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Is 3D Printing a Threat to Global Trade?

The Trade Effects You Didn't Hear About

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Abstract

In the mid-2000s, the production of hearing aids shifted almost entirely to 3D printing. Using difference-in-differences and synthetic control methods, this paper examines the effects of this shift on trade flows. The analysis finds that trade increased roughly 60 percent following the introduction of 3D printing. Revealed comparative advantage was reinforced, with exports growing most rapidly for middle- and high-income countries. The analysis also finds that developing countries increased their imports of hearing aids as a result of the innovation, benefitting consumers. As a robustness check, the paper examines 35 products that are partially 3D printed and finds positive and significant effects on trade. The results counter widespread views that 3D printing will shorten supply chains and reduce trade.

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Is 3D Printing a Threat to Global Trade?
The Trade Effects You Didn't Hear About[†]

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World Bank

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1. Introduction

Will 3D printing disrupt world trade? The new technology has been accompanied by predictions of a future where goods will be printed locally, global supply chains will be shortened, and international trade will be dramatically reduced. Firms (and perhaps even consumers) will be able to create a solid three-dimensional object from a digital file and will no longer need to import printable goods and components. One study finds that as much as 40 percent of trade could be eliminated by 2040.[1]

In contrast, many earlier improvements in production processes that have reduced production costs and/or improved quality have boosted international trade. The industrial revolution is perhaps the best example, where a transformation in technology and management practices brought huge productivity gains, output growth, and expanding trade. The impact of 3D printing technology on world trade is therefore an empirical question.

Early evidence suggests that firms (and countries) will continue to specialize and 3D printing will stimulate trade growth. While 3D printing allows product customization, it does not beat traditional manufacturing technologies for bulk production of simple items. Even for the specialized products where it is most effective, it is not leading to decentralized production. One example comes from dentistry, where custom products are in high demand but are being manufactured and exported by high-tech firms. Consider Renishaw, a British engineering company, that makes dental crowns and bridges from digital scans of patients' teeth. The printers run for 8-10 hours to make custom teeth from cobalt-chrome alloy powder, which are then exported. Dentists are not installing the machines to print teeth locally, rather the parts are shipped to dental labs in Europe, where a layer of porcelain is added before the teeth are shipped to dentists.[2] With 3D printing, the production process changed but the supply chain remains intact.

In addition to teeth, the innovative technology is also being used for several other goods, from running shoes to prosthetic limbs. The good where 3D printing is most common is hearing aids. Nearly 100 percent of all hearing aids consumed in the world are produced using 3D printing.[3] 3D printers transformed the hearing aid industry in less than 500 days in the mid-2000s, which makes this product a unique natural experiment to assess the trade effects of this technology. In particular, we use the example of hearing aids to examine the effects of 3D printing on international trade and to study how trade patterns have changed as production technologies shifted. Beyond this specific example, we also investigate trade in other goods where the use of 3D printing is expanding.

The main result is that 3D printing leads to an increase in world trade. We examine the data in two ways, first using a standard difference-in-difference technique and comparing the growth in hearing aid trade to other similar products. Second, we use synthetic controls. The results show that the development of 3D printing led to an increase in trade of 58 percent over nearly a decade, relative to the baseline. A dynamic extension of our model shows that the impact

[1] ING Report (Leering, 2017) https://www.ingwb.com/media/2088633/3d-printing-report-031017.pdf

[2] "A printed smile," The Economist, 28-Apr-2016.https://www.economist.com/science-and-technology/2016/04/28/a-printed-smile

[3] See Banker (2013).

on trade follows the large expansion of 3D printing in the hearing aid industry in 2007. Our results also indicate that comparative advantage is strengthened and the countries that appear to benefit the most from the introduction of the new technology are advanced and middle-income economies. When we study the impact on imports, results show that there is a stronger effect on developing countries, particularly low-income countries, pointing to welfare gains on the consumption side for these economies.

The intuition for the results is that 3D printing led to a reduction in the cost of production. Demand rose and trade expanded. There is no evidence that 3D printing shifted production closer to consumers and displaced trade. One reason is that hearing aids are light products which makes them relatively cheap to transport internationally -we come back to this point below. A second reason is because printing hearing aids in high volumes requires a large investment in technology and machinery and the presence of highly specialized inputs and services. The countries that were early innovators, Denmark, Switzerland and Singapore, remain the main export platforms. Some middle-income economies such as China, Mexico and Vietnam have also been able to substantially increase their market shares between 1995 and 2015. As a result, exports did not become more concentrated in the top producing countries following the introduction of 3D printing.

While these results are specific to hearing aids, the insights may be more general. We also examine 35 other products that are increasingly being 3D printed and find similar patterns. These budding 3D products have also experienced faster trade growth than otherwise similar goods. In contrast to the results for hearing aids, there is some evidence of disruption in comparative advantage which indicates that there might be differences across products that deserve further investigations as more data become available. We also investigate the extent to which the weight of 3D printable products affects our main result. Interestingly, we find that the positive effect of 3D printing on trade decreases with product weight and could even reverse for bulky products. These results suggest that while the technology appears to boost trade on average, it may be used to produce goods closer to consumers for products with high transport costs.[4]

This paper contributes to the literature on how new technologies affect international trade. Despite the large debate in the specialized press,[5] to our knowledge this is the first paper that empirically investigates the impact of 3D printing on trade. Goldfarb and Tucker (2017) have a recent survey of the literature on digital economics, which does not review any paper on 3D printing.

The paper is organized as follows. The next section describes 3D printing in hearing aids. Section 3 reports results for the difference-in-difference methodology. Section 4 reports results using synthetic controls. Section 5 explores other products that are being 3D printed. And Section 6 concludes.

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[4] Ideally, we would want to test the extent to which a second feature of hearing aids -the presence of relevant economies of scale- matters to explain the impact of 3D printing on trade. The presumption is that the production of products that are less subject to economies of scale can be more easily fragmented, leading to less trade. Unfortunately, differently from product weights, data on scale elasticities are not available at the level of disaggregation needed for this analysis.

[5] See the next section for a discussion on hearing aids as an example.

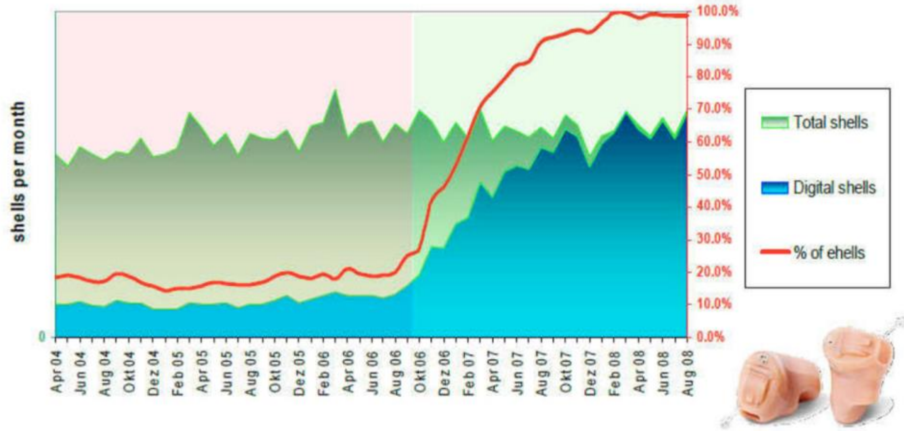
2. 3D printing in hearing aids

The hearing aid industry is unique in its virtually complete and rapid switch from traditional manufacturing to 3D printing. According to one observer, not one company that stuck to traditional manufacturing methods survived (d'Aveni, 2014). Despite attempts in the late 1980s and early 1990s, the 3D printing technology did not mature until the early 2000s. Importantly, the more efficient technology was adopted in fewer than 500 days (e.g., see Figure 1 for 3D printing adoption for the largest firm),[6] reducing production steps from nine to three: scanning, modeling, and printing (Sharma, 2013).

Three major inventions marked a turning point. First, in 2001, two Danish graduate students developed a prototype of a 3D scanner, which was used to scan hearing aid shells (Sandström, 2016). Widex – one of the three Danish hearing aid manufacturers – immediately signed an agreement for the development of a scanner. In addition to the scanner, the students also developed the software and founded 3Shape, a company that now controls 90 percent of the market for scanners and software for 3D printing. Second, a German firm, Dreve Materials, launched in 2002 a biocompatible material suitable for 3D printing processes of hearing aids. Finally, in 2005 EnvisionTEC, a producer of 3D printers, sold its first Selective Modulation printer to Phonak, a producer of hearing aids. After a period of trial and error, the new printer finally allowed hearing aid manufactures to produce shells similar in terms of color and material to the traditional ones. As the technology changed, there was a wave of industry consolidation. In 2006, the Phonak Group became the largest producer, after acquiring GN ReSound and the adoption of the technology spread rapidly.[7]

[6] Other companies switched to 3D printing during the same period. For instance, GN ReSound explored the technology in 2002 and by 2008 it transitioned 90 percent of its production to 3D printing (Sandström, 2016).
[7] "“Big-6″ to Become “Big-5″ as R&D Costs Drive Consolidation,” The Hearing Review, 1-Oct-2006. http://www.hearingreview.com/2006/10/big-6-to-become-big-5-as-rd-costs-drive-consolidation/

Figure 1: Adoption of 3D Printing for custom hearing aids at Phonak



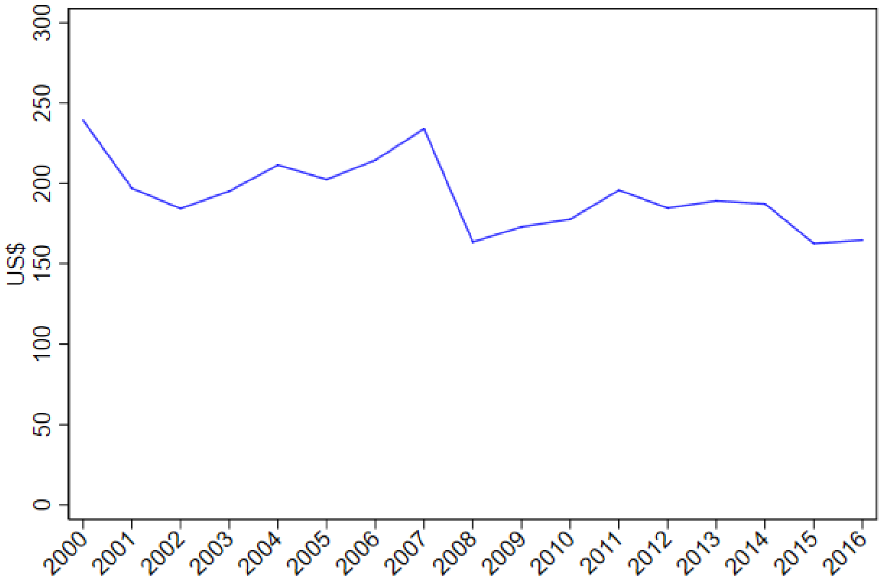
Source: Brans (2013)

The new technology fundamentally changed the industry because it produced a better product at a lower cost. The change is visible in US import price data and hearing aid usage. The United States is the number one importer of hearing aids and has relatively accurate data on unit prices. Figure 2, shows that the unit value of hearing aids imported into the United States dropped by around 25 percent after 2007, right around when the technology was adopted.[8]

Hearing aid usage also increased dramatically. From 2001 to 2008 only about 26 percent of the population above 70 with hearing loss used hearing aids, and the share was flat over the period. From 2008 to 2013 (last year of data), the share increased to 32 percent (Office of Disease Prevention and Health Promotion, US Government). Despite the potential benefits from the use of hearing aids, stigma, discomfort and cost had been among the most frequent reasons for rejecting the use of hearing instruments (Van den Brink et al., 1996). Two factors related to 3D printing could have contributed to the increased usage of hearing aids. First, improved quality: the high level of customization and cosmetic improvement achieved with the use of the technology, which reduced the stigma and discomfort. Second, the reduced cost of production of a high-quality product which resulted in lower prices.

