low skill workers. As in the aggregate specification, offshoring remains insignificant for both specifications. Exporting positively affects low skill workers training uptake but there is weak mixed evidence for high skill workers depending on whether

[13] A full display of interaction regressions by course type can be found in the Appendix beginning with table A3.

imports or offshoring is included in the regression.

Turning to the age results, we see that importing positively impacts both young and older workers similarly, whereas for offshoring, we now see that there is in fact a positive, although weaker, effect which only holds for older workers. Exports have a positive impact in both panels with no difference for older workers in the first panel and a slightly weaker impact in the bottom panel. It is perhaps surprising that older and younger workers do not see a more significant difference in their training uptake, however, this is consistent with the conclusions for vocational training in Simonsen and Skipper (2008). It is possible that the fact that older workers' skills are more out of date requires increases their training despite the negative effect of lower lifetime returns to training.

Small firms see a positive impact for both imports and offshoring, likely benefiting from the government subsidies. The effects are same for large firms for imports, and weaker for offshoring. Exports do not seem to matter in the top panel, but we see a negative effect for small firms and a positive effect for larger firms in the bottom panel.

As before, the coefficients for exporting vary across the panel setting. The magnitude of the firm-size coefficient would suggest a slightly higher effect for smaller firms but the difference between the groups is not significant. Furthermore, there is no evidence that upskilling in response to an import shock depends on the age of the worker.

6. Conclusion

This paper investigates how firms change their skill composition in response to exporting, importing and offshoring shocks. We explore both skill upgrading of workers through individual-level training responses, and changes in the firm employment composition by hiring and firing workers.

Overall, we find evidence that upskilling of workers is indeed related to the firms‘ trading activity. First of all, the results indicate that vocational courses are the main driver for trade-related worker training. We then find that importing and offshoring increase the skill-intensity of a firm and output whilst reducing employment, consistent with firing low-skill workers and adjustment along the extension margin to increase efficiency. We also find that importing increases the proportion of workers undertaking some form of training as some lower-skill workers are retained and upskilled. This provides some support to the predictions of Bernard et al. (2019) where firms reorient towards higher quality products when offshoring and to Costa et al. (2019) who find the reductions in training as the cost of imported inputs increases. There are no such impacts for exports at the firm-level, apparently contradicting the work of Bustos (2011), although there some weak evidence that employment also increases.

At the worker level our main results indicate that both importing and exporting increase the probability that workers start a training course. This is consistent with the firm level evidence for importing but not for exporting. For importing we find a different effect depending on the education of the worker, with unskilled workers being more likely to start training than skilled workers, consistent with importing lower skill intensive products and reassigning workers to higher skill or quality production. There is no clear evidence that older workers are trained more or less than younger workers as predicted by Simonsen and Skipper (2008), and firm size provides mixed evidence which implies smaller firms train more in response to offshoring but this is reversed for exports.

Future research could explore mechanisms by which firms decide to upskill or not, it also would be valuable to understand better the part that government subsidised training plays in overall employee training and the extent to which the content of the training is providing significant benefits for the productivity of workers.

