3D Printing, Trade and FDI

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Abstract

We analyze the relationship between 3D printing, the volume of trade and the structure of foreign direct investment (FDI). A novel framework with firm-specific heterogeneity and 3D printing generates three predictions. First, 3D printers are introduced in areas with high economic activity that face high transport costs. Second, technological progress in 3D printing leads to FDI dependent on traditional techniques gradually being replaced with FDI based on 3D printing techniques. Third, with wider adoption, further technological progress in 3D printing leads to a gradual replacement of international trade. Empirical evidence looking at the sectors with the highest rates of adoption supports the first hypothesis, while anecdotal evidence supports the second and third. Our results suggest that the traditional strategy of poor countries for export-led industrialization is threatened by the widespread adoption of 3D printing that replaces trade.

JEL classification: F10, F23, O33, O19.

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"Companies are re-imagining supply chains: a world of networked printers where logistics may be more about delivering digital design files – from one continent to printer farms in another – than about containers, ships and cargo planes"

— PWC report (2014), *3D printing and the new shape of industrial manufacturing*

1 Introduction

Three dimensional (3D) printing, also known as *additive manufacturing*, is emerging as a technology with the potential to change international trade and FDI drastically.[1] 3D printing is considered to be a disruptive technology that is expected to change the production process in several ways (Chen, 2016; Ford and Despeisse, 2016; Tofail et al., 2018): i) assembly lines can be reduced or could even disappear for many small manufactured products such as replacement parts for household appliances or cars because of the high flexibility of 3D printers to switch from producing one replacement part to another. This reduces the unit cost of parts that are not needed frequently or in large amounts such that the corresponding assembly lines would often sit idle; ii) a regionalization process is likely to emerge because production can be located close to the main markets without the need of having a large number of (low-paid) workers who are able to produce the particular good in the same region. This reduces the comparative advantage of countries with cheap labor and minimizes the costs of transporting goods and parts over long distances; iii) product variety could increase because it becomes easier to customize products and adapt them to consumer needs and tastes. This in turn allows to scale up customized production without the need of using more labor and thereby to substantially reduce the unit costs of tailored products; iv) the need to keep inventories is reduced because design files can be sent instantaneously to any location in the world; v) 3D printing implies a cleaner production process with less material waste than standard (subtractive) manufacturing, which again reduces unit costs; vi) regarding highly complex production processes (e.g., the construction of a villa as mentioned below), it allows to reduce the number of workers and the production time, which increases labor productivity substantially;[2] vii) it reduces the time needed for prototyping and hence it reduces the time lags in product development and therefore the costs of innovations.[3]

Examples of the successful use of 3D printing technologies abound – two of them are described in USA Today (2012). The first refers to Audiovox, an assembler of digital TVs for BMW headrests. Audiovox decided to use the technology to print the control button of the TVs, which saved the company incurring tooling expenses

[1]3D printing was invented in 1986 by Chuck Hull and creates objects by solidifying very thin layers of a special polymer by using a laser. Essentially, this pins down to printing successive layers of different materials, rather than removing or cutting material from a large piece (which is called *subtractive manufacturing*). Large 3D printers, which are capable of creating objects up to a meter in diameter and three meters in height, have been developed for industrial use (e.g. delta-style 3D printers by SeeMeCNC).

[2]This may cause disruptions in labor markets in the short run, but could have beneficial effects in the long run, in particular, in aging societies like Western Europe and Japan where the work force has already started to shrink (Abeliansky and Prettner, 2017).

[3]According to the findings of an extensive qualitative survey, the spread of 3D printing could have consequences for future trade and FDI (Jiang et al., 2017). In particular, one potential scenario projected for 2030 implies that companies will use the efficiency of selling online files instead of exporting the final products not only to test new foreign markets but also to cover niches of demand in already established ones. A second scenario foresees that former manufacturers could become pure designers, with the core job of the company being to guaranty the printability of the files.

and enabled it to deliver the parts much faster. The second example is the production of infrared cameras for domestic use. Given that the supplier had to go through several design changes, 3D printing served as a suitable production technology to cope with these kinds of requests. Furthermore, The Guardian (2015) reports how 3D printing could change production processes even in the construction sector. They describe the building of a villa in less than 1 month using only 8 workers, while, without 3D printing, it would have cost twice as much, have taken 3 times as long, and have required 30 workers.[4] Overall, the cost-effectiveness of additive manufacturing exceeds those of existing technologies in certain industries[5] – particularly for pieces required at a small scale and involving high degrees of complexity – which could challenge the competitive advantage of factories in low-wage countries and change the global value chains as we know them (Baldwin, 2013).

Although the technology is still quite young, an evaluation of the long-run economic consequences of its application can be done by extending a standard model of international trade and FDI to account for 3D printing. The existent studies in this field in which 3D printing is mentioned are mostly in the business literature (Campbell et al., 2011; Ford and Despeisse, 2016; Holmström et al., 2016; Rayna and Striukova, 2016; Stahl, 2013; Weller et al., 2015), in engineering (Ivanova et al., 2013; Chen, 2016; Tofail et al., 2018) or related to inventions or patents (Han and Sohn, 2015; Jiang et al., 2017). The only studies taking an economic perspective focus mostly on the effects of 3D printing on cost efficiency and market structure Baumers et al. (2016); Kleer and Piller (2019); Weller et al. (2015), but disregard the potential effects on internationalizion strategies of firms. Our study aims to close this gap in the literature by contributing along the following two central lines.

Firstly, we present a theoretical model that examines the impact of 3D printing on foreign direct investment (FDI) and international trade. The theoretical model predicts a product life-cycle-type development of production and trade: i) at the first stage, 3D printers are introduced in areas with high economic activity that are subject to high transport costs; ii) at the second stage, technological progress in 3D printers leads to a gradual replacement of traditional production structures used in FDI by those relying on 3D printing techniques – at that stage, international trade remains unaffected; iii) at the third stage, 3D printers are widely used and further technological progress in 3D printing leads to a gradual replacement of international trade by local production. From another theoretical perspective, Kleer and Piller (2019) investigate how additive manufacturing will affect the tradeoff between economies of scale and the benefits of local manufacturing. The propositions derived from a game-theory modeling strategy indicate that under some conditions, additive manufacturing will shift production from a centralized to a local production system.

[4]That said, there are also disadvantages and challenges for further developments. Printing times are still substantial, which is particularly restrictive if thousands of pieces are requested within a short time frame. Moreover, some of the printing materials and, thus, the final products are not yet resistant enough such that they have to undergo thorough testing to meet the standards required by regulators. Finally, the cost of the industrial printers – although it has been decreasing by a large amount over time – is still high enough to be prohibitive for small companies. Another issue worth mentioning is that different environmental conditions in different countries could change the characteristics of the powders used in the production process, which in turn alters the final product and often prohibits replication (Stahl, 2013; Ford, 2014).

[5]According to Wohlers Report 2014 (2014) the technology is mostly used in the automotive and health sector, although a lot of different industries also use it for prototyping.

Secondly, we assess the model's implications empirically. Given the lack of firm level data, we test the predictions using aggregate data on adoption, trade, and with a case study. The first prediction of the model is tested using a gravity model and the second and third predictions are evaluated by means of data from the hearing aid industry – one of the earliest adopters of 3D printing. The empirical results confirm the first prediction that 3D printing is adopted in areas with high economic activity that are subject to high transport costs, while the case study from the hearing aid industry provides some evidence in favor of the second and third predictions, namely that FDI is more and more carried out by relying on 3D printing and that international trade is gradually being replaced. To our knowledge, this is the first study that analyzes the specific economic effects of 3D printing and explores the potential economic consequences of introducing this technology into the production process. Our results are in line with those found recently in the engineering literature using a different approach. For instance, Chen (2016) predicts that the universal application of 3D printing will reduce drastically the worldwide transport volume of goods and will gradually locate manufacturing activities closer to the final consumers.

The paper is structured as follows. Section 2 presents the theoretical framework and explores the implications of introducing the new technology of 3D printing for trade and FDI. Section 3 describes the available data and the challenges for empirical research at this early stage of the adoption of 3D printing. Section 4 presents the empirical analysis and Section 5 concludes.

2 The 3D printing, trade and FDI: Theory

To explore the potential impact of 3D printing on international trade and FDI, we introduce this new automation technology into the state-of-the-art model of trade and FDI proposed by Helpman et al. (2004), the empirical usefulness of which has been confirmed by Yeaple (2009) and Helpman (2014).[6] Consider a world comprised of $i \in [1, n+1]$ open economies. In each economy there is one sector in which firms produce a homogenous good with a unitary labor input coefficient and another sector in which firms produce a continuum of manufactured goods $j \in (0, 1)$. Homogenous goods can be traded costlessly, while manufactured goods can be sold in the home country without transport costs, they can be exported to other countries subject to iceberg transport costs $\tau > 1$, or they can be produced directly in the destination country by subsidiaries established via greenfield FDI such that no transport costs apply. Production for the domestic market is subject to fixed costs cf_D, production for the export market is subject to fixed costs $cf_X > cf_D \cdot \tau^{1-\epsilon}$, and greenfield FDI is subject to fixed investment costs $cf_I > cf_X \cdot \tau^{\epsilon-1}$. In contrast to Helpman et al. (2004), there are two technologies available, the traditional technology and the 3D printing technology. As a consequence, FDI can occur in two different forms: a) firms incur a fixed investment cost cf_I to establish a foreign subsidiary that uses the traditional production technology, b) firms incur a fixed investment cost $cf_{3D} > cf_I$ to establish a foreign subsidiary based on the new technology of 3D printing. The use of 3D printers implies a superior production technology. We conceptualize this by

[6]Bustos (2011) also looks at technology upgrading but only in the context of exporting and provides a model for two technology choices: low and high. In her paper, free trade agreements favor exporting with technology upgrading.

assuming that the factor input requirement for the production of each good is reduced by the amount ξ. This is a minimum-invasive way of modeling the advantage of 3D printing over traditional production technologies that captures, as a short-cut formulation, the channels described in the introduction by which 3D printing leads to efficiency gains. Recall that all of these channels imply, in one way or the other, that unit costs decrease due to 3D printing. As we will see, the regionalization of production is one of the key implications of our model.[7]

In line with the literature (Melitz, 2003; Helpman et al., 2004; Helpman, 2006; Nishiyama and Yamaguchi, 2010), we assume that the only variable production factor is labor, which earns the wage rate w, and that, upon entering the industry, a firm draws its productivity level $\theta(j)$ from the distribution $G(\theta)$. This implies that the variable production cost is given by $w/\theta(j)$. Introducing accumulable physical capital as another production factor would complicate the model substantially because it implies a transition phase toward the long-run steady state. However, we do not find any reason to believe that considering physical capital would alter our main mechanisms and invalidate our results at the long-run steady state.