[8] However, according to the President's Council of Advisors on Science and Technology (PCAST), price reductions were only in part transmitted to consumers who typically pay more than $2,300 for just one hearing aid. https://obamawhitehouse.archives.gov/blog/2015/10/26/%E2%80%8Bpcast-recommends-changes-promote-innovation-hearing-technologies

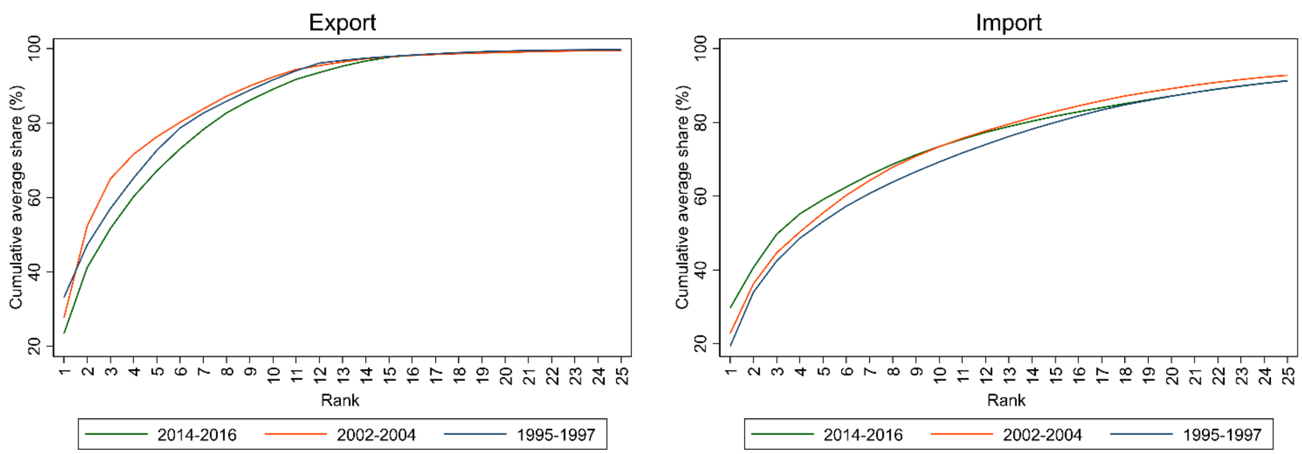
Figure 2: Unit Value of Hearing Aids (US Import data from UN Comtrade)



The advent of 3D printers has not fundamentally affected the industry's market structure. The hearing aid industry has been dominated for the past 15 years by six companies who control about 99 percent of the global market (Sandström, 2016). In terms of location of production and consumption, trade data show that 3D printing led to a reduction in export concentration, especially among the top 3 exporters (Figure 3). The export share of the world's largest top three exporters of hearing aids declined from 65 in the early 2000s to 52 today, reversing a trend of increasing consolidation from the mid-1990s to the early 2000s. Figure 3 shows the decrease in export concentration, especially between the periods 2002-2004 and 2014-2016, at the top of the distribution. In contrast, imports became slightly more concentrated, though the trend over time remained the same from 1990s to the 2000s and from the 2000s to the 2010s. Consumption of hearing aids is less concentrated than production. The import share of the top 10 largest importers was 69 percent in 1995-1997 and it increased to 73 percent in 2014-2016.[9]

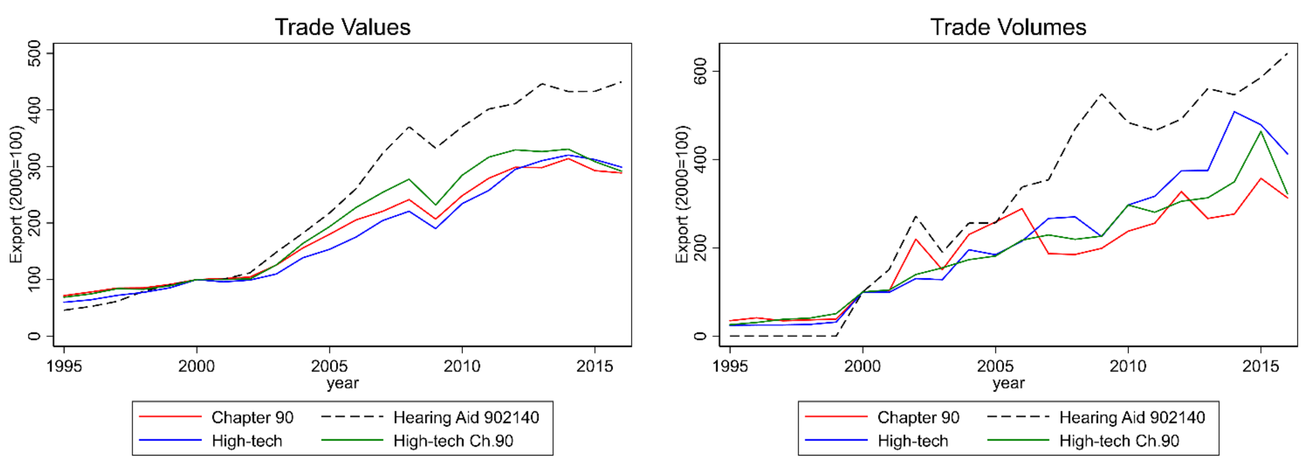
[9] While the cost of 3D printers per se, which is around $150,000, may not be high enough to justify the persistency of high levels of market concentration, there are other complementary technologies such as 3D scanners and software for three-dimensional modeling and, especially, requirements for technical competencies that make the industry subject to internal and external economies of scale. Sandström (2016) reports that the technicians' visual capabilities to optimize hearing aid shells (e.g. fitting the electronics component) remained largely intact with the use of 3D printing in the industry.

Figure 3: Evolution of export and import concentration



Before moving to the formal analysis, we take a first look at the trade data. Prima facie evidence supports the view that, rather than disrupting international trade flows, 3D printing boosted trade in hearing aids. Figure 4 shows that trade in hearing aids, HS code 902140, increased more than total trade in chapter 90 (optical, photographic, cinematographic, measuring, checking, medical or surgical instruments and apparatus; parts and accessories) and more rapidly than in the high-tech products listed in Appendix Table 5. We find that the divergence happened around 2007, precisely when the 3D printing technology was being adopted, and that distance between the series remained constant afterward. In the next sections, we investigate this relationship more formally, identifying the causal impact of 3D printing on trade using differences-in-differences and synthetic control methods.

Figure 4: Evolution of trade in goods



3. Differences-in-Differences

In this section, we study the impact of 3D printing on international trade flows using a differences-in-differences method. We ask the data four main related questions: what the impact of the new technology is on hearing aids' (i) average exports; (ii) comparative advantage; (iii) exports of countries at different level of developments; and (iv) imports.

In the simplest case, 3D printing would reduce trade if countries shifted from importing hearing aids to printing them. However, it could also affect comparative advantage, leading to a change in trade patterns, but no end to trade. In a standard Heckscher-Ohlin framework, the introduction of 3D printing technology would reduce the labor intensity of production. As a result, exports would shift to more capital abundant countries. The overall reshuffling of exports would also depend on the presence of economies of scale. Finally, the new technology reduced production costs and increased product quality, suggesting there should be greater demand, more production, and potentially more trade.

We begin by identifying the effect of 3D printing on trade by comparing hearing-aid exports before and after 2007 – the year production technology shifted – to exports of other products. The underlying assumption is that, controlling for other determinants of trade, trade in hearing aids would have moved in parallel to other products in the absence of the 3D printing technology. Thus, any divergence in hearing aids trade after 2007 is attributable to 3D printing.

To formally investigate the relationship between 3D printing and trade, we estimate the following equation:

$$X_{ikt}^{P} = \gamma_{ik} + \delta_{it} + \beta * I_{kt}(Hearing\ Aid\ 2007) + \varepsilon_{ikt} \quad (1)$$

where X_{ikt}^{P} is country i's log of exports of HS 6-digit product k within category product P in year t.[10] $I_{kt}(Hearing\ Aid\ 2007)$ is an indicator variable which takes value 1 for HS code 902140 "hearing aid" from year 2007 onward – the year in which the technology became widely used in the production of hearing aids (see Section 2). γ_{ik} and δ_{it} are country-product and country-year fixed effects, respectively. Country-product dummies capture the effect of time-invariant characteristics that determine the level of exports, including secular productivity and endowment differences that can determine the specialization trade patterns. While country-year fixed effects account for country specific shocks common to all products, including country-specific macroeconomic conditions.

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[10] We use product level bilateral trade data from WITS (UN Comtrade) reported at the 6-digit level in the HS 1988/92 classification for the period 1995-2016 . As common in the literature, we drop countries with population less than 5 million. Additionally, we keep only countries for which the World Bank provides information on the income level (see Table 9 or https://datahelpdesk.worldbank.org/knowledgebase/articles/378834-how-does-the-world-bank-classify-countries). The available data cover 117 countries and 330 products that are either classified as high-tech (see Table 5) or in HS chapter 90.

The coefficient on the indicator variable, β, captures differences in changes in export of hearing aids that are due to the introduction of the 3D printing technology. If the technology allows for the disaggregation of production, with printing performed geographically close to consumers (as it is implicitly assumed in recent reports -see the Introduction), the coefficient should be negative. On the other hand, if 3D printing, similarly to other technologies, expands quality or lowers prices, trade should expand, and the coefficient would be positive.

The econometric analysis shows that the average impact of 3D printing on trade in hearing aids is positive and statistically significant (Table 1). The results in the first column of Table 1 indicate that as hearing aids became 3D printed trade flows increased by up to 78 percent. The results are robust to using products that are high-tech and/or under HS chapter 90 in the control group. In our preferred specification, we compare trade in hearing aids to other high-tech products in HS chapter 90 – optical, photographic, cinematographic, measuring, checking, precision, medical or surgical instruments and apparatus. These are products with similar R&D and technology intensity that are likely to be subject to similar demand and supply shocks as hearing aids. In this specification, we find that 3D printing increases trade by 58 percent (from column 4, exp(0.456)-1). This effect could be interpreted as a lower bound, as there is evidence of 3D printing being used to some extent for the production of other high-tech products within chapter 90.[11]

Table 1: Effects of 3D printing on exports in hearing aids

	(1)	(2)	(3)	(4)
Sector control	HS Ch. 90 or High-tech	HS Ch. 90	High-tech	HS Ch. 90 and High-tech
VARIABLES	log(exports)	log(exports)	log(exports)	log(exports)
(Hearing Aid 2007-)	0.580***	0.550***	0.561***	0.456***
	(0.158)	(0.157)	(0.159)	(0.157)
Observations	476,248	234,932	360,007	118,678
R-squared	0.847	0.859	0.844	0.862
Period	1995-2016	1995-2016	1995-2016	1995-2016
Country-Year FE	YES	YES	YES	YES
Country-Product FE	YES	YES	YES	YES
% Zeroes	.44	.40	.44	.37

Note: Robust standard errors, clustered at the country-product level, are in parentheses. Countries with population over 5mln.
*** p<0.01, ** p<0.05, * p<0.1

[11] For instance, orthopedic appliances and other artificial parts of the body.