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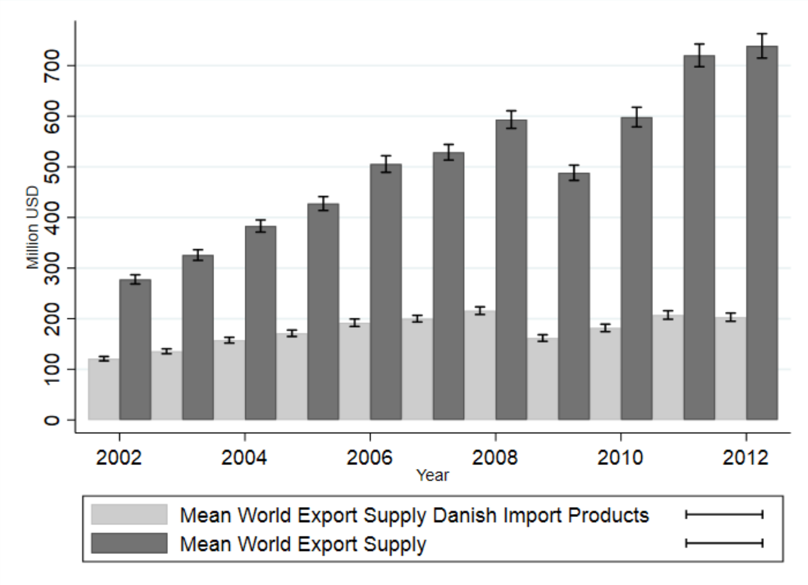
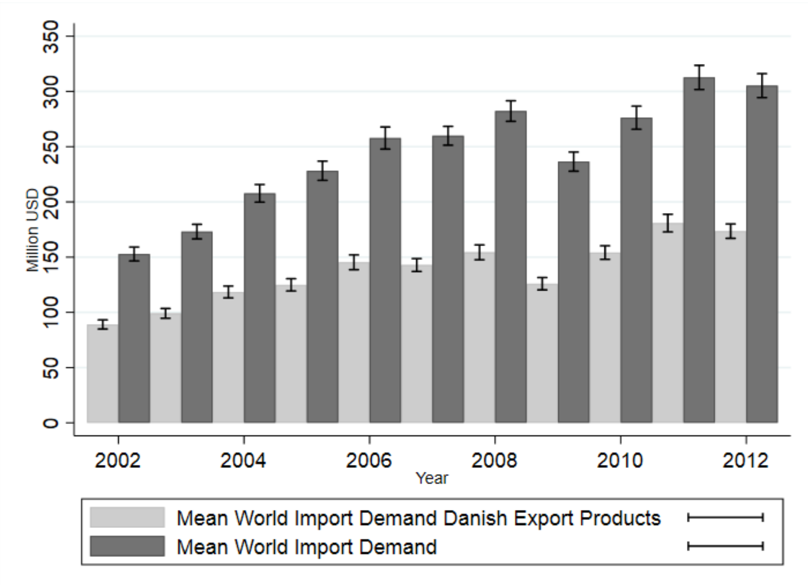
Appendix

Figure A1: World Export Supply and Danish Import Products over time



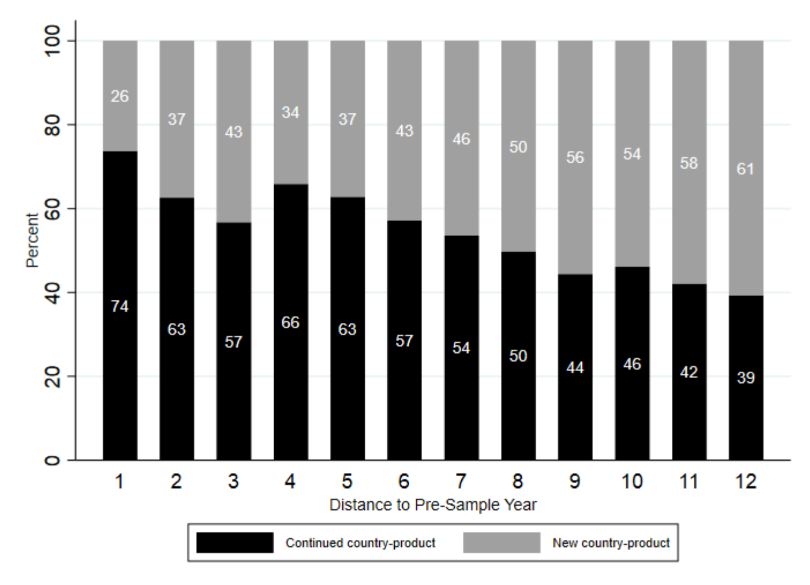
Notes: The dark bars represent the average world export supply, across country-product combinations. The light bars represent the average world export supply for products imported by Danish firms in the pre-sample year.