On the consumption side, we assume that households are identical across economies and have utility functions with a constant elasticity of substitution $\epsilon = 1/(1-\alpha) > 1$ between the different varieties. Following the notation of Helpman (2006), the demand for each variety is given by $x(j) = Ap(j)^{-\epsilon}$ with $x(j)$ being the quantity of good j, $p(j)$ being its price, and A denoting the demand level as determined by household income. The standard profit maximization problem in this setting leads to the familiar outcome that the profit-maximizing pricing strategy for firms is to charge a mark-up $1/\alpha$ over marginal cost (cf. Dixit and Stiglitz, 1977; Melitz, 2003). This implies that firms charge the price $p(j)_D = w/[\alpha\theta(j)]$ in the domestic market when producing with the traditional technology, the price $p(j)_X = w\tau/[\alpha\theta(j)]$ in the destination country if firms choose to export, the price $p(j)_I = w/[\alpha\theta(j)]$ in the destination country if firms choose to open a foreign subsidiary that is based on the traditional production technology, and the price $p(j)_{3D} = w/[(1+\xi)\alpha\theta(j)]$ in the destination country if firms choose to open a foreign subsidiary that is based on the superior 3D printing technology.

For the sake of clarity, we suppress the index j from now on. In this setting, a partitioning of firms occurs as follows: very unproductive firms that do not expect to recoup the fixed costs of production exit immediately. Firms that are productive enough to supply to the domestic market (but not to the foreign market) earn profits

$$\begin{aligned}\pi_D &= \theta^{\epsilon-1}(1-\alpha)A\left(\frac{w}{\alpha}\right)^{1-\epsilon} - cf_D \\ &\equiv \Theta B - cf_D,\end{aligned} \tag{1}$$

where we follow the notation of Helpman (2006) such that $\Theta = \theta^{\epsilon-1}$ and $B = (1-\alpha)A\,(w/\alpha)^{1-\epsilon}$.

Let the threshold level of productivity below which the firm would shut down be given by Θ_D. Then there exists a productivity level $\Theta_X > \Theta_D$ above which firms can recoup the additional fixed costs of exporting to

[7] As far as channel vii) is concerned, our framework does not explicitly capture declining innovation costs. Doing so would only strengthen our main results because the associated reduction in the fixed costs of production should lead to an earlier adoption of 3D printing.

the destination country i. These firms earn profits

$$\begin{aligned}\pi_D + \pi_X &= \theta^{\epsilon-1}(1-\alpha)A\left(\frac{w}{\alpha}\right)^{1-\epsilon} - cf_D + \tau^{1-\epsilon}\theta^{\epsilon-1}(1-\alpha)A^i\left(\frac{w}{\alpha}\right)^{1-\epsilon} - cf_X \\ &\equiv \Theta B - cf_D + \tau^{1-\epsilon}\Theta B^i - cf_X, \end{aligned} \tag{2}$$

where $B^i = (1-\alpha)A^i(w/\alpha)^{1-\epsilon}$ refers to the demand level – and hence to the economic activity – in the destination country i.

Greenfield FDI has the advantage that goods can be sold in the destination country without incurring transport costs. The primary disadvantage of FDI is the higher fixed cost when compared to exporting because a new plant has to be established abroad. Consequently, more productive firms with a productivity level above $\Theta_I > \Theta_X$ find it more profitable to exit the export business to country i and to open a subsidiary there instead. These firms earn profits

$$\begin{aligned}\pi_D + \pi_I &= \theta^{\epsilon-1}(1-\alpha)A\left(\frac{w}{\alpha}\right)^{1-\epsilon} - cf_D + \theta^{\epsilon-1}(1-\alpha)A^i\left(\frac{w}{\alpha}\right)^{1-\epsilon} - cf_I \\ &\equiv \Theta B - cf_D + \Theta B^i - cf_I \end{aligned} \tag{3}$$

but they still do not invest in the new technology of 3D printers when establishing their subsidiaries. The reason is that 3D printing facilities, while leading to lower variable production costs, come with a higher fixed cost than traditional FDI.

Firms with productivity levels above Θ_{3D} will choose to base their subsidiary in the foreign economy using the superior 3D printing technology. Initially, Θ_{3D} will be very high because the 3D printing technology is new and the introduction of any new technology comes with high fixed costs. Immediately after the invention of 3D printing, $\Theta_{3D} > \Theta_I$ will therefore hold. At that point only the most productive firms will use 3D printing in case that they invest and open a subsidiary. Their profits are given by

$$\begin{aligned}\pi_D + \pi_{3D} &= \theta^{\epsilon-1}(1-\alpha)A\left(\frac{w}{\alpha}\right)^{1-\epsilon} - cf_D + \theta^{\epsilon-1}(1-\alpha)A^i\left[\frac{w}{(1+\xi)\alpha}\right]^{1-\epsilon} - cf_{3D} \\ &\equiv \Theta B - cf_D + \Theta(1+\xi)^{\epsilon-1}B^i - cf_{3D}. \end{aligned} \tag{4}$$

Over time, technological progress in 3D printing leads to falling fixed costs, such that other scenarios also become feasible as we will see below. This development is consistent with the evolution of the price of 3D printers between 2008 and 2010 when the cost of 3D printers decreased by half (cf. Wohlers Report 2014, 2014). Considering the fast technological evolution of 3D printing over that time period and the generally positive rate of inflation, this corresponds to a huge decline in the performance-adjusted real price of 3D printers during 2000-2010 alone.

It is important to mention that – for the scenarios considered so far – firms who produce with the traditional technology at home find that upgrading their existing technology to 3D printing technology would not pay off because of the high fixed costs of 3D printing. If we allow for lower fixed costs of 3D printing at home than

Figure 1: The effect of 3D printing technology on FDI and trade (introduction phase)

Figure 2: The effect of 3D printing technology on FDI and trade in the adoption phase

abroad, for example, because the installation and monitoring costs of new technologies are lower at home, firms might also produce with the 3D printing technology at home. Thus, they would also export goods that are produced domestically by 3D printing technologies. Our three main predictions with regards to the adoption of 3D printing, the replacement of traditional FDI by 3D printing, and the replacement of international trade by localized 3D printing would not change qualitatively in this case. However, the exposition would become much more complicated. In particular, we would have two additional curves in Figures (1)-(3) related to domestic production with 3D printers and to exporting 3D printed goods. A graphical description of this situation is available upon request. For illustrative purposes, we use the simplified setting here to deliver the main testable hypotheses in a straightforward manner. However, it is important to keep in mind that the theoretical predictions are robust to a situation in which firms also use the 3D printing technology at home.

As in Helpman (2006) we focus on countries of equal size assuming $A^i = A$ for all i, to provide a graphical illustration of the model outcome. Note that this only applies to the graphs but that, in general, countries differ with respect to demand levels A^i and hence with respect to economic activity in our framework.

The initial scenario (introduction phase) is depicted in Figure 1 and shows the profit components from domestic sales (π_D), from exports (π_X), from FDI relying on traditional production technologies (π_I), and from FDI relying on 3D printing technologies (π_{3D}) in the case of high fixed costs of 3D printers. Fixed costs are depicted on the negative part of the vertical axis, while productivity $\Theta = \theta^{\epsilon-1}$ is depicted on the horizontal axis. Similar to Helpman et al. (2004) and Helpman (2006), firms with productivity below Θ_D shut down, firms with productivity $\Theta_D < \Theta < \Theta_X$ produce for the domestic market only, firms with productivity $\Theta_X < \Theta < \Theta_I$ produce for the domestic market and export, and firms with productivity $\Theta_I < \Theta < \Theta_{3D}$ pursue FDI relying on the traditional production techniques (besides producing for the domestic market). Note that the slopes of the lines π_D and π_I are the same because the associated type of FDI simply replicates the domestic technology in the foreign economy, while the slope of the line π_X is lower because iceberg transport costs reduce profits per unit shipped. The new element is the red line that refers to the additional profits due to FDI via 3D printing. This line is steeper than all the other lines because the use of 3D printers raises efficiency by the amount ξ. At the stage depicted in Figure 1, the fixed costs of 3D printing are still very high, such that the productivity level necessary for a firm to invest in this technology is large ($> \Theta_{3D}$). In this scenario, only the most productive firms choose to establish subsidiaries using 3D printing technologies.

Now suppose that technological progress reduces the fixed cost of 3D printers. This scenario (adoption phase) is depicted in Figure 2, where cf_{3D} is reduced such that the red line of additional profits due to FDI via 3D printing shifts upward. This implies that FDI relying on traditional technologies decreases and is gradually replaced by FDI relying on 3D printing. In this scenario, international trade still remains unaffected by technological progress with respect to 3D printers. The reason is that the variable cost savings of 3D printing

Figure 3: The effect of 3D printing technology on FDI and trade in the maturity phase

are large enough to compete with traditional FDI, whose fixed costs are larger than the fixed costs of exporting. At the same time, however, the variable cost savings of 3D printing are still not large enough to compete with the firms that only face the lower fixed cost of exporting.