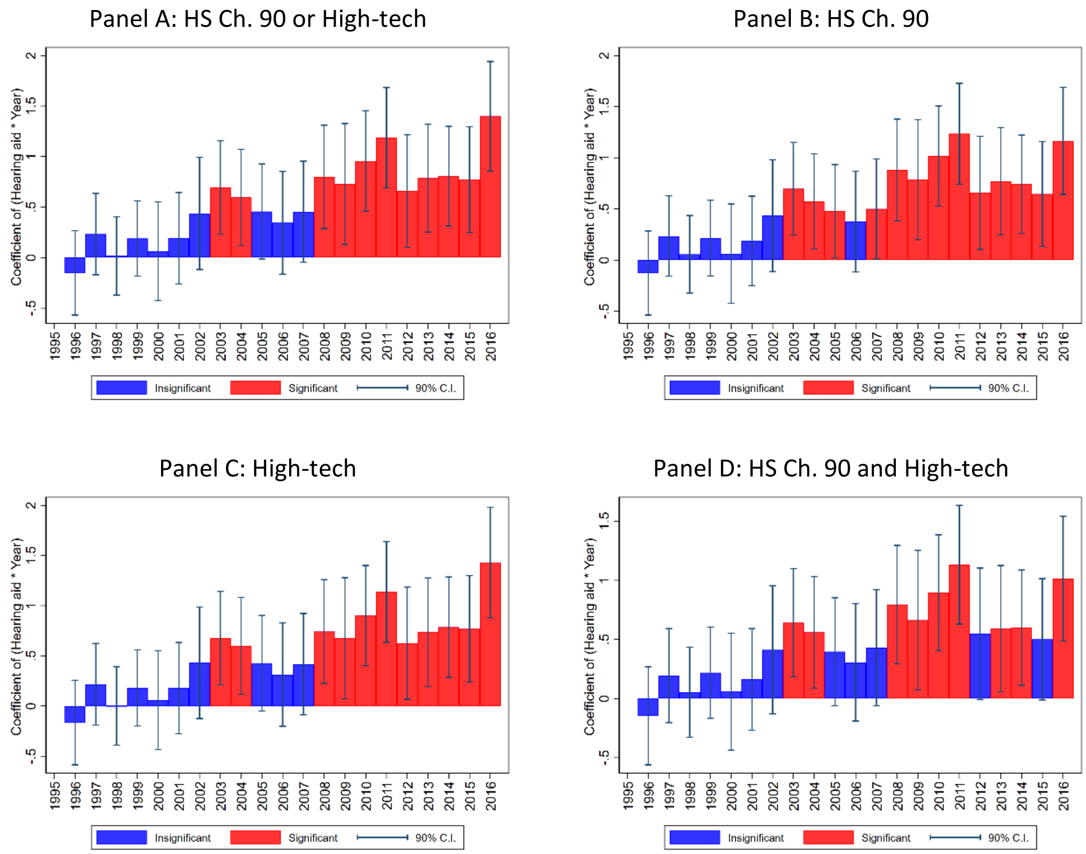
As a second step, we test for dynamic effects and perform a robustness check on the treatment year, we estimate the following equation:

$$X_{ikt}^{P} = \gamma_{ik} + \delta_{it} + \sum_{year=1996}^{2016} \beta_{year} * (Hearing\ Aid * year) + \varepsilon_{ikt} \qquad (2)$$

where the coefficients on the interactions between $Hearing\ Aid$ and the $year$ dummy variables, β_{year}, capture the yearly difference between trade in hearing aid and other products with respect to the difference in 1995 the excluded category due to the collinearity with country-product, γ_{ik}, fixed effects.

The results when we estimate equation (2) are presented in Figure 5 which shows the coefficients of the interaction term for different years. We find that trade in hearing aids diverged markedly from non-3D products after 2007 – i.e., when the technology started to be adopted – irrespectively of the control group. There is also some evidence of trade increasing around 2004, when the technology was already deployed in the production of hearing aid shells, although only for a fraction of production (see Figure 1). Trade in hearing aids progressively diverged in years subsequent to 2007 (with peaks in 2011 and 2016), consistently with the view that the technology allowed to reduce costs and improve quality leading to increasing sales over time.

Figure 5:Dynamic effects



In Table 2 we study the impact of 3D printing on exports of countries with different levels of revealed comparative advantage (RCA). As 3D printing weakened the comparative advantage in hearing aids of labor abundant countries, one might expect a reshuffling in comparative advantage in the years after the diffusion of the new technology. Results in Table 2 fail to support this view. Columns 1 to 4 suggest that 3D printing had stronger effect on countries with a comparative advantage, although the effect was not statistically different from countries with a comparative disadvantage.

In columns 5-8, we explore the effect on different groups in more detail. Countries with RCA>1 are split into two groups, those with revealed comparative advantage above the median (given RCA>1) and those with revealed comparative advantage below the median. Similarly, for countries with RCA<1. We find that countries with a small comparative advantage (*Dummy Low RCA 1995-2000 > 1* in columns 5 to 8) –benefitted the most.

Table 2: Effects of 3D printing on RCA in hearing aids

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Sector control	HS Ch. 90 or High-tech	HS Ch. 90	High-tech	HS Ch. 90 and High-tech	HS Ch. 90 or High-tech	HS Ch. 90	High-tech	HS Ch. 90 and High-tech
VARIABLES	log(exports)	log(exports)	log(exports)	log(exports)	log(exports)	log(exports)	log(exports)	log(exports)
(Hearing Aid 2007-)	0.562***	0.532***	0.545***	0.442***				
	(0.171)	(0.170)	(0.172)	(0.170)				
(Hearing Aid 2007-)*(Dummy RCA 1995-2000 > 1)	0.230	0.225	0.213	0.167				
	(0.227)	(0.233)	(0.235)	(0.265)				
(Hearing Aid 2007-)*(Dummy Low RCA 1995-2000 < 1)					0.551*	0.476*	0.544*	0.377
					(0.289)	(0.283)	(0.291)	(0.277)
(Hearing Aid 2007-)*(Dummy High RCA 1995-2000 < 1)					0.566***	0.551***	0.545***	0.464**
					(0.207)	(0.206)	(0.208)	(0.208)
(Hearing Aid 2007-)*(Dummy Low RCA 1995-2000 > 1)					0.981***	0.964***	0.952***	0.851***
					(0.149)	(0.150)	(0.161)	(0.190)
(Hearing Aid 2007-)*(Dummy High RCA 1995-2000 > 1)					0.508***	0.448***	0.467***	0.248
					(0.153)	(0.168)	(0.180)	(0.263)
Observations	476,248	234,932	360,007	118,678	476,248	234,932	360,007	118,678
R-squared	0.847	0.859	0.844	0.862	0.847	0.859	0.844	0.862
Sum of coefficients	.792***	.757***	.758***	.609***	2.606***	2.439***	2.508***	1.939***
Period	1995-2016	1995-2016	1995-2016	1995-2016	1995-2016	1995-2016	1995-2016	1995-2016
Country-Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Country-Product FE	YES	YES	YES	YES	YES	YES	YES	YES
% Zeroes	.44	.4	.44	.37	.44	.4	.44	.37

Note: Robust standard errors, clustered at the country-product level, are in parentheses. Countries with population over 5mln.
*** p<0.01, ** p<0.05, * p<0.1

In Table 3 we investigate the impact of 3D printing on countries at various stages of development. Results in columns 1 to 4 suggest that 3D printing had a similar impact on trade of developing and developed countries. However, when we use a finer disaggregation for developing countries, we find heterogenous effects. In columns 5-8 we find that 3D printing particularly benefitted exports of upper middle-income economies and high-income countries, while it had a negative impact on exports from low-income economies.[12] In sum, we find that only emerging and advanced economies appear to have benefited from the new technology, consistent with the new technology being relatively less labor intensive.

[12] See Appendix Table 8.

Table 3: Effects of 3D printing on exports in hearing aids for countries at different levels of development

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Sector control	HS Ch. 90 or High-tech	HS Ch. 90	High-tech	HS Ch. 90 and High-tech	HS Ch. 90 or High-tech	HS Ch. 90	High-tech	HS Ch. 90 and High-tech
VARIABLES	log(exports)	log(exports)	log(exports)	log(exports)	log(exports)	log(exports)	log(exports)	log(exports)
(Hearing Aid 2007-)	0.584***	0.583***	0.560***	0.501***				
	(0.190)	(0.193)	(0.190)	(0.193)				
(Hearing Aid 2007-)*(Dummy Developing)	-0.007	-0.061	0.002	-0.085				
	(0.310)	(0.309)	(0.311)	(0.311)				
(Hearing Aid 2007-)*(Dummy Low income)					-0.744	-0.870*	-0.780	-1.111**
					(0.481)	(0.477)	(0.478)	(0.462)
(Hearing Aid 2007-)*(Dummy Lower middle income)					0.503	0.501	0.488	0.435
					(0.453)	(0.438)	(0.464)	(0.457)
(Hearing Aid 2007-)*(Dummy Upper middle income)					0.929***	0.843***	0.919***	0.728***
					(0.290)	(0.294)	(0.285)	(0.279)
(Hearing Aid 2007-)*(Dummy High income)					0.584***	0.583***	0.560***	0.501***
					(0.190)	(0.193)	(0.190)	(0.193)
Observations	476,248	234,932	360,007	118,678	476,248	234,932	360,007	118,678
R-squared	0.847	0.859	0.844	0.862	0.847	0.859	0.844	0.862
Sum of coefficients	.577**	.522**	.562**	.416*	1.272*	1.057	1.188	.553
Period	1995-2016	1995-2016	1995-2016	1995-2016	1995-2016	1995-2016	1995-2016	1995-2016
Country-Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Country-Product FE	YES	YES	YES	YES	YES	YES	YES	YES
% Zeroes	.44	.4	.44	.37	.44	.4	.44	.37

Note: Robust standard errors, clustered at the country-product level, are in parentheses. Countries with population over 5mln.

*** p<0.01, ** p<0.05, * p<0.1

Finally, we estimate equation (1) on the log of imports. This specification allows to understand which consumers are benefitting from the technology by expanding their demand for hearing aids. In addition, a focus on imports has two advantages. First, the share of zero trade flows, especially for the hearing aid industry, is lower, as a higher number of countries consume hearing aids than produces them.[13] Second, this specification serves as an additional robustness test in terms of the 3D printing treatment. Given that a small number of exporting countries dominate the hearing aid industry, effects may not be widespread, or a few outliers could drive results. Imports are likely to be affected to a greater extent across a wider number of countries.