Figure A2: World Import Demand and Danish Export Products over time



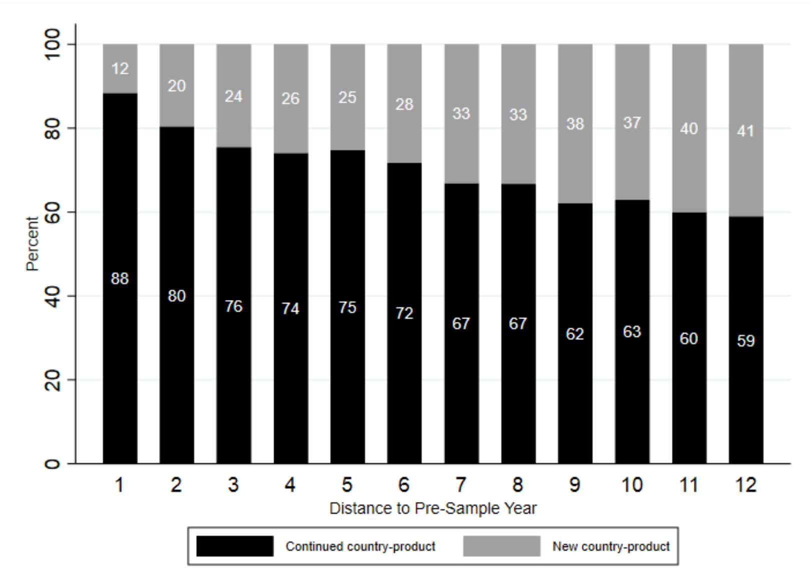
Notes: The dark bars represent the average world import demand, across country-product combinations. The light bars represent the average world import demand for products exported by Danish firms in the pre-sample year.

Figure A3: Importing: Persistence of country-product combinations from pre-sample year.



Notes: This graph shows the average share of continued product-country combination of importing firms, by distance from the pre-sample year.

Figure A4: Exporting: Persistence of country-product combinations from pre-sample year.



Notes: This graph shows the average share of continued product-country combination of exporting firms, by distance from the pre-sample year.

Table A1: First-stage results for firm-level regression

	2nd stg incl. Offshoring & Exports		2nd stg incl. Imports + Exports	
	Offshoring	Exports	Imports	Exports
	(1)	(2)	(3)	(4)
world export supply - offshoring	0.00554	-0.0614*		
	(0.907)	(0.054)		
trade costs - offshoring	-0.0432	2.507		
	(0.999)	(0.876)		
world export supply - imports			0.0513***	-0.104
			(0.003)	(0.143)
trade costs - imports			4.730	19.30
			(0.576)	(0.128)
world import demand - exporting	0.0813**	0.153***	0.0273*	0.125***
	(0.039)	(0.000)	(0.096)	(0.001)
trade costs - exports	-50.04*	-8.510	-47.71***	-31.46**
	(0.083)	(0.630)	(0.000)	(0.040)
Obs	7,887	7,887	7,887	7,887
F-stat	6.677***	4.973***	24.25***	4.297***
	(0.000)	(0.001)	(0.000)	(0.002)

Notes: The samples use only the firm-years that have positive offshoring/importing/exporting values. All regressions include firm and year fixed effects. P-values in parentheses, robust standard errors used.
*** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table A2: First Stage IV Regression worker-level

	log imports$_{(t-1)}$	log export$_{(t-1)}$	log export($_{(t-1)}$)	log offshoring$_{(t-1)}$
	(1)	(2)	(3)	(4)
world export supply instrument$_{(t-1)}$	0.204***	0.320***		
	(0.030)	(0.0286)		
log transport cost importing$_{(t-1)}$	0.656***	0.845***		
	(0.050)	(0.0618)		
world import supply offshoring instrument$_{(t-1)}$			0.036	0.265***
			(0.028)	(0.033)
log transport cost offshoring$_{(t-1)}$			0.821***	-0.122**
			(0.060)	(0.055)
world import demand instrument$_{(t-1)}$	0.197***	0.00367	0.311***	0.196***
	(0.019)	(0.0610)	(0.026)	(0.026)
log transport cost exporting$_{(t-1)}$	-0.184***	-0.219***	-0.175***	0.698***
	(0.045)	(0.0588)	(0.053)	(0.060)
Constant	5.591***	6.973***	5.480***	2.408**
	(0.807)	(1.362)	(1.097)	(1.063)
Observations	1,216,972	1,216,972	1,197,713	1,197,713
Number worker	258,359	258,359	256,441	255,515
Adjusted R-squared	0.160	0.189	0.188	0.122
F-statistics for instruments	91.54	75.72	74.48	74.56

Notes: Table A2 presents the first stage from worker-level IV regressions. All specifications include worker, firm, industry-year and regional fixed effects. Standard errors clustered at worker levels. Standard errors in parentheses.
*** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table A3: Worker Level Regressions, Interaction Skill