Finally, suppose that technological progress reduces the fixed cost of 3D printing further, as shown in Figure 3. At this stage (maturity phase) the variable cost savings of 3D printing are large enough to enable these firms to start competing with exporters. This implies that $\Theta_I > \Theta_{3D}$ and all FDI is based upon 3D printing technologies. Additional reductions in fixed costs would lead to a partial replacement of trade in manufactured goods. Note, however, that trade in homogenous goods (e.g., in the materials used by the 3D printers) could still increase.

An analogous result to the ones presented here would hold if technological progress came in the form of higher efficiency (increasing ξ) instead of the reduction in fixed costs. In this case, technological progress in 3D printing would lead to a counterclockwise rotation of π^i_{3D} as shown by the red lines in Figures 1, 2, and 3. Consequently, technological progress in 3D printing would again imply that traditional FDI is replaced by FDI based upon 3D printing first and only later would trade in manufactured goods be replaced. The qualitative results are the same as in the case in which technological progress with respect to 3D printers assumes the form of reductions in the fixed costs of 3D printers.

To summarize, our framework is robust to different modifications such as using 3D printing also at home and modeling technological progress in 3D printing as an increase in efficiency. The theory implies the following testable predictions: i) the introduction of 3D printers takes place predominantly in areas with high economic activity (countries or regions with a large A^i) that are contemporaneously subject to high transport costs; ii) initially, technological progress with respect to 3D printers leads to a gradual replacement of FDI using traditional production structures with FDI that uses 3D printing technology – at that stage international trade in manufactured goods stays unaffected; iii) at later stages, when 3D printers are already widely used, further technological progress with respect to 3D printers leads to a gradual replacement of international trade in manufactured goods. Given that the 3D printing technology is still quite young (see Wang et al., 2016, for an analysis of the drivers of its adoption), the lack of appropriate time series data implies that some theoretical predictions can only be assessed by means of case studies. We proceed with a general description of the 3D printing industry and our data sources and present an empirical test of prediction i) in Section 4. Then we proceed with a case study of the hearing aid industry and an analysis of the corresponding data that both support predictions ii) and iii).

3 3D printing, patenting, production, and trade: the data

The 3D printing industry has existed for over two decades, and has recently gained importance when the initial patents started to expire. Figure 4 shows the evolution of patents related to 3D printing technology in the United

States. We observe that the number of patents has skyrocketed in the most recent years, which emphasizes the growing importance of this technology. This is confirmed by the Wohlers Report 2014 (2014), containing not only the patents granted but also the applications of patents in the United States, which exhibit a similar trend.

Figure 4: 3D Printing Patents

Source: Patent iNSIGHT Pro (2014)

Data on production, use, and trade of 3D printers are scarce. In terms of production of the printers, data are not easily accessible for the public because not all the companies that produce printers are traded on stock markets such that the data are often confidential. Consequently, we rely on information from newspaper articles and reports from consulting firms or independent organizations. As we can see in Figure 5, the number of industrial 3D printers sold[8] has been increasing over time, especially since the 2000's, in case of the United States. A steady rise can also be observed in Germany, closely followed by Israel. The jump in the Israeli figure for the year 2013 and the corresponding decrease in the United States for the same year is due to the merger of two companies, Stratasys from the United States and Stratasys and Object from Israel. The resulting company was registered in Israel (Wohlers Report 2014, 2014), which explains the increase in case of Israel and the decrease in case of the United States.

Figure 5: Printers sold by a selected group of countries

Source: Authors' calculations based on data from Wohlers Report 2014 (2014). Note: The unit of measurement is the number of printers. RHS in case of the United Kingdom refers to the right hand-side axis, where the unit of measurement is the same but the scale is different.

The main producers of industrial 3D printers are located in countries that are pioneers in 3D printing technology and where most patents are registered. This can be seen in Figure 6, which displays the number of patents per country. The United States is the leader, followed by China, Japan, and Germany. Most of the governments of these countries are financing research centers and initiatives to boost the technology. In the United States, for example, the National Additive Manufacturing Innovation Institute was created in 2012 and President Obama referred to it in his Presidential speech in 2013: "A once-shuttered warehouse is now a state-of-the-art lab where new workers are mastering the 3-D printing that has the potential to revolutionize the way we make almost everything"[9]. During the same speech he announced three extra manufacturing hubs planned for the future "to turn regions left behind by globalization into global centers of high-tech jobs". In the case of China, provincial, central, and city governments supported the 3D printing sector by investing in capital equipment and R&D, and by offering tax refunds, low-interest-rate loans, and land for construction. Moreover, in 2013, new 3D printing industrial parks and centers were developed in three provinces (see Wohlers Report 2014, 2014). The European Union also finances the development of 3D printing through several channels such

[8]These numbers were calculated from the Wohlers Report 2014 (2014) and comprise only a limited number of the 3D printers' producers who provide data to the report.

[9]`http://edition.cnn.com/2013/02/13/tech/innovation/obama-3d-printing/`.

as the European Space Agency or the European Union's Framework Funding.

Figure 6: Amount of patents related to additive manufacturing (selected countries)

Source: Intellectual Property Office (2013). Note: The countries included in the figure (in order of appearance) are the United States, China, Japan, Germany, Great Britain, South Korea, Israel, Canada, France, and Australia.

An important aspect of the 3D printing business is that the industry includes the production of inputs and materials used to print products, software development, printing parts for final products, and the production of prototypes.[10] Figure 7 displays the increase in parts for final products as a share of the whole 3D printing market including services and total product revenues from 3D printing (Wohlers Report 2014, 2014). We clearly observe that the share of parts has been increasing steadily over time, which indicates that more companies have started to include 3D printed parts in their final products. This has been (partly) due to the price reduction of 3D printers over time (Wohlers Report 2014, 2014).[11]

Figure 7: Participation of parts production for final goods in total revenues

Source: Authors' elaboration based on Wohlers Report 2014 (2014)

To measure the adoption of the new 3D printing technology, we proceed with the analysis of international trade in 3D printers. Due to the lack of comparable data on trade and domestic sales to properly assess the actual adoption per country, we use trade statistics[12]. We adopt a similar strategy as Caselli and Coleman (2001) who also use trade data to proxy for technology adoption (computers in their case). In a similar vein, Acharya and Keller (2009) and Bournakis et al. (2018) use imports as a measure of technology or knowledge transfer, respectively. Therefore, we focus on printers under the 8477.80 code of the Harmonized System (HS)[13], which, according to Hodes and Mohseni (2014), is where printers should be classified[14]. Figures 8 and 9 show the evolution of the volume and the value of exports of the main exporting countries. Figure 9 shows that Germany, China, and the United States are the main exporters in terms of the value of exports, while, in terms of the volume, the United Kingdom became the main exporter in 2006 (Figure 8). Surprisingly, the United States is only the third largest exporter (in terms of volume and also in terms of value), which could be due to

[10]Nemlioglu and Mallick (2017) suggest that if firms not only innovate but also invest in good managerial practices, then their productivity would be even higher.

[11]Wohlers Report 2014 (2014) notes that the increase in the average selling price of the printers after 2010 could be explained by increased sales in "high-end" printers (including the ones that produce metal parts) and by a reduction in sales of the lower priced industrial printers because the consumer printers are starting to capture a part of this segment.

[12]We are unable to consider printers that are produced locally or that are sold in the domestic market due to lack of data for the whole sample of countries.

[13]This code includes "Machinery for working rubber/plastics/for the manufacture of products from these materials, not specified/incld. elsewhere in this Ch., Other machinery, n.e.s. in 84.77"

[14]This classification is also suggested by the German Statistical Office, an Argentinean 3D printing machines producer (Trimaker), and an exporting advisory agency from the United States (Flexport).

the fact that the printers produced in the United States are mainly sold in the domestic market.

Figure 8: Volume of printers exported under HS code 8477.80 (in thousands)

Source: Authors' calculations based on data from UN-Comtrade. Note: The unit of measurement are thousands of printers exported. RHS in case of the United Kingdom refers to the right hand-side axis, where the unit of measurement is the same but the scale is different.

Figure 9: Value of printers exported under HS code 8477.80 (in millions of US$)

Source: Authors' calculations based on data from UN-Comtrade

4 Empirical evidence

4.1 Trade of 3D printers, transport costs, and domestic demand

In this section, we use a gravity model of trade to estimate the determinants of bilateral trade flows (Feenstra, 2002; Head and Mayer, 2014). Gravity models have been also used to estimate the effects of different components of trade costs on trade and to assess the effects of a number of policy measures. Since we are mainly interested in the effects of demand in the destination country and the effects of transport costs on the adoption of 3D printers, we consider it as appropriate for our purposes. In particular, it is useful for testing the first prediction derived from the theoretical model in Section 2, which states that countries subject to higher transport costs and with a high level of domestic demand will have more 3D printers. Given the lack of available data at the firm level (as stipulated by the model), we have to rely on country-level data.

Based on Anderson and van Wincoop (2003), we consider a number of country-specific and bilateral factors as determinants of bilateral trade such as the Gross Domestic Product (GDP) and variables that proxy for trade frictions.[15] We estimate a cross-sectional specification for the year 2013 – the latest year for which the data are available – that has the following form:

$$\begin{aligned} \ln X_{ij} = \beta_0 + \beta_1 \ln GDP_i + \beta_2 \ln GDP_j + \beta_3 \ln trancost_{ij} + \beta_4 \ln dist_{ij} + \beta_5 rta_{ij} + \\ + \beta_6 comlang_{ij} + \beta_7 colony_{ij} + \beta_8 \ln P_i + \beta_9 \ln P_j + u_{ij}, \end{aligned} \tag{5}$$

where β_k for $k = 0, \ldots 7$ denote the parameters to be estimated and X_{ij} denotes exports from exporter i to importer j of products classified in the HS code 8477.80 (as a proxy for trade in 3D printers), obtained from UN-Comtrade. We consider the quantity of 3D printers exported because there is a wide dispersion in the values of printers available for sale (see Wohlers Report 2014 (2014) for a selected list of the available printers and the corresponding prices) and in these cases the quantity is a better unit of measurement (Vido and Prentice, 2003). Moreover, if there is an innovation that results in a price decrease of 3D printers, less "value" would be

[15] Trade frictions are defined (as in most of the related literature) in a multiplicative manner. After the logarithmic transformation we obtain a linear regression for estimation.

traded but obviously this does not indicate lower technology adoption.