Overall the estimates on the impact of hearing aids on imports are qualitatively similar to those found for exports, however there are some quantitative differences. Results in column 1 of Table 4 suggest that 3D printing increases imports by 104 percent while the impact on exports, for the specification that uses high-tech products within chapter 90, suggests an increase by around 58 percent. We find that countries with a large revealed disadvantage (i.e., *Dummy Low RCA 1995-2000 < 1* equal to one), countries unlikely to produce hearing aids domestically, import disproportionately more after the introduction of 3D printing. Column 4 shows that there is stronger impact on developing countries' imports. Column 5 shows that the impact of 3D printing on imports is uniform across developing countries with a marginally stronger impact on low income economies. These findings suggest that the 3D innovation made hearing aids more available to developing country residents with hearing loss.

In summary, this section documents a strongly positive impact of 3D printing on trade using differences-in-differences techniques. The results show that the technology allowed producers, especially in upper middle- and high-income countries, to increase their export competitiveness. As a result, this increase in competitiveness benefited consumers in developing countries that increased their imports of hearing aids.

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[13] Indeed, the last row of Table 4 shows that the share of zeroes, 28 percent, is smaller than the one for exports which ranges between 37 and 44 percent.

Table 4: Effects of 3D printing on imports

	(1)	(2)	(3)	(4)	(5)
Sector control	HS Ch. 90 and High-tech	HS Ch. 90 and High-tech	HS Ch. 90 and High-tech	HS Ch. 90 and High-tech	HS Ch. 90 and High-tech
VARIABLES	log(imports)	log(imports)	log(imports)	log(imports)	log(imports)
(Hearing Aid 2007-)	0.715***	0.715***		0.493***	
	(0.068)	(0.072)		(0.084)	
(Hearing Aid 2007-)*(Dummy RCA 1995-2000 > 1)		-0.004			
		(0.164)			
(Hearing Aid 2007-)*(Dummy Developing)				0.351***	
				(0.124)	
(Hearing Aid 2007-)*(Dummy Low RCA 1995-2000 < 1)			0.989***		
			(0.117)		
(Hearing Aid 2007-)*(Dummy High RCA 1995-2000 < 1)			0.545***		
			(0.082)		
(Hearing Aid 2007-)*(Dummy Low RCA 1995-2000 > 1)			0.724***		
			(0.117)		
(Hearing Aid 2007-)*(Dummy High RCA 1995-2000 > 1)			0.694**		
			(0.319)		
(Hearing Aid 2007-)*(Dummy Low income)					0.891***
					(0.171)
(Hearing Aid 2007-)*(Dummy Lower middle income)					0.812***
					(0.139)
(Hearing Aid 2007-)*(Dummy Upper middle income)					0.860***
					(0.150)
(Hearing Aid 2007-)*(Dummy High income)					0.493***
					(0.084)
Observations	137,376	137,376	137,376	137,376	137,376
R-squared	0.907	0.907	0.907	0.907	0.907
Sum coefficients	.715***	.711***	2.951***	.843***	3.056***
Period	1995-2016	1995-2016	1995-2016	1995-2016	1995-2016
Country-Year FE	YES	YES	YES	YES	YES
Country-Product FE	YES	YES	YES	YES	YES
% Zeroes	.28	.28	.28	.28	.28

Note: Robust standard errors, clustered at the country-product level, are in parentheses. Countries with population over 5mln.
*** p<0.01, ** p<0.05, * p<0.1

4. Synthetic Control Method (SCM)

In this section we complement the differences-in-differences analysis from the previous section with a Synthetic Control Method (SCM) first developed by Abadie and Gardeazabal (2003) and refined by Abadie et al. (2010, 2013). This method offers two main advantages over a differences-in-differences approach. First, the SCM allows for a data-driven selection process of suitable control groups. Second, the framework allows for the effect of confounding factors on the outcome variable to vary over time. The idea behind the method is to obtain for each treated unit a synthetic control by using a weighted average of untreated units to match the observable characteristics and pretreatment outcome of the treated unit. Thus, the method should be less subject to the omitted variables bias typical of a differences-in-differences estimation.

Synthetic control methods have been mostly used in the context of a single treated unit. For instance, Abadie and Gardeazabal (2003) study the economic impact of terrorism in the Basque region.[14] Billmeier and Nannicini (2013) are an early exception, they assess the impact of several episodes of economic liberalization on real GDP per capita, but do not estimate average effects. More recently, the method has been extended to multiple treatments. Cavallo et al. (2013) examine the short and long run consequences of natural disasters. While Acemoglu et al. (2016) estimate the value of political connections for all firms trading on the NYSE and Nasdaq.

The paper contributes to the SCM literature by determining the statistical significance of the treatment effects using the permutation method developed by Cavallo et al. (2013) and limiting it to 5,000 randomly drawn placebo treatment groups as in Acemoglu et al. (2016). Following Cavallo et al. (2013), we define the significance level (*p-value*) at each post treatment period *l* as

$$p\text{-}value_l = \Pr(|\bar{\alpha}_l^{PL}| \geq |\bar{\alpha}_l|) = \frac{\sum_{np=1}^{N_{\overline{PL}}} I(|\bar{\alpha}_l^{PL(np)}| \geq |\bar{\alpha}_l|)}{N_{\overline{PL}}} \tag{3}$$

where $\bar{\alpha}_l$ is the weighted average of the treatment effects of the treated units with weights being the inverse of the pre-treatment root mean squared error. As each treated unit may use different set of controls, we assign to each of these controls a random treatment in the same period as the treated unit to obtain a placebo effect. For each treated unit we then select a random placebo effect and aggregate all the selected effects using the inverse of the pre-treatment root mean squared error as weights and repeat the procedure 5,000 times.

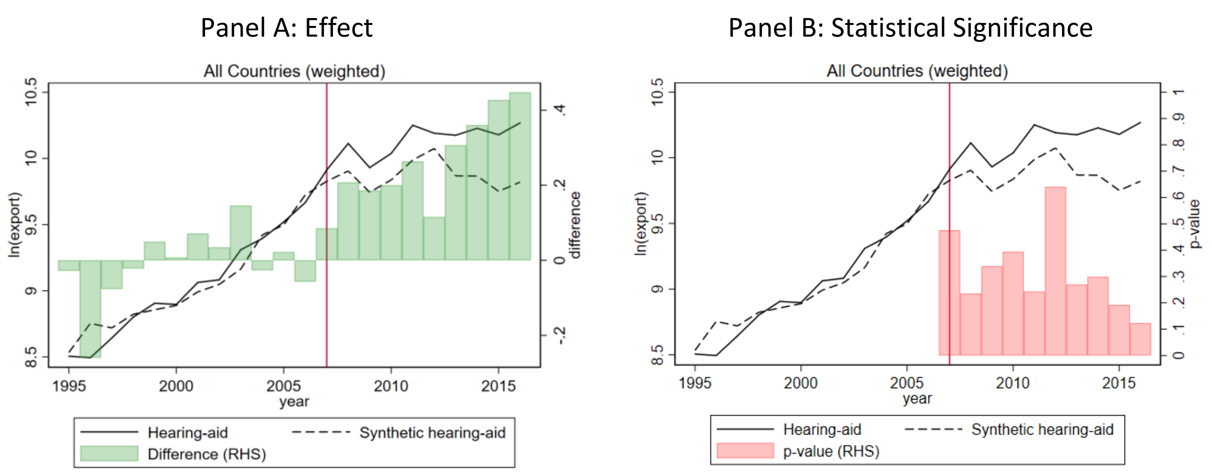
To implement the SCM analysis we need to select the pool of possible controls to use and identify the characteristics to be matched. For each country, a synthetic control is constructed using the country's exports of high-tech products within HS chapter 90. In terms of characteristics, we use lagged outcome variables: 1995, 2000, and 2005. For instance, we use a combination of German exports of high-tech sectors within chapter 90 to construct a synthetic control for exports of hearing-aids for Germany. This allows us to control for country specific time-varying shocks such as financial crises and the unemployment rate.

[14] See also Caselli (2017) who uses synthetic control methods to evaluate the impact of an exchange rate intervention on inflation in the Czech Republic.

Note that a downside of this approach is that the synthetic control method requires data for treated units over the entire sample period for matching purposes. Therefore, our sample needs to be composed of continuous exporters of hearing aids, limiting the analysis to 33 countries. To compare more clearly the results with the analysis in the previous section, Table 10 reports the results for the difference-in-difference specification used in Section 3 (equation 1) for the sample of 33 countries of the SCM analysis. As it appears from Table 10, results from this subsample of countries are not different from the results in Section 3. This suggests that potential differences between the difference-in-difference approach and the SCM analysis are not likely to be driven by the more restricted sample in the latter.

Figure 6 presents the average effect pooling all the 33 countries together. The difference between the hearing aid series and the synthetic control is directly comparable to the coefficients reported in Table 1 – as both capture the treatment effect on the logarithmic transformation of exports. First, we find 3D printing increased trade by around 56 percent in 2016.[15] The magnitude of effect is almost identical to the one estimated using a differences-in-differences approach in column 4 of Table 1. Second, we find that synthetic series mimics well hearing aid trade in the pre-treatment period. The *p-values* suggest that the effect becomes statistically significant at the 0.12 level towards the end of the period of observation.[16]

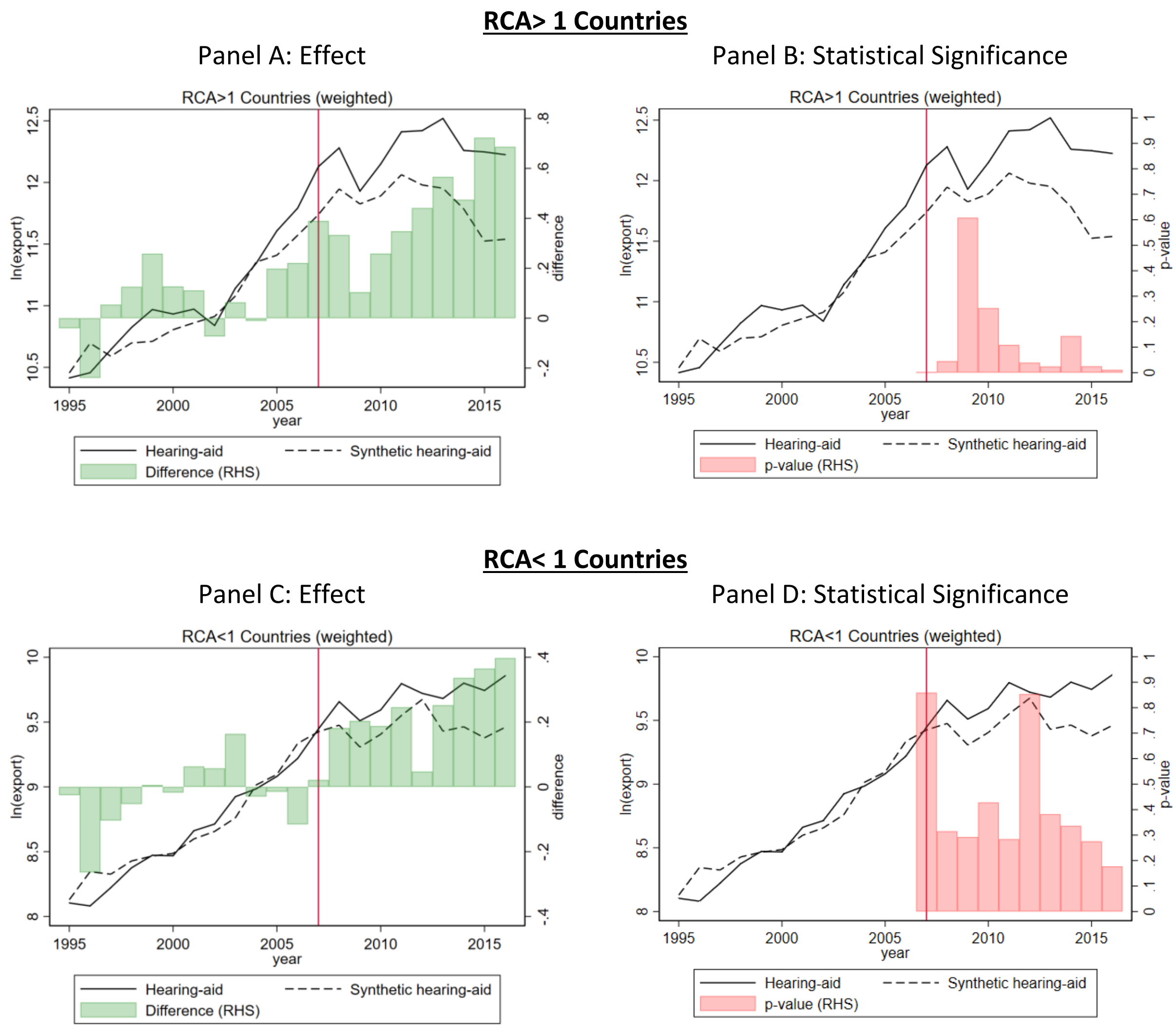
Figure 6: Effects of 3D printing on trade in hearing aids (Synthetic Control Method)