	Any course (1)	Basic courses (2)	Vocational courses (3)	Further courses (4)
				log imports$_{(t-1)}$
0.130***	-0.000952	0.122***	0.0136***	
	(0.0114)	(0.00267)	(0.0110)	(0.00371)
log imports x high-skilled$_{(t-1)}$	-0.0474**	0.0115**	-0.0214	-0.0560***
	(0.0193)	(0.00459)	(0.0176)	(0.00970)
log exports$_{(t-1)}$	0.0376***	-0.00600**	0.0382***	-0.000832
	(0.0110)	(0.00297)	(0.0109)	(0.00271)
log exports x high-skilled$_{(t-1)}$	0.0318*	-0.0111**	0.0150	0.0445***
	(0.0186)	(0.00445)	(0.0170)	(0.00914)
Observations	1,216,972	1,216,972	1,216,972	1,216,972
log exports$_{(t-1)}$	0.268***	0.00919	0.272***	-0.00797
	(0.0410)	(0.00768)	(0.0402)	(0.00836)
log exports x high-skilled$_{(t-1)}$	-0.0247*	-0.0119***	-0.0337***	0.0288***
	(0.0136)	(0.00276)	(0.0126)	(0.00581)
log offshoring$_{(t-1)}$	0.00929	-0.00467	-0.000322	0.0111***
	(0.0151)	(0.00301)	(0.0147)	(0.00369)
log offshoring x high-skilled$_{(t-1)}$	0.0127	0.0117***	0.0306**	-0.0390***
	(0.0135)	(0.00277)	(0.0126)	(0.00572)
Observations	1,197,550	1,197,550	1,197,550	1,197,550

Notes: Table A3 presents the results from linear probability regressions using binary variables for *course started* as dependent variables. All specifications include worker, firm, industry-year and regional fixed effects.*high-skilled* equals one if at least tertiary education.Log imports, log offshoring, log exports and their interactions with *high-skilled* in previous period are instrumented using transport costs, world export supply and world import demand interacted with *high-skilled* in the previous period. Standard errors clustered at worker levels. Standard errors in parentheses.
*** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table A4: Worker Level Regressions, Interaction Age of Worker

	Any course	Basic courses	Vocational courses	Further courses
	(1)	(2)	(3)	(4)
log imports$_{(t-1)}$	0.114***	0.000743	0.110***	0.00481
	(0.0139)	-0.0039	-0.0137	-0.00401
log imports x age high$_{(t-1)}$	0.00822	-0.00015	0.0122	-0.00499
	(0.0122)	-0.0035	-0.0118	-0.00417
log exports$_{(t-1)}$	0.0438***	-0.00786*	0.0517***	0.00902**
	(0.0147)	-0.00446	-0.0146	-0.0043
log exports x age high$_{(t-1)}$	-0.0143	0.000327	-0.0189*	0.00680*
	(0.0114	-0.00322	-0.011	-0.00402
Observations	1,216,972	1,216,972	1,216,972	1,216,972
log exports$_{(t-1)}$	0.222***	-0.0182**	0.249***	-0.0116
	(0.0363)	-0.00821	-0.0356	-0.0102
log exports x age high$_{(t-1)}$	-0.0544***	-0.00859**	-0.0703***	0.00833
	(0.0168)	-0.00384	-0.0164	-0.00548
log offshoring$_{(t-1)}$	-0.00931	0.00614	-0.0169	0.00621
	(0.0183)	-0.00414	-0.0179	-0.00503
log offshoring x age high$_{(t-1)}$	0.0418***	-0.00659**	0.0539***	-0.00541
	(0.0134)	-0.00317	-0.013	-0.00429
Observations	1,197,550	1,197,550	1,197,550	1,197,550

Notes: Table A4 presents the results from linear probability regressions using binary variables for *course started* as dependent variables. All specifications include worker, firm, industry-year and regional fixed effects.*age high* equals one if worker is older than 40 years. Log imports, log offshoring, log exports and their interactions with *age high* in the previous period are instrumented using transport costs, world export supply and world import demand interacted with *age high* in the previous period. Standard errors clustered at worker levels. Standard errors in parentheses.
*** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table A5: Worker Level Regressions, Interaction Firm Size