Data on GDP_i and GDP_j were obtained from the World Development Indicators database of the World Bank. Distance ($dist$) refers to the geographical distance between capital cities of the trading countries, rta takes the value of one if both countries are members of the same regional trade agreement[16], common language ($comlang$) is a dummy variable that takes the value of one if both countries share an official language and zero otherwise; $colony$ is a dummy variable that takes the value of one if two countries ever shared a colonial relationship and zero otherwise. All these dummy variables were retrieved from the Centre d'Etudes Prospectives et d'Informations Internationales[17]. The multilateral resistance terms P_i and P_j are controlled for by adding continental dummies, country dummies, or alternatively using the Bonus Vetus OLS approximation (Baier and Bergstrand, 2009). This approximation is a log-linear first-order Taylor series expansion of the multilateral price terms of the Anderson and van Wincoop (2003) model. In essence, this expansion provides three extra terms for each trade cost variable (t_{ij}). The first term is basically a simple average of the trading cost of the exporter i across all partners j, while the second term is the simple average of all the trade costs between all of the partners. Finally, the third term is the average of the trading cost of importer j with all of its partners[18].

Several proxies for transport costs ($trancost_{ij}$)[19] of products produced with 3D printers are used. The first is the ad-valorem equivalent of transporting goods between countries obtained from the OECD website[20] for goods classified under Chapters 84, 87, and 90 of the HS classification. These three categories were chosen because they include parts for automobiles (Chapters 84 and 87) and medical prosthetics and hearing aids (Chapter 90) as examples of products already being produced with 3D printing. Based on the available information, the data set includes 106 exporting countries (when including the zeroes in the dependent variable, otherwise 52) and 33 importing countries (OECD)[21]. The OECD transport cost data set reports unitary and ad-valorem transport costs[22]. We considered the ad-valorem measure because it better reflects the impact of transportation costs. Hummels (2007) shows that transport costs relative to the price of the good have not fallen across time for bulk cargo and they have remained fairly stable for liner shipping, unlike the value per ton (Venables and Behar, 2010). This transport cost variable is only available for exports to OECD countries.

According to the information gathered from 3D printing companies, consumers of 3D-produced goods usually

[16] This variable is constructed with information from Jose De Sousa's website (`http://jdesousa.univ.free.fr/data.htm`).

[17] `http://www.cepii.fr/`

[18] This means that each trade cost variable is then modified according to the following formula: $\ln t_{ij} + \frac{1}{N}\sum_{j=1}^{N}\ln t_{ij} - \frac{1}{N^2}\sum_{i=1}^{N}\sum_{j=1}^{N}\ln t_{ij} + \frac{1}{N}\sum_{i=1}^{N}\ln t_{ij}$.

[19] This variable is expressed in the regression tables as $tcoecd$ when the transport cost measure is the one from the OECD data set (with the suffix representing the chapter of the HS) and $tcfedex$ when it is the one from Fedex, as will be described in what follows.

[20] `https://stats.oecd.org/Index.aspx?DataSetCode=MTC`.

[21] We use the latest year available in the data set which is 2007.

[22] This data set is built linking together data from countries' customs (Argentina, Australia, Brazil, Bolivia, Chile, Colombia, Ecuador, New Zealand, Paraguay, Peru, United States, and Paraguay), Containizerization International and Drewry consulting (Korinek, 2008)

buy products online and receive them by mail. Hence, we also gathered transport cost data for two packages from online inquiries at the Fedex website to check whether the results hold true for this alternative transport cost measure. The corresponding summary statistics can be found in Table 7 and in Table 8 of the Appendix. For the first package, we consider a box of machinery (could also be applied to parts thereof) with a volume of 0.6mx0.6mx0.6m. It has a value of US$2,500, with a weight of 25 kg, using the Fedex International Economy Freight service. For the second package, the price and dimensions correspond to hearing aids that are priced at US$3,000 and the box weighs 1 kg, sent with a Fedex Small Box using the Fedex International Economy service. For both items, we obtain information for sending the package from the United States and China to about 120 destinations (capital cities)[23]. These two countries were chosen because they are the main producers of 3D printers in the developed and developing world, respectively. We assumed that the item is shipped one week after the data collection[24].

Using the data described above, we estimate a number of gravity models using Ordinary Least Squares (OLS) and the Pseudo Poisson Maximum Likelihood estimator (PPML)[25]. The second estimator is especially useful because it allows us to include the zeroes in exports[26] and it also allows for the presence of heteroscedasticity. Table 1 shows the estimated coefficients of the OECD transport cost measure of three selected chapters of the HS classification for a cross-section of countries for the year 2013[27]. We report the estimation results for Equation (5) obtained for the three different product groups. Alternative ways of introducing the multilateral resistance terms are used. In columns (1) and (4) we control for continent of country of origin and destination, whereas in column (2) country dummies are included (origin and destination) and in columns (3) and (5) the Bonus Vetus specification is used. As a first robustness check, we estimate the same specifications also by relying on the OECD transport cost measure and using panel data for the period 1997–2013. As a second robustness check, we estimate placebo regressions using total bilateral trade instead of trade in 3D printers.

The transport cost variable has a positive and statistically significant association with exports of 3D printers (at the 1-10 percent significance level) and this result is mostly robust across different specifications. The elasticity of trade with respect to transport costs is relatively high in magnitude indicating that a 1 percent increase in the ad-valorem transport cost is associated with an increase in exports of 3D printers of around 0.7 percent [model (2), chapter 84]. Translating this into numbers, the average ad-valorem transport cost is around 3 percent and the average number of printers shipped (bilaterally) is 33. Hence, countries whose transport costs are double the average, export about 23 printers more than countries with average transport costs. Model

[23]For the United States, New York was considered because it exceeds the population and economic activity of Washington D.C.

[24]The Fedex data were collected during the months of February and July 2015 from `https://www.fedex.com/ratefinder/home?link=4&cc=US&language=en`.

[25]Unfortunately, the estimations did not converge with dummies of country of origin and destination when using this method.

[26]This is a benefit over the OLS model specification since in the OLS the dependent variable is logged and therefore zeroes are dropped from the estimation. In the PPML model specification the dependent variable is in levels and then allows for the inclusion of zero trade flows.

[27]The transport cost variable is for the year 2007 since this is the last available year in the dataset.

(2), which includes country of origin and destination dummies, is probably the most suitable to obtain an unbiased coefficient estimate of the transport cost variable because it controls for all sorts of country-specific heterogeneity. Regarding the other controls that are included in the regressions, the results can be found in Tables 9, 10, and 11 in the Appendix. The estimated coefficients for the GDP variables, which proxy for the level of economic activity, are positive and statistically significant in all specifications. The estimated income elasticities are in most cases higher for the exporter country than for the importer, with only one exception (column 5). The magnitudes vary between 0.77 [column (5), chapter 90] and 1.48 [column (4), chapter 84] for the exporter country and 0.56 [column (3), chapter 90] and 1.18 [column (4), chapter 87] for the importer country. The latter indicates that an increase in income in the destination market of 5 percent leads to an increase in exports of 3D printers of around 3-6 percent. The RTA dummy is not statistically significant in most of the specifications, which is probably due to the fact that in a cross-sectional setting, we are not able to control for the endogeneity of this variable and also because the considered product line is subject to very low tariffs. It is worth noting that in our estimation we disentangle the effect of pure transport costs and the distance effect. The distance coefficient could reflect cultural differences or differences in tastes, as pointed out by related research (Felbermayr and Toubal, 2010) or the incidence of geographical impediments that are very specific and go beyond the traditional gravity controls (Giuliano et al., 2014). Cultural variables, namely common language and common colonial past, also exhibit the expected positive sign and are statistically significant in most cases.

To summarize, the empirical results using the OECD measure of transport costs are in line with the first prediction of the theoretical model, indicating that the introduction of 3D printers occurs predominantly in areas of high economic activity [positive and statistically significant effect of GDP in destination (j)] that are subject to high costs of transporting goods produced with 3D printing (positive and statistically significant effect of *lntrancost*). Since the transport cost variable is used with lags in the gravity model, with the latest value being for the year 2007, we can rule out endogeneity issues concerning reverse causality.

Table 2 shows the cross-sectional results using the alternative transport cost measure referring to the postal delivery of two different packages. Now the explained variable is exports from the United States and China to about 120 destinations. Regarding the transport costs, we find positive and statistically significant coefficients for the PPML estimator, but not for the OLS specification. The reason could be that this is a very small sample. Moreover, in most cases – either with the OLS or with the PPML estimator – we obtain positive and statistically significant estimates for the GDP coefficient of the importer country. Overall, the results are mostly consistent with those of Table 9. To control for multilateral resistance and heterogeneity of the importer, we include continent dummies of the importer. Distance is not always significant, which is not surprising given the use of continental dummies. Instead of the GDP of the exporter, we include an exporter dummy that takes the value of one when the exporter is the United States. The coefficient of this variable has a negative sign. This might indicate that the United States exports fewer printers than what gravity would predict. Since the United States is a pioneer in 3D printing, it might be that a substantial amount of printers remain in the local economy.