[15] In 2016, the difference between the logarithm of hearing aid trade and the synthetic control is 0.448. This implies that observed trade is 56.5 percent higher than the control: $(\exp(.448) - 1)$*100=56.5178.
[16] The *p-value* is equal to 0.12 in 2016.

To investigate the impact of 3D printing on countries with different levels of comparative advantage, we split countries into different groups according to their average RCA for the 1995-2000 period (see Appendix Table 9). Panels A and C of Figure 7 report the differences between hearing aid trade and the synthetic series. The results show that 3D printing had a stronger effect on exports of countries with a revealed comparative advantage. The differences in 2016 are almost equal to the coefficients estimated using the differences-in-differences approach. The synthetic control method suggests that 3D printing doubled the exports of countries with a comparative advantage and increased exports by 50 percent for the other countries, while the estimated impact with the differences-in-differences approach is 84 and 56 percent, respectively. Panels B and D suggest that the effect is significant only for countries with a pre-existing comparative advantage in hearing aids.

Figure 7: Effects of 3D printing on RCA in hearing aids (Synthetic Control Method)

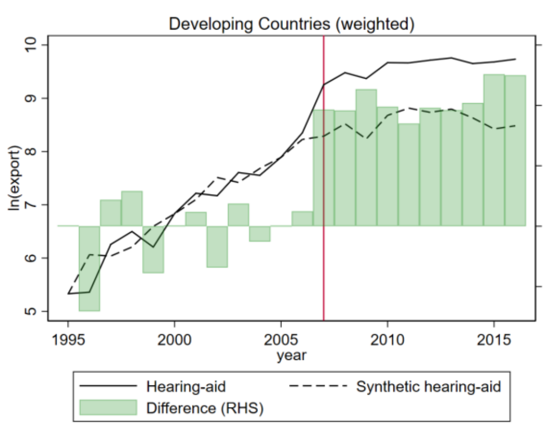


In Figure 8 we investigate the impact of 3D printing on advanced and developing countries. Results in Panels A and C show that 3D printing had a very large impact on developing countries' trade – more than twice as much as the effect on developed countries – unlike the differences-in-differences estimates. Once we use the same sample, which excludes low income economies, the magnitudes across techniques are comparable as the impact for developing economies is driven by the middle-income economies (see Table 10). Estimates of *p-value* in Panels B and C suggest that results are highly significant for developing countries, while the effect for developed countries is not significantly different from the effect of the placebo treatments.

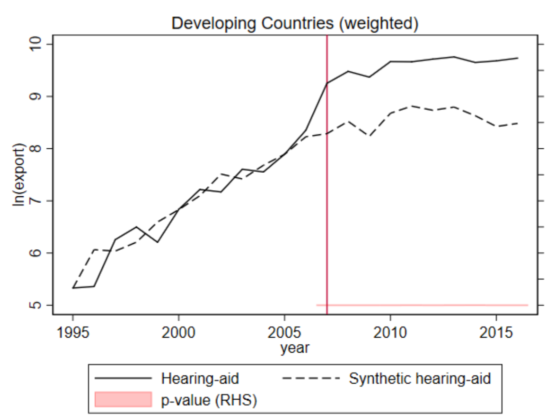
Figure 8: Effects of 3D printing on trade for countries at different levels of development (Synthetic Control Method)

Developing Countries

Panel A: Effect

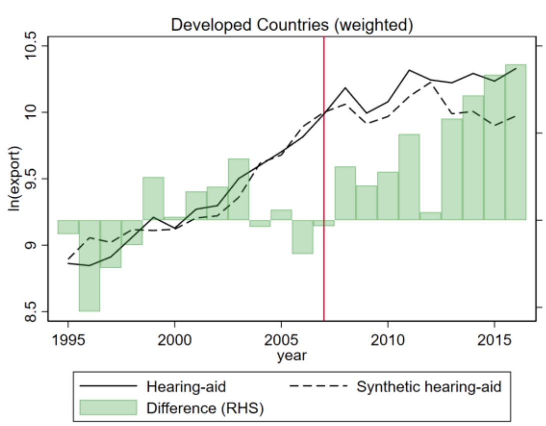


Panel B: Statistical Significance

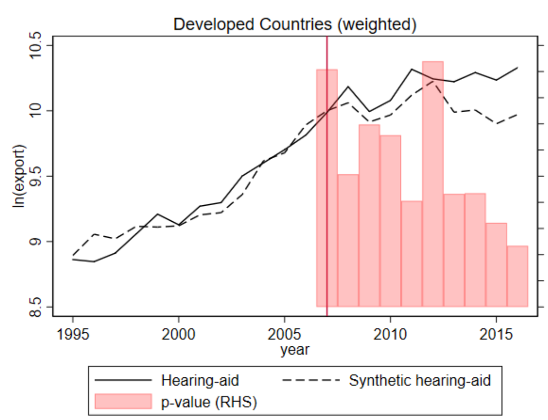


Developed Countries

Panel C: Effect



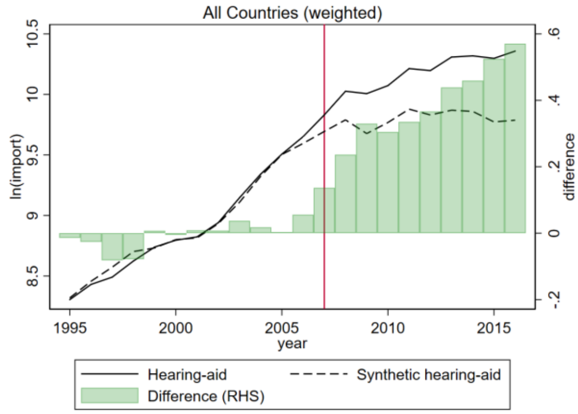
Panel D: Statistical Significance



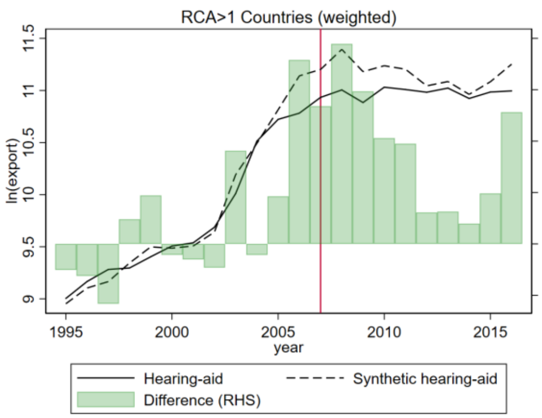
As in the previous section, we also evaluate the impact of 3D printing on imports. Figure 9 presents the results on differences between hearing-aid imports and the respective synthetic controls. The 3D printing technology is estimated to have increased imports by 77 percent in 2016 (Panel A). The increase in imports is mostly driven by an expansion in demand by countries with a relative disadvantage in hearing aids (Panel B). Both results are strongly statistically significant (Figure 10, Panels A and B). Consistently with the difference-in-difference approach, the new technology also appears to have benefited consumers in developing countries. Developed countries' imports increased by 53 percent in 2015 and 71 percent in 2016, although this effect is not consistently statistically significant, while the increase in developing countries was 116 percent in 2015 and 93 percent in 2016 and always statistically significant (Figure 9 Panel C and Figure 10 Panel C).

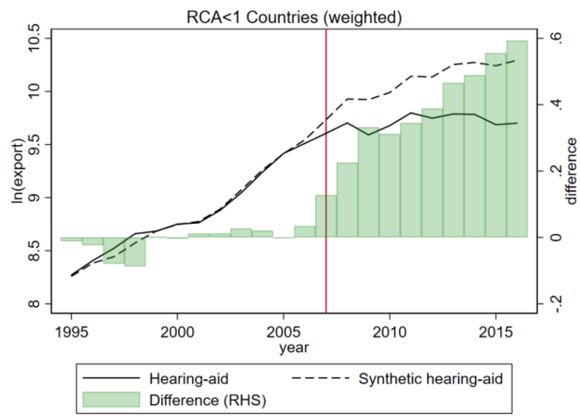
Figure 9: Effects of 3D printing on imports (Synthetic Control Method) – log difference