	Any course (1)	Basic courses (2)	Vocational courses (3)	Further courses (4)
log imports$_{(t-1)}$	0.131**	-0.0250	0.165***	0.00745
	(0.0622)	(0.0160)	(0.0619)	(0.0127)
log imports x large firm $_{(t-1)}$	-0.0186	0.0240	-0.0520	-0.00619
	(0.0598)	(0.0156)	(0.0594)	(0.0122)
log exports$_{(t-1)}$	0.0713	0.0123	0.0534	-0.00268
	(0.0442)	(0.0118)	(0.0437)	(0.00862)
log exports x large firm $_{(t-1)}$	-0.0288	-0.0174	-0.00856	-0.00204
	(0.0441)	(0.0117)	(0.0437)	(0.00869)
Observations	1,216,972	1,216,972	1,216,972	1,216,972
log exports$_{(t-1)}$	-0.0839***	-0.0164**	-0.0868***	0.00450
	(0.0272)	(0.00648)	(0.0264)	(0.00618)
log exports x large firm $_{(t-1)}$	0.165***	0.0149**	0.170***	-0.00496
	(0.0301)	(0.00716)	(0.0292)	(0.00688)
log offshoring$_{(t-1)}$	0.169***	0.00966*	0.173***	-0.000868
	(0.0216)	(0.00500)	(0.0209)	(0.00515)
log offshoring x large firm $_{(t-1)}$	-0.0966***	-0.00830*	-0.104***	0.00132
	(0.0195)	(0.00456)	(0.0189)	(0.00458)
Observations	1,197,550	1,197,550	1,197,550	1,197,550

Notes: Table A5 presents the results from linear probability regressions using binary variables for *course started* as dependent variables. All specifications include worker, firm, industry-year and regional fixed effects.*large firm* equals one if firm is larger than median firm in the sample. Log imports, log offshoring, log exports and their interactions with in the previous period *large firm* are instrumented using transport costs, world export supply and world import demand interacted with *large firm* in the previous period. Standard errors clustered at worker levels. Standard errors in parentheses.
*** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Conclusion

This Ph.D. thesis has examined different topics of international economics. Each chapter can contribute to our understanding how firms interact in the global economy. The first chapter has analyzed how vertical integration of multinational companies affect the productivity spillover to local firms. We build on previous studies that have shown that the most important channel for productivity spillover is the interaction between local suppliers and foreign affiliates. We argue that multinational companies that have invested in industries that are linked by the value chain might source inputs within the boundaries of the group. The possibility of internal sourcing reduces the likelihood of collaboration with unrelated local suppliers resulting in weaker productivity spillovers. To test our hypothesis we derived two new measures of foreign presence depending on the vertical integration status of the multinational companies. Our analysis used a rich panel dataset of European manufacturing companies. Our results indicate that local firms receive a productivity spillover only from foreign affiliates that belong to multinational companies that are not vertically integrated in their industry. This result contributes to our understanding of the complexity of multinational production and the mechanisms of productivity spillovers.

The second chapter analyzed how the exposure to industrial robots affects the offshoring to high income and low and middle income countries. In the past, the offshoring of low-skilled labour intensive manufacturing production from high-income countries has contributed to the development of developing countries. Industrial robots have the potential to replace certain tasks that are carried out by low-skilled labor. To study the question whether the exposure to industrial robots decreases offshoring we used a matched worker-firm dataset of Danish manufacturing companies and construct firm-level shift-share instruments for industrial robot exposure. Our results show that exposure to advances in the commercial availability of industrial robots had a positive impact on offshoring to all countries and particularly to low and middle income countries. We further find that only the subset of low and middle income countries that are already offshoring destinations for Denmark benefit from the increase in offshoring. This result contributes to our understanding of the connection between international trade and automation.

The third chapter studied the effect of international trade on the skill intensity of firms and the upskilling of workers. We used a matched worker-firm dataset of Danish manufacturing companies. Our empirical strategy was to identify exogenous changes in the firms' trading activity using World Import Demand, World Export Supply and transport costs to instrument for exporting, importing and offshoring. Our results indicate that importing and offshoring increases the skill-intensity of firms and that importing increases the proportion of workers undertaking training. At the worker level our main results indicate that exporting and importing in-crease the probability that workers start vocational courses. This result contributes to our understanding of how international trade can have an impact on the education of workers.

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