The next robustness check relies on using panel data. Table 3 shows the results of the panel data regressions

Table 1: Cross-sectional regressions with different OECD measures of transport costs

	OLS (1)	OLS-CD (2)	OLS - BV (3)	PPML (4)	PPML - BV (5)
			Chapter 84		
lntrancost	0.605**	0.738**	1.401***	0.521*	1.066***
	(0.248)	(0.333)	(0.250)	(0.272)	(0.359)
lngdpi	1.120***		0.795***	1.477***	0.815***
	(0.098)		(0.102)	(0.111)	(0.071)
lngdpj	0.721***		0.627***	1.072***	1.046***
	(0.093)		(0.095)	(0.132)	(0.103)
N	359	359	359	856	856
(Pseudo) R^2	0.430	0.724	0.383	0.700	0.472
			Chapter 87		
lntrancost	0.617***	0.510*	0.936***	0.379**	0.389*
	(0.164)	(0.273)	(0.232)	(0.167)	(0.203)
lngdpi	1.173***		0.785***	1.458***	0.775***
	(0.101)		(0.101)	(0.105)	(0.077)
lngdpj	0.745***		0.582***	1.118***	1.045***
	(0.099)		(0.112)	(0.139)	(0.094)
N	339	6339	339	755	755
(Pseudo) R^2	0.453	0.721	0.356	0.718	0.411
			Chapter 90		
lntrancost	0.512***	0.385**	0.938***	0.351**	0.333
	(0.182)	(0.170)	(0.222)	(0.175)	(0.251)
lngdpi	1.146***		0.809***	1.442***	0.766***
	(0.091)		(0.089)	(0.108)	(0.074)
lngdpj	0.774***		0.563***	1.097***	1.044***
	(0.096)		(0.101)	(0.128)	(0.099)
N	339	339	339	714	714
(Pseudo) R^2	0.453	0.721	0.356	0.718	0.411
Dummy Var.	Continent	Countries	-	Continent	-

Notes: Standard errors are clustered at the importer level. *,** and *** indicate significance at the 10, 5, and 1 percent level, respectively. CD stands for country dummies. A constant term, distance (in logs), and dummies for common language, former colony and regional trade agreements are included in all regressions, the coefficients are not reported to save space. In columns (1) to (3) the log of the amount of printers is the dependent variable, while in (4) and (5) it is in units. Columns (3) and (5) control for multilateral resistance with the Baier and Bergstrand (2009) methodology – each bilateral trade cost is included using the following formula: $\ln t_{ij} + \frac{1}{N}\sum_{j=1}^{N} \ln t_{ij} - \frac{1}{N^2}\sum_{i=1}^{N}\sum_{j=1}^{N} \ln t_{ij} + \frac{1}{N}\sum_{i=1}^{N} \ln t_{ij}$. The subheading "Chapter" refers to the chapter of the harmonized system for which the transport cost comes from, i.e. these transport costs are for products classified under the respective chapter.

Table 2: Cross-sectional regressions with Fedex measure of transport cost

	Larger package				Hearing aid package			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
lntrancost	0.137	1.213***	-0.140	0.793*	0.152	1.153**	0.008	1.147**
	(0.410)	(0.432)	(0.414)	(0.430)	(0.546)	(0.533)	(0.569)	(0.554)
lndist	-0.231	-0.579**	-0.412*	-0.330	-0.246	-0.430**	-0.454**	-0.238
	(0.196)	(0.226)	(0.212)	(0.221)	(0.190)	(0.192)	(0.217)	(0.200)
comlang	0.116	0.685**	-0.048	0.617**	0.120	0.523	0.000	0.576**
	(0.329)	(0.338)	(0.361)	(0.247)	(0.312)	(0.367)	(0.352)	(0.270)
colony	0.585	0.351	0.981**	0.771**	0.553	0.437	0.984**	0.859**
	(0.371)	(0.363)	(0.427)	(0.387)	(0.364)	(0.396)	(0.419)	(0.391)
rta	1.317***	2.033***	0.979***	1.712***	1.203***	1.902***	0.859***	1.715***
	(0.279)	(0.294)	(0.297)	(0.338)	(0.280)	(0.320)	(0.311)	(0.336)
lngdpj	0.843***	0.779***	0.810***	0.757***	0.837***	0.676***	0.824***	0.722***
	(0.064)	(0.062)	(0.065)	(0.055)	(0.057)	(0.047)	(0.058)	(0.057)
United States	-2.850***	-2.293***	-2.860***	-2.242***	-2.951***	-3.087***	-2.827***	-2.860***
	(0.255)	(0.312)	(0.243)	(0.273)	(0.256)	(0.461)	(0.271)	(0.377)
N	174	207	174	207	177	211	177	211
(Pseudo) R^2	0.690	0.699	0.721	0.752	0.683	0.677	0.716	0.770
Dummy Var.	-	-	Cont. (d)	Cont. (d)	-	-	Cont. (d)	Cont. (d)
Origin	United States and China							

Notes: Robust standard errors for the OLS regressions. *,** and *** indicate significance at the 10, 5, and 1 percent level, respectively. A constant term is included in all regressions – the coefficients are not reported to save space. Columns (1), (3), (5), and (7) are estimated with OLS and the log of the amount of printers is the dependent variable, while in (2), (4), (6), and (8), units is the dependent variable, while the estimator is PPML.

when using the OECD transport costs for the different product groups. In this setting, we consistently find positive coefficients for most of the transport cost measures, as predicted by the theory. In nearly all models, the estimated coefficients for the variable of interest are slightly lower in magnitude than the cross-sectional estimates. Moreover, the coefficient of GDP of the destination country is also positive and statistically significant, which is again in line with the theory. The magnitude of the effects is slightly lower than in the cross-sectional regressions, while the opposite is true in column (5), which includes zeroes in the dependent variable. Consequently, in the panel data specification, the inclusion of zeroes [columns (4) and (5)] magnifies the effect of the variables of interest. This is expected, since including the data points for which there is no trade increases the transport cost and income elasticities. This indicates that disregarding zero trade leads to a downward bias. The results for the OECD transport costs (as well as the bilateral variables distance, colony, rta, and common language) do not seem to be robust to the PPML estimator with the Bonus Vetus adjustment [model (5)], where the coefficient is no longer statistically significant. A reason might be that the demeaning of the data is wiping out most of the variability. We also see from the Pseudo R-squared that the fit of the model using this estimator is poor. Counter-intuitive results with an opposite sign of the estimated coefficient for some traditional gravity variables have also been reported by Berden et al. (2014) and Portugal-Perez and Wilson (2012). The estimates of coefficients for the control variables can be found in Tables 12, 13, and 14 in the Appendix.

As a third robustness check we estimate several placebo regressions to show that our estimates are not reflecting a given correlation for a specific sample. For this, we obtain the total value of bilateral trade from UN-COMTRADE and we restrict the data to the sample of countries and years of the previous exercise. Now we have total trade value as the dependent variable, instead of the trade of printers. We take our former

Table 3: Panel regressions with different OECD measures of transport costs

	OLS (1)	OLS-CD (2)	OLS - BV (3)	PPML (4)	PPML - BV (5)
Chapter 84					
lntrancost	0.348***	0.210*	0.430**	1.816***	0.231
	(0.130)	(0.119)	(0.169)	(0.406)	(0.310)
lngdpi	0.987***	0.711***	0.687***	1.187***	0.746***
	(0.053)	(0.191)	(0.047)	(0.136)	(0.073)
lngdpj	0.551***	0.581***	0.440***	1.136***	0.773***
	(0.062)	(0.182)	(0.045)	(0.186)	(0.088)
N	3,894	3,894	3,894	12,531	12,531
(Pseudo) R^2	0.376	0.575	0.318	0.272	0.030
Chapter 87					
lntrancost	0.446***	0.151*	0.315***	1.113***	-0.116
	(0.105)	(0.082)	(0.119)	(0.246)	(0.250)
lngdpi	1.025***	0.679***	0.697***	1.062***	0.736***
	(0.055)	(0.195)	(0.049)	(0.125)	(0.074)
lngdpj	0.557***	0.528***	0.445***	1.071***	0.757***
	(0.066)	(0.184)	(0.046)	(0.179)	(0.083)
N	3,650	3,650	3,650	10,717	10,717
(Pseudo) R^2	0.386	0.577	0.316	0.238	0.033
Chapter 90					
lntrancost	0.412***	0.072	0.273*	1.014***	-0.313
	(0.108)	(0.096)	(0.141)	(0.243)	(0.299)
lngdpi	1.024***	0.662***	0.712***	1.140***	0.740***
	(0.057)	(0.196)	(0.050)	(0.120)	(0.076)
lngdpj	0.586***	0.538***	0.442***	1.151***	0.754***
	(0.069)	(0.184)	(0.046)	(0.199)	(0.081)
N	3,639	3,639	3,639	10,308	10,308
(Pseudo) R^2	0.386	0.577	0.318	0.216	0.036
Dummy Var.	Continent	Countries	-	Continent	-

Notes: Standard errors are clustered at the importer level. *,** and *** indicate significance at the 10, 5, and 1 percent level, respectively. CD stands for country dummies. A constant term, distance (in logs), and dummies for common language, former colony and regional trade agreements are included in all regressions, the coefficients are not reported to save space. In columns (1) to (3) the log of the amount of printers is the dependent variable, while in (4) and (5) it is in units. Columns (3) and (5) control for multilateral resistance with the Baier and Bergstrand (2009) methodology – each bilateral trade cost is included using the following formula: $\ln t_{ij} + \frac{1}{N}\sum_{j=1}^{N}\ln t_{ij} - \frac{1}{N^2}\sum_{i=1}^{N}\sum_{j=1}^{N}\ln t_{ij} + \frac{1}{N}\sum_{i=1}^{N}\ln t_{ij}$. The subheading "Chapter" refers to the chapter of the harmonized system for which the transport cost comes from, i.e. these transport costs are for products classified under the respective chapter.

preferred specifications (employing the Bonus Vetus correction, which considers multilateral resistance, in both a panel and cross-sectional setting) and use the new dependent variable. Tables 4 and 5 present the results using the OECD and the Fedex transport cost proxies for a cross-section; and Table 6 presents the estimates using the OECD measure in a panel data setting. The estimated coefficients for the transport cost variable are in general negative and sometimes statistically significant. Consequently, we obtain a very different picture in comparison to the regressions using exports of products related to 3D printing, where we found a positive relationship between transport costs and trade. This outcome indicates that our previous result is not driven by our reduced sample of countries and years.