Panel A: Overall effects

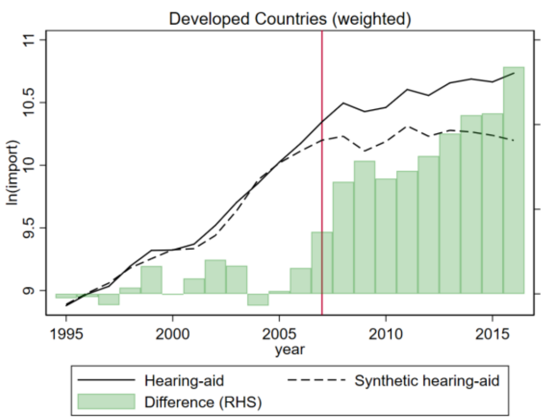


Panel B: RCA





Panel C: Development



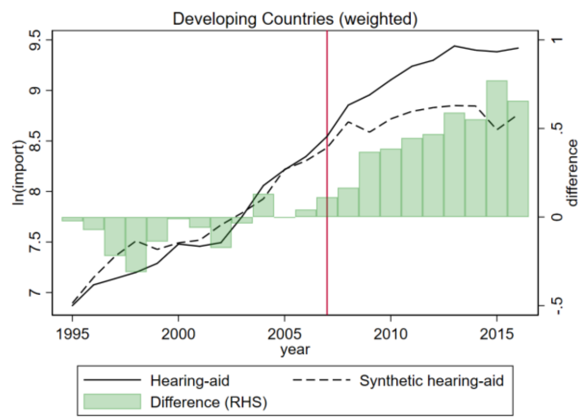
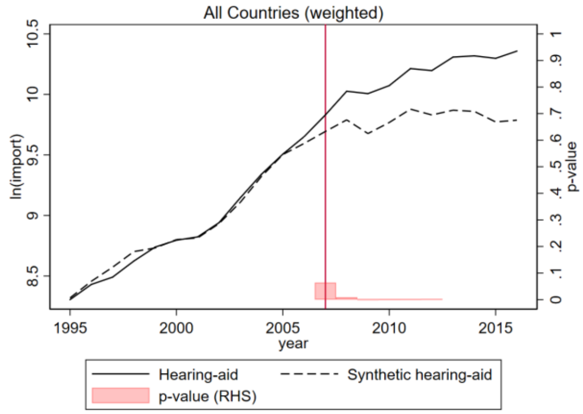
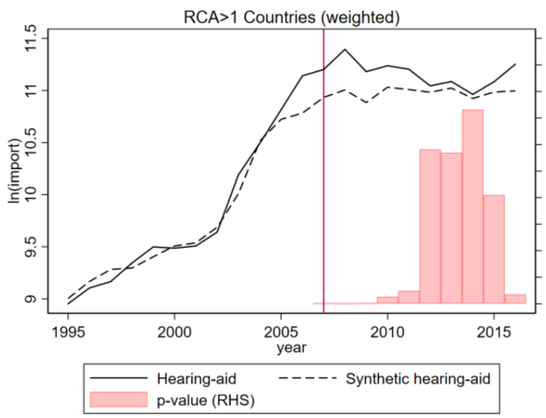


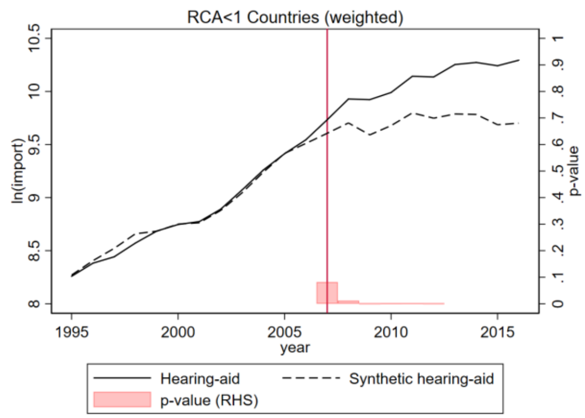
Figure 10: Effects of 3D printing on imports (Synthetic Control Method) – statistical significance

Panel A: Overall effects

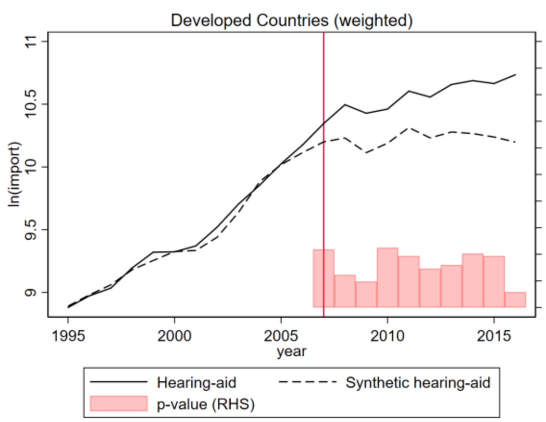


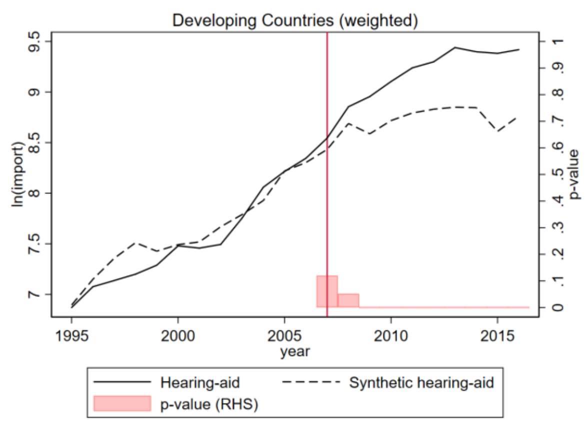
Panel B: RCA





Panel C: Development





5. Other 3D printable sectors

This section expands the differences-in-differences analysis to 3D printable sectors. Arvis et al. (2017) identify 4-digit SITC sub-groups deemed to be 3D printable in the short-medium term or that are currently 3D printable based on reviews of industry reports, websites, news articles, and interviews with industry participants (see Table 6 for the full list). Analyzing the trade impact of the new technology on these sectors allows to investigate the extent to which the results of previous sections are general and not specific to hearing aids. But there are two main limitations to using this list. First, 4-digit SITC sub-groups include a large number of products with different characteristics. For instance, within sub-group SITC 6659, "articles made of glass, n.e.s.", there are 144 products ranging from laboratory glassware to coral imitation of glass. As a result, within each sub-group there can be products that are 3D printable and products that are not. Second, there is no clear distinction between printed and printable, or any indicator on the diffusion within each sub-group. This complicates the identification of the impact of 3D printing on trade as we assume that each sector is affected by the technology in the same way and also in the same year.

As a first exercise, Table 4 presents the results on the impact of the diffusion of 3D printing on 3D printable sectors. As in the previous section, we assume that the technology became available in 2007. Column 1 confirms the positive impact of the technology on trade that was established in the previous sections. However, we find that the coefficient is sizably smaller than the ones reported in Table 1. The difference could be due to the fact that 3D printing has not yet been adopted by most of the printable industries. In other words, we are including in the treatment group units that should be used as controls which in turn biases the effects downwards.

Differently from the hearing aids example, we find that the technology decreased trade for countries that used to have a comparative advantage in 3D printable products. Similarly to the previous analysis, we find a positive impact of the new technology on exports of advance and emerging economies. Taken together, these results are suggestive of 3D printing leading to a reshuffling in comparative advantage from labor abundant / developing economies to capital abundant / advanced economies.[17] But the impact on trade growth suggests that concentration forces may be still relevant for this broader set of products. Finally, this evidence should not be interpreted as conclusive given the quality of the data used in this exercise and the uncertainty around the timing and extent of the adoption of the technology.

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[17] For instance, Adidas makes most of its shoes in Asia but its 3D printed shoes, Futurecraft 4D, come from a plant in the Bavarian town of Ansbach, Germany, or Carbon's Silicon Valley office. https://www.forbes.com/sites/andriacheng/2018/05/22/with-adidas-3d-printing-may-finally-see-its-mass-retail-potential/#562ca1454a60

Table 5: 3D printable products pooled

VARIABLES	(1) log(exports)	(2) log(exports)	(3) log(exports)	(4) log(exports)	(5) log(exports)
(3D printable 2007-)	0.059***	0.119***		0.095***	
	(0.019)	(0.021)		(0.023)	
(3D printable 2007-)*(Dummy RCA 1995-2000 > 1)		-0.390***			
		(0.046)			
(3D printable 2007-)*(Dummy Developing)				-0.051	
				(0.034)	
(3D printable 2007-)*(Dummy Low RCA 1995-2000 < 1)			0.236***		
			(0.039)		
(3D printable 2007-)*(Dummy High RCA 1995-2000 < 1)			0.051**		
			(0.023)		
(3D printable 2007-)*(Dummy Low RCA 1995-2000 > 1)			-0.194***		
			(0.053)		
(3D printable 2007-)*(Dummy High RCA 1995-2000 > 1)			-0.416***		
			(0.067)		
(3D printable 2007-)*(Dummy Low income)					-0.081
					(0.062)
(3D printable 2007-)*(Dummy Lower middle income)					0.018
					(0.040)
(3D printable 2007-)*(Dummy Upper middle income)					0.143***
					(0.038)
(3D printable 2007-)*(Dummy High income)					0.095***
					(0.023)
Observations	1,945,693	1,945,693	1,945,693	1,945,693	1,945,693
R-squared	0.869	0.869	0.869	0.869	0.869
Sum of coefficients	.059***	-.271***	-.323***	.044*	.175**
Period	1995-2016	1995-2016	1995-2016	1995-2016	1995-2016
Country-Year FE	YES	YES	YES	YES	YES
Country-Product FE	YES	YES	YES	YES	YES
% Zeroes	.27	.27	.27	.27	.27

Note: Robust standard errors, clustered at the country-product level, are in parentheses. Countries with population over 5mln.
*** p<0.01, ** p<0.05, * p<0.1

As a second exercise, we exploit product level characteristics to identify heterogenous effects of 3D printing on trade. This allows to study the extent to which the impact of 3D printing on trade in the previous sections depends on the product characteristics of hearing aids. Specifically, we investigate if product weight plays a role in the decision of localizing production closer to consumers versus concentrating the production in one location. Intuitively, for products like hearing aids that are light and hence have lower transport costs, incentives to localize production closer to consumer should be lower than for heavier products. Ideally, we would also like to identify how the impact of 3D printing on trade varies based on the interplay between economies of scale intensity and product weight. Unfortunately, data on scale elasticities is available only for a limited number of 2-digit sectors (see Bartelme, Costinot, Donaldson and Rodriguez-Clare, 2018).

To formally test for differential impacts of 3D printing on trade in heavy and light goods, we augment equation (1) by an interaction term between $I_{kt}(3Dprinting\ 2007)$ and product k's log of weight. The weight of product k is defined as the median unit weight of HS 6-digit products corresponding to a 4-digit SITC product.[18] The unit weight measure for printable sectors varies from 52 grams for spectacles (SITC 8842) to 98 kilograms for machine tools for deburring (SITC 7316). Before describing the results from this specification, it is important to stress some caveats. First there may be an aggregation bias, if some products in a category are light and others are heavy. In addition, the effects could be misidentified if weight is a determinant of technology adoption. Moreover, it is possible that the technology could affect product weight as it may allow to design new structures that are lighter and use less material.

With these caveats in mind, Figure 11 presents the results on the impact of 3D printing on exports and imports as a function of product weight. Panel A shows that the impact of 3D printing on exports decreases with product weight. Exports of lighter products such as spectacles increased the most after the technology became available while the impact becomes insignificant for heavier product such as aircraft and spacecraft parts. Results in Panel B suggest that the availability of 3D printing led to a statistically significant decrease in import of heavy printable products, mainly machineries. The results suggest that 3D printing is more likely to lead to fragmented production for products that are light and, hence, cheaper to trade. On the other hand, there is some evidence that the technology could be used to produce goods closer to consumers for products subject to high transport costs.

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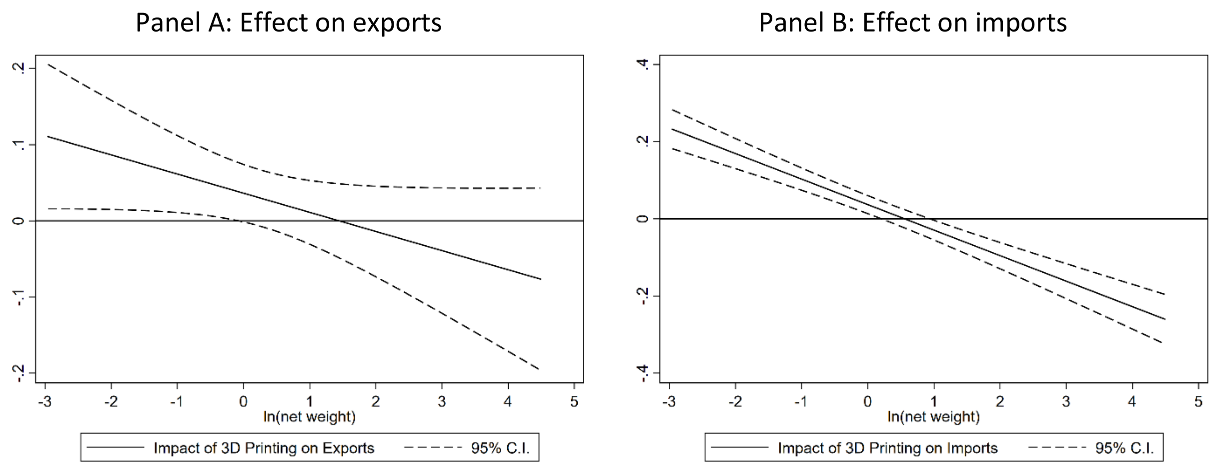
[18] We calculate unit weights with HS 6-digit data, instead of SITC 4-digit, as the information is provided on a more detailed degree of disaggregation.

Figure 11: Effects of 3D printing on trade conditional on weight



6. Conclusion

3D printing is a new technology that allows to produce customized products from a digital file. This paper takes a first look at the impact of this technology on international trade using a difference-in-difference technique and synthetic control methods. We focus on hearing aids, a product that since the mid-2000s has almost exclusively been produced employing the 3D printing technology. Contrary to what appears as conventional wisdom, we find that the new technology leads to an increase in world trade as it allows to reduce production costs. An analysis of 35 other products that are increasingly using 3D printing confirms this main insight, but also suggests that product characteristics such as bulkiness can affect the relationship between 3D printing and trade. As more information on the adoption of the new technology in different sectors becomes available, uncovering the sources of these differential trade effects of 3D printing could be a fruitful avenue for future research.

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APPENDIX

Table 6: List of High-Tech products (OECD – Eberth, 2008)

HS code	Product name
280450	Boron; tellurium
280461	Silicon containing by weight not less than 99.99% of silicon
280469	Silicon nes
280470	Phosphorus
280480	Arsenic
280490	Selenium
280521	Calcium
280522	Strontium and barium
280530	Rare-earth metals, scandium and yttrium
282520	Lithium oxide and hydroxide
282530	Vanadium oxides and hydroxides
282540	Nickel oxides and hydroxides
282550	Copper oxides and hydroxides
282560	Germanium oxides and zirconium dioxide
282570	Molybdenum oxides and hydroxides
282580	Antimony oxides
284410	Natural uranium & its compounds; mixtures cntg natural uranium/its co
284420	Uranium U235+ & its compds, plutonium & its compds, their mx & compds
284430	Uranium U235- & its compds, thorium & its compds, their mx & compds t
284440	Radio active elements & isotopes nes, their mixtures & compounds ther
284450	Spent fuel elements of nuclear reactors
284510	Heavy water (deuterium oxide)
284590	Isotopes nes and their compounds
284610	Cerium compounds
284690	Compds of rare-earth met nes, of yttrium/scandium/mx of these metals
293710	Pituitary anterior hormones and their derivatives, in bulk
293721	Cortisone, hydrocortisone, prednisone and prednisolone, in bulk
293722	Halogenated derivatives of adrenal cortical hormones, in bulk
293729	Adrenal cortical hormon nes, in blk; deriv of adren cor horm, nes, in
293791	Insulin and its salts, in bulk
293792	oestrogens and progestogens, in bulk
293799	Hormones nes & thr derivs, in bulk; steroids nes usd prim as horm, in
293810	Rutoside (rutin) and its derivatives, in bulk
293890	Glycosides & their salts, ethers, esters & other derivatives, nes, in
294110	Penicillins and their derivatives, in bulk; salts thereof
294120	Streptomycins and their derivatives, in bulk; salts thereof
294130	Tetracyclines and their derivatives, in bulk; salts thereof
294140	Chloramphenicol and its derivatives, in bulk; salts thereof
294150	Erythromycin and its derivatives, in bulk; salts thereof

HS code	Product name
294190	Antibiotics nes, in bulk
300110	Glands and other organs, dried, powdered or not, for therapeutic uses
300120	Extracts of glands/oth organs/of their secretions, for therapeutic us
300190	Heparin & its salts; human/animal substances f therap/prophltc uses,
300210	Antisera and other blood fractions
300220	Vaccines, human use
300290	Human blood; animl blood f therap, prophltc/diag uses; microbial prep
300310	Penicillins or streptomycins and their derivatives, formulated, in bu
300320	Antibiotics nes, formulated, in bulk
300331	Insulin, formulated, in bulk
300339	Hormones nes, formulatd, not cntg antibiotics, in bulk, o/t contracep
300410	Penicillins or streptomycins and their derivatives, in dosage
300420	Antibiotics nes, in dosage
300431	Insulin, in dosage
300432	Adrenal cortex hormones, in dosage
300439	Hormones nes, not containing antibiotics, in dosage, o/t contraceptiv
320411	Disperse dyes and preparations based thereon
320412	Acid and mordant dyes and preparations based thereon
320413	Basic dyes and preparations based thereon
320414	Direct dyes and preparations based thereon
320415	Vat dyes and preparations based thereon
320416	Reactive dyes and preparations based thereon
320417	Synthetic organic pigments and preparations based thereon
320419	Synthetic organic colourg matter nes, prep of syn orgn colourg matter
320420	Synthetic organic products used as fluorescent brightening agents
320490	Synthetic organic products used as luminophores
320500	Color lakes and preparations based thereon
380810	Insecticides, packaged for retail sale or formulated
380820	Fungicides, packaged for retail sale or formulated
380830	Herbicides, anti-sproutg prod & plant growth regs, packd f retail/for
380840	Disinfectants, packaged for retail sale or formulated
380890	Pesticides includg rodenticides, nes, packagd for retail sale/formula
390760	Polyethylene terephthalate
840110	Nuclear reactors
840120	Machinery and apparatus for isotopic separation and parts thereof
840130	Fuel elements (cartridges), non-irradiated, for nuclear reactors
840140	Parts of nuclear reactors
841111	Turbo-jets of a thrust not exceeding 25 KN
841112	Turbo-jets of a thrust exceeding 25 KN
841121	Turbo-propellers of a power not exceeding 1100 KW
841122	Turbo-propellers of a power exceeding 1100 KW
841181	Gas turbines nes of a power not exceeding 5000 KW
841182	Gas turbines nes of a power exceeding 5000 KW

HS code	Product name
841191	Parts of turbo-jets or turbo-propellers
841199	Parts of gas turbines nes
841210	Reaction engines nes other than turbo jets
845610	Mach-tls f work any mat by rem of mat optd by laser/lt/photo beam pro
845620	Mach-tls for work any mat by rem of mat optd by ultrasonic processes
845630	Mach-tls f work any mat by rem of mat optd by electro-discharg proces
845710	Machining centres, for working metal
845811	Horizontal lathes numerically controlled for removing metal
845891	Lathes nes numerically controlled for removing metal
845921	Drilling mches nes; numerically controlled for removing metal
845931	Boring-milling mches nes, numerically controlled for removing metal
845951	Milling mach, knee-type numerically controlled for removing metal
845961	Milling machines nes, numerically controlled for removing metal
846011	Fl-surf grindg mach in which pos of 1 axis acc to 0.01 mm n/c rem met
846021	Grindg mach in which pos of 1 axis to an acc to 0.01mm n/c f rem met
846031	Sharpening (tool or cutter grinding) mach n/c for removing metal
846040	Honing or lapping machines for removing metal
846221	Bendg foldg stgtg or flatteng mach (inc presses) n/c for workg met
846231	Shearg mach (inc presse) o/t combind punchg/shearg mach n/c f wrkg me
846241	Punchg/notchg mach (inc presse)inc comb pnch/shear mach n/c f wrkg me
846693	Parts & accessories nes for use on machines of headg No 84.56 to 84.6
846694	Parts & accessories nes for use on machines of headg No 84.62 or 84.6
847110	Analogue or hybrid automatic data processing machines
847330	Parts & accessories of automatic data processg machines & units there
851521	Electric mach/app for resistance welding of metal fully or partly aut
851531	Elec mach & app for arc (inc plasma arc) weldg of met fully/partly au
851730	Telephonic or telegraphic switching apparatus
851790	Parts of electrical apparatus for line telephone or line telegraphy
851810	Microphones and stands therefor
851821	Single loudspeakers, mounted in the same enclosure
851822	Multiple loudspeakers, mounted in the same enclosure
851829	Loudspeakers, nes
851830	Headphones, earphones and combined microphone/speaker sets
851840	Audio-frequency electric amplifiers
851850	Electric sound amplifier sets
851890	Parts of microphones, loudspeakrs, headphones, earphones & elec sound
851999	Sound reproducing apparatus, not incorporating a sound recorder, nes
852110	Video recording or reproducing apparatus magnetic tape-type
852190	Video recording or reproducing apparatus nes
852510	Transmission apparatus for radio-teleph radio-broadcastg or televisio
852520	Transmission apparatus, for radioteleph incorporatg reception apparat
852530	Television cameras
852610	Radar aparatus

HS code	Product name
852691	Radio navigational aid apparatus
852692	Radio remote control apparatus
852790	Radio reception apparatus nes
853110	Burglar or fire alarms and similar apparatus
853120	Indicator panels incorporatg liquid crystal device/light emittg diode
853180	Electric sound or visual signalling apparatus, nes
853221	Electrical capacitors, fixed, tantalum, nes
853222	Electrical capacitors, fixed, aluminium electrolytic, nes
853223	Electrical capacitors, fixed, ceramic dielectric, single layer, nes
853224	Electrical capacitors, fixed, ceramic dielectric, multilayer, nes
853400	Printed circuits
853710	Boards, panels, includg numerical control panels, for a voltage </=10
854081	Receiver or amplifier valves and tubes
854089	Valve and tubes, nes
854110	Diodes, other than photosensitive or light emitting diodes
854121	Transistors, oth than photosensit, w a dissipation rate < 1 W
854129	Transistors, other than photosensitive transistors, nes
854130	Thyristors, diacs and triacs, other than photosensitive devices
854140	Photosensitive semiconduct device, photovoltaic cells & light emit di
854150	Semiconductor devices, nes
854160	Mounted piezo-electric crystals
854190	Parts of mounted piezo-electric crystals and semiconductor devices
854219	Monolithic integrated circuits, nes
854290	Parts of electronic integrated circuits and microassemblies
854320	Signal generators
854330	Machines & apparatus for electroplating, electrolysis or electrophore
854390	Parts of electrical machines & apparatus havg individual functions, n
854470	optical fibre cables, made up of individually sheathed fibres
871000	Tanks and other armored fighting vehicles, motorised, and parts
880211	Helicopters of an unladen weight not exceeding 2, 000 kg
880212	Helicopters of an unladen weight exceeding 2, 000 kg
880220	Aircraft nes of an unladen weight not exceeding 2, 000 kg
880230	Aircraft nes of an unladen weight > 2, 000 kg but not exceedg 15, 000
880240	Aircraft nes of an unladen weight exceeding 15, 000 kg
880310	Aircraft propellers and rotors and parts thereof
880320	Aircraft under-carriages and parts thereof
900110	optical fibs, optical fib bundles & cables, oth than those of headg 8
900120	Sheets and plates of polarizing material
900130	Contact lenses
900190	Prisms, mirrors & other optical elements of any material, unmounted,
900510	Binoculars
900580	Monoculars, other optical telescopes, astronomical inst & mountings,
900610	Cameras of a kind used for preparing printing plates or cylinders