Table 4: Placebo cross-sectional regressions with different OECD measures of transport costs

	(1)	(2)	(3)	(4)	(5)	(6)
lntrancost	-0.102	-0.224*	-0.022	-0.183	-0.036	0.070
	(0.213)	(0.122)	(0.159)	(0.155)	(0.156)	(0.096)
lndist	-0.803***	-0.670***	-0.755***	-0.675***	-0.799***	-0.748***
	(0.203)	(0.066)	(0.184)	(0.047)	(0.211)	(0.047)
comlang	0.261	-0.462	0.374	-0.343	0.226	-0.426
	(0.226)	(0.313)	(0.294)	(0.257)	(0.257)	(0.264)
colony	0.133	-0.251	0.113	-0.381	0.152	-0.241
	(0.182)	(0.223)	(0.189)	(0.276)	(0.188)	(0.251)
rta	0.314	1.333***	0.283	1.374***	0.182	1.494***
	(0.441)	(0.296)	(0.468)	(0.218)	(0.484)	(0.287)
lngdpi	0.839***	0.926***	0.808***	0.941***	0.841***	0.910***
	(0.062)	(0.085)	(0.055)	(0.091)	(0.063)	(0.075)
lngdpj	0.771***	0.955***	0.762***	0.977***	0.767***	0.965***
	(0.059)	(0.084)	(0.057)	(0.089)	(0.057)	(0.098)
N	359	856	339	755	339	714
(Pseudo) R^2	0.747	0.786	0.742	0.779	0.741	0.756
Chapter	84	84	87	87	90	90

Notes: Standard errors are clustered at the importer-country level. *,** and *** indicate significance at the 10, 5, and 1 percent level, respectively. A constant term is included in all regressions – the coefficients are not reported to save space. Columns (1), (3), and (5) are estimated with OLS and the log of (total) bilateral trade is the dependent variable, while in (2), (4), and (6) the total value itself is the dependent variable, while the estimator is PPML. The Baier and Bergstrand (2009) methodology applied to each bilateral trade cost is involves using the following formula: $\ln t_{ijt} + \frac{1}{N}\sum_{j=1}^{N} \ln t_{ijt} - \frac{1}{N^2}\sum_{i=1}^{N}\sum_{j=1}^{N} \ln t_{ij} + \frac{1}{N}\sum_{i=1}^{N} \ln t_{ijt}$.

In summary, using alternative transport cost measures, we find that countries subject to higher transport costs in products susceptible of being produced with 3D printing import more goods classified under code 8477.80, which is the code that includes 3D printers. In addition, the GDP of the destination country is positive and statistically significant. Both of these results are in line with the first prediction of our theoretical framework. Moreover, the placebo regressions indicate that the documented relationship is not prevalent for total bilateral trade.

4.2 3D printing adoption and the hearing aid sector

The use of additive manufacturing in the production process is more widespread and started earlier than the consumer use. Benson and Magee (2015) have analyzed several indicators based on patent data since 1976 and have identified 3D printing as the 4th most innovative technology (out of a sample of 28). According to a

Table 5: Placebo cross-sectional regressions with Fedex measure of transport cost

	Larger package				Hearing aid package			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
lntrancost	-0.477**	-0.340*	-0.539**	-0.287*	-0.281	0.100	-0.172	-0.320
	(0.214)	(0.193)	(0.212)	(0.156)	(0.319)	(0.346)	(0.285)	(0.265)
lndist	-0.488***	-0.378***	-0.653***	-0.333***	-0.548***	-0.491***	-0.706***	-0.370***
	(0.128)	(0.098)	(0.133)	(0.081)	(0.120)	(0.079)	(0.125)	(0.076)
comlang	0.485***	-0.125	0.348**	-0.165	0.581***	-0.084	0.471***	-0.096
	(0.159)	(0.281)	(0.164)	(0.230)	(0.166)	(0.278)	(0.172)	(0.207)
colony	-0.293	-0.418**	0.099	-0.078	-0.260	-0.383*	0.141	-0.114
	(0.207)	(0.212)	(0.234)	(0.259)	(0.205)	(0.204)	(0.232)	(0.247)
rta	0.888***	1.008***	0.462***	0.787***	0.907***	1.182***	0.491***	0.866***
	(0.162)	(0.232)	(0.149)	(0.175)	(0.166)	(0.256)	(0.149)	(0.188)
lngdpj	0.782***	0.875***	0.791***	0.801***	0.810***	0.921***	0.829***	0.827***
	(0.038)	(0.062)	(0.036)	(0.033)	(0.038)	(0.058)	(0.035)	(0.029)
United States	-0.613***	-0.290*	-0.560***	-0.227*	-0.397**	-0.218	-0.361**	-0.057
	(0.155)	(0.157)	(0.136)	(0.134)	(0.181)	(0.211)	(0.162)	(0.147)
N	174	207	174	207	177	211	177	211
(Pseudo) R^2	0.780	0.881	0.829	0.944	0.775	0.891	0.822	0.947
Dummy Var.	-	-	Cont. (d)	Cont. (d)	-	-	Cont. (d)	Cont. (d)
Origin	United States and China							

Notes: Robust standard errors reported in parenthesis. *,** and *** indicate significance at the 10, 5, and 1 percent level, respectively. A constant term is included in all regressions – the coefficients are not reported to save space. Columns (1), (3), (5), and (7) are estimated with OLS and the log of (total) bilateral trade is the dependent variable, while in (2), (4), (6), and (8), the total value is the dependent variable, while the estimator is PPML.

Table 6: Placebo panel regressions with different OECD measures of transport costs

	(1)	(2)	(3)	(4)	(5)	(6)
lntrancost	-0.322***	-0.257	-0.206**	-0.111	-0.221***	-0.002
	(0.088)	(0.194)	(0.083)	(0.102)	(0.079)	(0.120)
lndist	-0.580***	-0.418**	-0.500***	-0.451***	-0.559***	-0.472***
	(0.142)	(0.198)	(0.164)	(0.170)	(0.172)	(0.157)
comlang	0.307	-0.328	0.387*	-0.215	0.328	-0.280
	(0.212)	(0.317)	(0.227)	(0.293)	(0.235)	(0.290)
colony	0.108	-0.251	0.052	-0.327	0.091	-0.250
	(0.215)	(0.242)	(0.218)	(0.256)	(0.222)	(0.248)
rta	0.754***	1.656***	0.748**	1.757***	0.724**	1.799***
	(0.286)	(0.349)	(0.314)	(0.341)	(0.323)	(0.344)
lngdpi	0.670***	0.837***	0.676***	0.838***	0.684***	0.819***
	(0.033)	(0.048)	(0.034)	(0.049)	(0.034)	(0.051)
lngdpj	0.756***	0.923***	0.751***	0.944***	0.758***	0.944***
	(0.028)	(0.059)	(0.030)	(0.066)	(0.030)	(0.065)
Observations	3,894	12,531	3,650	10,717	3,639	10,308
R^2	0.732	0.793	0.739	0.783	0.741	0.782
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Chapter	84	84	87	87	90	90

Notes: Standard errors are clustered at the country-pair level. *,** and *** indicate significance at the 10, 5, and 1 percent level, respectively. A constant term is included in all regressions – the coefficients are not reported to save space. Columns (1), (3), and (5) are estimated with OLS and the log of (total) bilateral trade is the dependent variable, while in (2), (4), and (6) the total value itself is the dependent variable, while the estimator is PPML. The Baier and Bergstrand (2009) methodology applied to each bilateral trade cost is involves using the following formula: $\ln t_{ijt} + \frac{1}{N}\sum_{j=1}^{N}\ln t_{ijt} - \frac{1}{N^2}\sum_{i=1}^{N}\sum_{j=1}^{N}\ln t_{ij} + \frac{1}{N}\sum_{i=1}^{N}\ln t_{ijt}$.

report by PricewaterhouseCoopers (2014), among almost 200 firms surveyed in the United States, two thirds of manufacturers are adopting 3D printing in some way, while one fourth plan to do so in the future, and only less than 10 percent have no intention of doing so. A similar report by Deloitte (2014) for Swiss companies reveals that 64 percent believe that 3D printing has the potential to be a key technology. This implies that 3D printing is already in the maturity phase, at least in some industries. The information collected from several reports and newspaper articles leads us to conclude that the main sectors in which 3D printing has had a clear impact is medicine – especially for tailored products such as hearing aids – and the automotive industry. In the following, we discuss the application of 3D printing in the hearing aid industry as a case study of the successful adoption of the technology.

4.2.1 The hearing aid industry. Case study: Sonova/Phonak

An interesting case within the medical sector is the hearing aid industry, which has been using additive manufacturing for more than a decade. Industry experts claim that over 10 million hearing aids have already been produced by additive manufacturing. Among the main companies in the business, Starkey started using 3D printing in 1998, while Phonak entered the market in 2000 (Sharma, 2013). Sharma (2013) states that the use of 3D printing technology has reduced the manufacturing process from nine steps to only three (scanning, modeling, and printing). Materialise[28] reports that 99 percent of the world's hearing aids have been produced with Rapid Shell Modeling since 2000[29]. Despite the fact that the technology is more efficient and reduces costs as compared to traditional technologies, only a few companies can afford the initial investments that it requires. Starkey, one of the leading firms is engaged in foreign direct investment with over 30 printers operating across seven different production locations worldwide (Sharma, 2013). In relation to the predictions of the theoretical model, we calculated the correlations between the one-year lag of the sales of the industrial 3D printers (available for 17 countries) collected by Wohlers Report 2014 (2014) and the volume of imported hearing aids, as classified under the tariff line 9021.40.[30] Using data from 1992 until 2012, we observe a negative correlation of 0.13, which is statistically significant at the 10 percent level[31]. The statistical significance of the correlation disappears when the period is restricted to 1992-2000 and it is significant at the 5 percent level for the 2001-2012

[28] http://www.materialise.com/cases/the-hearing-aid-industry-will-never-be-the-same-again.

[29] The procedure has been greatly simplified over time and is carried out as follows. Firstly, an impression of the ear canal of the customer is taken by the audiologist. Secondly, this impression is sent to the hearing-aid manufacturer who creates the digital model (some audiologists can scan the ear impression themselves and send the data plus other ordering options such as Cerumen protection). Thirdly, the shell is printed and manually post-processed. Then the device is assembled with all the necessary components such as electronic parts, loudspeaker, microphones; equipped with a removal line, and lacquered for a high-tech finish. Concerning the time needed, "EnvisionTEC's printers can print 65 hearing aid shells or 47 hearing aid modules within 60 to 90 minutes"(retrieved from http://www.forbes.com/sites/rakeshsharma/2013/07/08/the-3d-printing-revolution-you-have-not-heard-about/) and Starkey is able to sculpt and mold the final product in 24 hours (Sharma, 2013).

[30] This tariff line is not specific to the customized hearing-aids.

[31] The year 2013, although available, was excluded because Stratasys relocated their headquarters to Israel and therefore results could be biased. The correlation for 2013 is still statistically significant, although somewhat smaller.

period[32]. This provides support for the validity of the third prediction of our model that trade in manufactured goods is gradually being replaced if 3D printers are already comparatively cheap. This seems to be the case in the hearing aid industry, in which 3D printers are already widely used.

To get more detailed information on the adoption of 3D printing in the industry, we contacted Sonova – another industry leader – which owns the Phonak hearing aid brand. Also using additive manufacturing, they produce several Custom Earpieces for Behind-The-Ear and Receiver-In-Canal hearing aids. The adoption of 3D printing reduces the time requirements for production and the production costs substantially and it facilitates a reproducible production process across the company's locations. Their technology allows them to produce up to 40 shells when using the EnvisionTec Perfactory III printer, with a printing time of approximately 80 minutes. Just some of the many advantages of the technology are quick turnaround times, an environmentally friendly process with a safe working environment, and a group-wide unique process that provides the customer with the same product quality regardless of their geographical location. Indeed, Sonova has different manufacturing sites (using 3D printing) around the globe. More specifically, there is one facility in Latin America, three in North America, five in Europe, three in Asia, and two in Oceania. From these facilities, the two newest ones were opened in Asia and in Latin America. This case study provides an excellent example for the theoretical predictions: only the most productive firms are using the newest technology (3D printing) and are already engaged in FDI in different locations across the world. Moreover, the markets they serve are characterized by a high demand, particularly Europe and North America.

To summarize, the presented company-level evidence is in line with the second theoretical prediction, and the data of the hearing aid industry supports the third. We expect the patterns to become much clearer once more detailed data become available over the following years and decades.

5 Conclusions

We analyze the relations between 3D printing, trade, and FDI from a theoretical and an empirical perspective. 3D printing is still in its infancy and a high degree of uncertainty surrounds the future impact of this technology on production relocation and on trade, as highlighted in the engineering literature (Tofail et al., 2018). The product life-cycle-type theory presented in this paper (cf. Rayna and Striukova, 2016) indicates that the wider adoption of 3D printing in industrial processes around the world could eventually lead to "glo-calization" – shipping parts and components internationally becoming less important – and threaten the export-led industrialization strategy of low income countries in the future (see Jiang et al., 2017, for a similar argument based on a qualitative analysis).

The results obtained in the empirical analysis confirm the first prediction of the model. Countries with higher GDPs that are subject to higher transport costs are indeed importing more 3D printers, which points

[32] 2001 was chosen instead of 2000 since the adoption of the technology was lagged by one time period. The statistical significance of the correlations would be the same for the period 1992-1999 and 2000-2012 without the lagged adoption, although smaller in absolute value.

towards adopting the technology. Moreover, the relationship between imported hearing aids and the adoption of 3D printing and the results presented in the case study provide some evidence in support of the second and the third predictions of the model. The case study shows that FDI in terms of 3D printing seems to be replacing traditional FDI in the most productive firms of the customized hearing aids industry and it also seems to reduce the volume of trade in particular goods that can be produced efficiently with 3D printers. Only when more data on the firm-level adoption of 3D printing become available, an extension of the empirical assessment of the theoretical predictions will be feasible.

Promising future research avenues include the incorporation into the theoretical framework of the benefits of customization that 3D printing allows for and the analysis of the relationship between the adoption of 3D printing and the labor market. It might also be interesting to analyze the effects that 3D printing will have on wage inequality. For instance, 3D printing might replace low-skilled workers such that the skill premium and wage inequality increase (Mallick and Sousa, 2017; Neves et al., 2018; Lankisch et al., 2019) and could also lead to a decrease in the labor share (Ergül and Göksel, 2019; Prettner, 2017). Although there is some degree of uncertainty regarding the time frame for these changes, there is surely going to be a gradual transformation in the the production process of some products (e.g. automobiles and medical products). Consequently, the economic, social, environmental, and security implications of 3D printing merit further research by economists, social scientists, lawyers, and engineers alike.

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6 Appendix

6.1 Summary statistics

Table 7: Summary statistics: cross-section

Variable	Mean	P50	S.D.	Min.	Max.	N.
lnquan	3.522	3.367	2.424	0.000	10.110	359.000
lntrancost(84)	-3.590	-3.455	0.790	-6.571	-0.941	856.000
lntrancost(87)	-3.585	-3.464	1.009	-6.166	-0.835	755.000
lntrancost(90)	-3.931	-3.740	0.938	-7.601	-1.099	714.000
lntrancost-fedex (25kg)	7.015	7.019	0.373	4.690	7.569	207.000
lntrancost-fedex (1kg)	5.014	5.061	0.217	4.293	5.364	211.000
lndist	9.050	9.161	0.553	5.371	9.892	856.000
comlang	0.123	0.000	0.328	0.000	1.000	856.000
colony	0.027	0.000	0.162	0.000	1.000	856.000
rta	0.137	0.000	0.344	0.000	1.000	856.000
lngdpi	26.751	26.721	1.785	21.819	30.451	856.000
lngdpj	27.216	26.659	1.636	24.743	30.451	856.000

Table 8: Summary statistics: panel

Variable	Mean	P50	S.D.	Min.	Max.	N.
lnquan	3.180	2.890	2.351	0	12.554	3894
lntrancost(84)	-3.457	-3.350	0.790	-8.517	-0.223	12531
lntrancost(87)	-3.343	-3.163	0.981	-8.517	-0.173	10717
lntrancost(90)	-3.762	-3.654	0.941	-9.210	0.141	10308
lndist	9.074	9.183	0.568	5.371	9.892	12531
comlang	0.131	0	0.338	0	1	12531
colony	0.027	0	0.162	0	1	12531
rta	0.053	0	0.224	0	1	12531
lngdpi	26.166	26.219	1.893	20.359	30.451	12531
lngdpj	26.627	26.292	1.844	22.793	30.451	12531

6.2 Extended Tables

Table 9: Cross-sectional regressions with OECD measure of transport cost (Chapter 84)

	OLS (1)	OLS-CD (2)	OLS - BV (3)	PPML (4)	PPML - BV (5)
lntrancost	0.605**	0.738**	1.401***	0.521*	1.066***
	(0.248)	(0.333)	(0.250)	(0.272)	(0.359)
lndist	-1.034***	-1.591***	-1.033***	-1.399***	-1.010
	(0.218)	(0.224)	(0.357)	(0.151)	(0.629)
comlang	0.594**	1.053***	0.720**	0.128	0.809***
	(0.279)	(0.339)	(0.314)	(0.188)	(0.290)
colony	-0.126	0.491	0.770**	0.481**	1.162**
	(0.414)	(0.421)	(0.200)	(0.197)	(0.537)
rta	0.296	-0.357	0.286	0.684***	0.610
	(0.201)	(0.386)	(0.271)	(0.164)	(0.587)
lngdpi	1.120***		0.795***	1.477***	0.815***
	(0.098)		(0.102)	(0.111)	(0.071)
lngdpj	0.721***		0.627***	1.072***	1.046***
	(0.093)		(0.095)	(0.132)	(0.103)
(Pseudo)R^2	0.43	0.72	0.38	0.70	0.47
N	359	359	359	856	856
Dummy Var.	Continent	Countries	-	Continent	-

Notes: Standard errors are clustered at the importer level. *,** and *** indicate significance at the 10, 5, and 1 percent level, respectively. CD stands for country dummies. A constant term is included in all regressions – the coefficient is not reported to save space. In columns (1) to (3) the log of the amount of printers is the dependent variable, while in (4) and (5) it is in units. Columns (3) and (5) control for multilateral resistance with the Baier and Bergstrand (2009) methodology – each bilateral trade cost is included using the following formula: $\ln t_{ij} + \frac{1}{N}\sum_{j=1}^{N}\ln t_{ij} - \frac{1}{N^2}\sum_{i=1}^{N}\sum_{j=1}^{N}\ln t_{ij} + \frac{1}{N}\sum_{i=1}^{N}\ln t_{ij}$.

Table 10: Cross-sectional regressions with OECD measure of transport cost (Chapter 87)

	OLS (1)	OLS-CD (2)	OLS - BV (3)	PPML (4)	PPML - BV (5)
lntrancost	0.617***	0.510*	0.936***	0.379**	0.389*
	(0.164)	(0.273)	(0.232)	(0.167)	(0.203)
lndist	-1.303***	-1.741***	-1.451***	-1.335***	-0.533
	(0.207)	(0.246)	(0.441)	(0.163)	(0.491)
comlang	0.298	0.855**	0.242	0.069	0.705**
	(0.235)	(0.335)	(0.499)	(0.172)	(0.322)
colony	0.001	0.611	1.107*	0.605***	1.544***
	(0.398)	(0.461)	(0.587)	(0.149)	(0.527)
rta	0.382*	-0.324	-0.213	0.710***	0.614
	(0.209)	(0.407)	(0.357)	(0.168)	(0.405)
lngdpi	1.173***		0.785***	1.458***	0.775***
	(0.101)		(0.101)	(0.105)	(0.077)
lngdpj	0.745***		0.582***	1.118***	1.045***
	(0.099)		(0.112)	(0.139)	(0.094)
N	339	339	339	755	755
(Pseudo)R^2	0.453	0.721	0.356	0.718	0.411
Dummy Var.	Continent	Countries	-	Continent	-

Notes: Standard errors are clustered at the importer level. *,** and *** indicate significance at the 10, 5, and 1 percent level, respectively. CD stands for country dummies. A constant term is included in all regressions – the coefficient is not reported to save space. In columns (1) to (3) the log of the amount of printers is the dependent variable, while in (4) and (5) it is in units. Columns (3) and (5) control for multilateral resistance with the Baier and Bergstrand (2009) methodology – each bilateral trade cost is included using the following formula: $\ln t_{ij} + \frac{1}{N}\sum_{j=1}^{N}\ln t_{ij} - \frac{1}{N^2}\sum_{i=1}^{N}\sum_{j=1}^{N}\ln t_{ij} + \frac{1}{N}\sum_{i=1}^{N}\ln t_{ij}$.

Table 11: Cross-sectional regressions with OECD measure of transport cost (Chapter 90)

	OLS (1)	OLS-CD (2)	OLS - BV (3)	PPML (4)	PPML - BV (5)
lntrancost	0.512***	0.385**	0.938***	0.351**	0.333
	(0.182)	(0.170)	(0.222)	(0.175)	(0.251)
lndist	-1.110***	-1.573***	-1.236***	-1.228***	-0.402
	(0.212)	(0.245)	(0.387)	(0.175)	(0.509)
comlang	0.314	0.826***	0.406	0.154	0.683**
	(0.229)	(0.298)	(0.466)	(0.198)	(0.321)
colony	-0.071	0.593	0.910	0.534***	1.407**
	(0.418)	(0.469)	(0.612)	(0.190)	(0.568)
rta	0.331*	-0.442	-0.286	0.692***	0.581
	(0.183)	(0.334)	(0.312)	(0.170)	(0.399)
lngdpi	1.146***		0.809***	1.442***	0.766***
	(0.091)		(0.089)	(0.108)	(0.074)
lngdpj	0.774***		0.563***	1.097***	1.044***
	(0.096)		(0.101)	(0.128)	(0.099)
N	339	339	339	714	714
(Pseudo)R^2	0.453	0.721	0.356	0.718	0.411
Dummy Var.	Continent	Countries	-	Continent	-

Notes: Standard errors are clustered at the importer level. *,** and *** indicate significance at the 10, 5, and 1 percent level, respectively. CD stands for country dummies. A constant term is included in all regressions – the coefficient is not reported to save space. In columns (1) to (3) the log of the amount of printers is the dependent variable, while in (4) and (5) it is in units. Columns (3) and (5) control for multilateral resistance with the Baier and Bergstrand (2009) methodology – each bilateral trade cost is included using the following formula: $\ln t_{ij} + \frac{1}{N}\sum_{j=1}^{N} \ln t_{ij} - \frac{1}{N^2}\sum_{i=1}^{N}\sum_{j=1}^{N} \ln t_{ij} + \frac{1}{N}\sum_{i=1}^{N} \ln t_{ij}$.

Table 12: Panel regressions with OECD transport cost measure (Chapter 84)

	OLS (1)	OLS-CD (2)	OLS - BV (3)	PPML (4)	PPML - BV (5)
lntrancost	0.348***	0.210*	0.430**	1.816***	0.231
	(0.130)	(0.119)	(0.169)	(0.406)	(0.310)
lndist	-0.893***	-1.085***	-0.813***	-1.259***	-0.991
	(0.143)	(0.117)	(0.229)	(0.243)	(0.744)
comlang	0.394**	0.878***	0.609**	0.644*	0.723*
	(0.188)	(0.169)	(0.238)	(0.337)	(0.398)
colony	-0.456*	0.215	0.366	-0.739***	-2.795
	(0.248)	(0.205)	(0.333)	(0.284)	(2.893)
rta	0.526**	0.410**	0.347	1.090**	-0.575
	(0.233)	(0.194)	(0.338)	(0.454)	(1.358)
lngdpi	0.987***	0.711***	0.687***	1.187***	0.746***
	(0.053)	(0.191)	(0.047)	(0.136)	(0.073)
lngdpj	0.551***	0.581***	0.440***	1.136***	0.773***
	(0.062)	(0.182)	(0.045)	(0.186)	(0.088)
N	3,894	3,894	3,894	12,531	12,531
(Pseudo)R^2	0.376	0.575	0.318	0.272	0.030
Dummy Var.	Continent	Countries	-	Continent	-

Notes: Standard errors clustered at the country-pair level. *,** and *** indicate significance at the 10, 5, and 1 percent level, respectively. CD stands for country dummies. A constant term is included in all regressions – the coefficient is not reported to save space. In columns (1) to (3) the log of the amount of printers is the dependent variable, while in (4) and (5) it is in units. Columns (3) and (5) control for multilateral resistance with the Baier and Bergstrand (2009) methodology – each bilateral trade cost is included using the following formula: $\ln t_{ijt} + \frac{1}{N}\sum_{j=1}^{N} \ln t_{ijt} - \frac{1}{N^2}\sum_{i=1}^{N}\sum_{j=1}^{N} \ln t_{ijt} + \frac{1}{N}\sum_{i=1}^{N} \ln t_{ijt}$. All columns include time dummies. Convergence problems of the PPML estimator were encountered when trying to estimate the equivalent to (2).

Table 13: Panel regressions with OECD transport cost measure (Chapter 87)

	OLS (1)	OLS-CD (2)	OLS - BV (3)	PPML (4)	PPML - BV (5)
lntrancost	0.446***	0.151*	0.315***	1.113***	-0.116
	(0.105)	(0.082)	(0.119)	(0.246)	(0.250)
lndist	-1.023***	-1.168***	-0.887***	-1.194***	-0.773
	(0.149)	(0.139)	(0.256)	(0.247)	(0.748)
comlang	0.354*	0.889***	0.542**	0.262	0.559
	(0.199)	(0.190)	(0.262)	(0.300)	(0.484)
colony	-0.403	0.253	0.447	-0.123	-2.838
	(0.260)	(0.214)	(0.352)	(0.344)	(3.038)
rta	0.622**	0.431**	0.434	1.055**	-0.387
	(0.248)	(0.213)	(0.372)	(0.471)	(1.385)
lngdpi	1.025***	0.679***	0.697***	1.062***	0.736***
	(0.055)	(0.195)	(0.049)	(0.125)	(0.074)
lngdpj	0.557***	0.528***	0.445***	1.071***	0.757***
	(0.066)	(0.184)	(0.046)	(0.179)	(0.083)
N	3,650	3,650	3,650	10,717	10,717
(Pseudo)R^2	0.386	0.577	0.316	0.238	0.033
Dummy Var.	Continent	Countries	-	Continent	-

Notes: Standard errors clustered at the country-pair level. *,** and *** indicate significance at the 10, 5, and 1 percent level, respectively. CD stands for country dummies. A constant term is included in all regressions – the coefficient is not reported to save space. In columns (1) to (3) the log of the amount of printers is the dependent variable, while in (4) and (5) it is in units. Columns (3) and (5) control for multilateral resistance with the Baier and Bergstrand (2009) methodology – each bilateral trade cost is included using the following formula: $\ln t_{ijt} + \frac{1}{N}\sum_{j=1}^{N}\ln t_{ijt} - \frac{1}{N^2}\sum_{i=1}^{N}\sum_{j=1}^{N}\ln t_{ijt} + \frac{1}{N}\sum_{i=1}^{N}\ln t_{ijt}$. All columns include time dummies. Convergence problems of the PPML estimator were encountered when trying to estimate the equivalent to (2).

Table 14: Panel regressions with OECD transport cost measure (Chapter 90)

	OLS (1)	OLS-CD (2)	OLS - BV (3)	PPML (4)	PPML - BV (5)
lntrancost	0.412***	0.072	0.273*	1.014***	-0.313
	(0.108)	(0.096)	(0.141)	(0.243)	(0.299)
lndist	-0.912***	-1.122***	-0.850***	-1.047***	-0.663
	(0.155)	(0.143)	(0.254)	(0.256)	(0.665)
comlang	0.384*	0.876***	0.587**	0.357	0.473
	(0.197)	(0.185)	(0.256)	(0.314)	(0.442)
colony	-0.467*	0.251	0.374	-0.548**	-2.818
	(0.256)	(0.214)	(0.350)	(0.268)	(3.019)
rta	0.585**	0.408*	0.374	1.563***	-0.377
	(0.241)	(0.212)	(0.359)	(0.580)	(1.219)
lngdpi	1.024***	0.662***	0.712***	1.140***	0.740***
	(0.057)	(0.196)	(0.050)	(0.120)	(0.076)
lngdpj	0.586***	0.538***	0.442***	1.151***	0.754***
	(0.069)	(0.184)	(0.046)	(0.199)	(0.081)
N	3,639	3,639	3,639	10,308	10,306
(Pseudo)R^2	0.386	0.577	0.318	0.216	0.036
Dummy Var.	Continent	Countries	-	Continent	-

Notes: Standard errors clustered at the country-pair level. *,** and *** indicate significance at the 10, 5, and 1 percent level, respectively. CD stands for country dummies. A constant term is included in all regressions – the coefficient is not reported to save space. In columns (1) to (3) the log of the amount of printers is the dependent variable, while in (4) and (5) it is in units. Columns (3) and (5) control for multilateral resistance with the Baier and Bergstrand (2009) methodology – each bilateral trade cost is included using the following formula: $\ln t_{ijt} + \frac{1}{N}\sum_{j=1}^{N}\ln t_{ijt} - \frac{1}{N^2}\sum_{i=1}^{N}\sum_{j=1}^{N}\ln t_{ijt} + \frac{1}{N}\sum_{i=1}^{N}\ln t_{ijt}$. All columns include time dummies. Convergence problems of the PPML estimator were encountered when trying to estimate the equivalent to (2).