HS code	Product name
900620	Cameras of a kind used for recordg doc on microfilm or oth microforms
900630	Cameras designed for special use, underwater, aerial survey, etc
900640	Instant print cameras
900711	Cinema cameras f film of less than 16 mm width/for double-8 mm film
900719	Cinematographic cameras, nes
900911	Electrostatic photo-copying apparatus, direct process type
900912	Electrostatic photo-copying apparatus, indirect process type
900921	Photo-copying apparatus, incorporating an optical system, nes
900922	Contact type photo-copying apparatus, nes
901110	Stereoscopic microscopes
901120	Microscopes, for microphotography, microcinematography o microproject
901180	Microscopes, optical, nes
901190	Parts and accessories for optical microscopes
901210	Microscopes other than optical microscopes and diffraction apparatus
901290	Parts and accessories for microscopes other than optical microscopes
901320	Lasers, other than laser diodes
901380	optical devices, appliances and instruments, nes, of this Chapter
901410	Direction finding compasses
901420	Instruments & appl f aeronautical/space navigation (oth thn compasses
901480	Navigational instruments and appliances nes
901490	Parts & access for direction findg compasses & other navigational ins
901510	Rangefinders
901520	Theodolites and tacheometers
901530	Surveying levels
901540	Photogrammetrical surveying instruments and appliances
901580	Surveyg, hydrographic, oceanographic, meteorologic/geophysical inst n
901590	Parts and accessories for use with the apparatus of heading No 90.15
901600	Balances of a sensitivity of 5 cg or better with or without weights
901841	Dental drill engines, whether o not combi on a single base w oth equi
902111	Artificial joints
902119	Orthopaedic or fracture appliances, nes
902130	Artificial parts of the body, nes
902140	Hearing aids, excluding parts and accessories
902150	Pacemakers for stimulating heart muscles, excluding parts & accessori
902230	X-ray tubes
902300	Instruments, apparatus and models, designed for demonstrational purpo
902410	Machines & appliances for testing the mechanical properties of metals
902480	Machines & appliances f testg the mechanical properties of oth materi
902490	Parts & accessories of mach & appl for testg mech properties of mater
902511	Thermometers, not combined with other instruments, liquid-filled
902519	Thermometers, not combined with other instruments, nes
902580	Hydrometers, pyrometers, hygrometers & psychrometers, recordg or not,
902590	Parts and accessories for use with the apparatus of heading No 90.25

HS code	Product name
902610	Instruments & apparatus for measurg o checkg the flow o level of liqu
902620	Instruments and apparatus for measuring or checking pressure
902680	Instruments & apparatus for measurg o check variables of liq o gases,
902690	Parts of inst & app for measurg or checkg variables of liq or gases,
902710	Gas or smoke analysis apparatus
902720	Chromatographs and electrophoresis instruments
902730	Spectrometers, spectrophotometers & spectrographs usg optical radiati
902740	Exposure meters
902750	Instruments and apparatus using optical radiations (UV, visible, IR),
902780	Instruments and apparatus for physical or chemical analysis, nes
902790	Microtomes; parts & access of inst & app for physical or chem analysi
903010	Instruments & apparatus for measuring or detecting ionising radiation
903020	Cathode-ray oscilloscopes and cathoderay oscillographs
903031	Multimeters
903039	Inst & app, for measurg or checkg voltage, current, etc w/o a record
903040	Instruments & apparatus, specially designed for telecommunications ne
903089	Instruments & apparatus for measurg or checkg electrical quantities n
903090	Parts & access for inst & app for meas or checkg electrical quantitie
903210	Thermostats
903220	Manostats
903281	Hydraulic or pneumatic automatic regulating or controlling inst & app
903289	Automatic regulating or controlling instruments and apparatus, nes
903290	Parts & access for automatic regulatg or controllg instruments & app,
903300	Parts & access nes for machines, appliances, inst or app of Chapter 9
930100	Military weapons, other than revolvers, pistols & arms of headg No 93
930200	Revolvers and pistols, other than those of heading No 93.03 or 93.04
930310	Muzzle-loading firearms
930320	Shotguns incl combination shotgun-rifles sporting, huntg/target-shoot
930330	Rifles, sporting, hunting or targetshooting, nes
930390	Firearms & sim devices operatd by the firg of an explosive charge nes
930400	Arms nes, excluding those of heading No 93.07
930510	Parts & accessories of revolvers or pistols of headg Nos 93.01 to 93.
930521	Shotgun barrels of heading No 93.03
930529	Parts and accessories of shotguns or rifles, nes of heading No 93.03
930590	Parts and accessories nes of heading Nos 93.01 to 93.04
930610	Cartridges f rivetg/sim tools/for captive-bolt humane killers incl pt
930621	Cartridges, shotgun
930629	Air gun pellets and parts of shotgun cartridges
930630	Cartridges nes and parts thereof
930690	Munitions of war & pts thereof & other ammunitions & projectiles & pt
930700	Swords, cutlasses, bayonets, lances & sim arms & parts, scabbards & s

Table 7: Major products that are currently 3D printed or likely to be 3D printable

SITC-4	SITC Revision 3/4 Product Description
5817	Fittings for tubes, pipes & hoses (e.g., joints, elbows, flanges), of plastics
6637	Refractory ceramic goods (e.g., retorts, crucibles, muffles, nozzles, plugs, supports, cupels, tubes, pipes, sheaths & rods), n.e.s.
6639	Articles of ceramic materials, n.e.s.
6652	Glassware of a kind used for table, kitchen, toilet, office, indoor decoration or similar purposes
6659	Articles made of glass, n.e.s.
6768	Angles, shapes and sections (excluding rails) and sheet piling, of iron or steel
6827	Copper tubes, pipes and tube or pipe fittings (e.g., couplings, elbows, sleeves)
6951	Hand tools, the following: spades, shovels, mattocks, picks, hoes, forks & rakes; axes, billhooks & similar hewing tools; secateurs & pruners of any kind; scythes, sickles, hay knives, hedge shears, timber wedges & other tools
6953	Spanners & wrenches, hand-operated (including torque meter wrenches but not including tap wrenches); interchangeable spanner sockets, with/without handles.
6956	Knives and cutting blades, for machines or for mechanical appliances; interchangeable tools for hand tools or for machine tools; plates, sticks, tips and the like for tools
7119	Parts for the boilers and auxiliary plant of subgroups 711.1 and 711.2
7128	Parts for the turbines of subgroup 712.1
7249	Parts for the machines of subgroups 724.7 and 775.1
7259	Parts of the machines of group 725
7272	Other food-processing machinery and parts thereof, n.e.s.
7316	Machine tools for deburring, sharpening, grinding, honing, lapping, polishing or otherwise finishing metal, sintered metal carbides or cermets by means of grinding stones, abrasives or polishing products (other than gear-cutting, gear-grinding
7438	Parts for the pumps, compressors, fans & hoods of subgroups 743.1 & 743.4
7499	Machinery parts, not containing electrical connectors, insulators, coils, contacts or other electrical features, n.e.s.
8721	Dental instruments and appliances, n.e.s.
8842	Spectacles and spectacle frames
8939	Articles of plastics, n.e.s.
8991	Articles and manufactures of carving or moulding materials, n.e.s.
8992	Artificial flowers, foliage and fruit and parts thereof; articles made of artificial flowers, foliage or fruit
8993	Candles; matches, pyrophoric alloys, articles of combustible materials; smokers requisites
7491	Moulding Boxes
7149	Parts of the engines and motors (SITC-4:
8721	Dental instruments and appliances, n.e.s.
5413	Antibiotics and Medicines
5421	Antibiotics and Medicines
5429	Antibiotics and Medicines
7929	Aircraft and Spacecraft Parts
8512	Footwear and Insoles
8513	Footwear and Insoles
8519	Footwear and Insoles
8996	Orthopedic Devices (hearing aids)

Table 8: WB income classification

Country Name	World Bank Income Group	**Country Name**	World Bank Income Group
Afghanistan	Low income	Australia	High income
Benin	Low income	Austria	High income
Burkina Faso	Low income	Belgium	High income
Burundi	Low income	Canada	High income
Chad	Low income	Chile	High income
Ethiopia	Low income	Czech Republic	High income
Guinea	Low income	Denmark	High income
Haiti	Low income	Finland	High income
Korea, Dem. People's Rep.	Low income	France	High income
Madagascar	Low income	Germany	High income
Malawi	Low income	Greece	High income
Mali	Low income	Hong Kong SAR, China	High income
Mozambique	Low income	Hungary	High income
Nepal	Low income	Israel	High income
Niger	Low income	Italy	High income
Rwanda	Low income	Japan	High income
Senegal	Low income	Korea, Rep.	High income
Sierra Leone	Low income	Netherlands	High income
Somalia	Low income	Norway	High income
South Sudan	Low income	Poland	High income
Tanzania	Low income	Portugal	High income
Togo	Low income	Saudi Arabia	High income
Uganda	Low income	Singapore	High income
Zimbabwe	Low income	Slovak Republic	High income
Angola	Lower middle income	Spain	High income
Bangladesh	Lower middle income	Sweden	High income
Bolivia	Lower middle income	Switzerland	High income
Cambodia	Lower middle income	United Arab Emirates	High income
Cameroon	Lower middle income	United Kingdom	High income
Congo, Rep.	Lower middle income	United States	High income
Côte d'Ivoire	Lower middle income		
Egypt, Arab Rep.	Lower middle income		
El Salvador	Lower middle income		
Ghana	Lower middle income		
Guatemala	Lower middle income		
Honduras	Lower middle income		
India	Lower middle income		
Indonesia	Lower middle income		
Jordan	Lower middle income		
Kenya	Lower middle income		
Kyrgyz Republic	Lower middle income		
Lao PDR	Lower middle income		
Morocco	Lower middle income		
Myanmar	Lower middle income		
Nicaragua	Lower middle income		
Nigeria	Lower middle income		
Pakistan	Lower middle income		
Papua New Guinea	Lower middle income		
Philippines	Lower middle income		

Country Name	World Bank Income Group	**Country Name**	World Bank Income Group
Sri Lanka	Lower middle income		
Sudan	Lower middle income		
Syrian Arab Republic	Lower middle income		
Tajikistan	Lower middle income		
Tunisia	Lower middle income		
Ukraine	Lower middle income		
Uzbekistan	Lower middle income		
Vietnam	Lower middle income		
Yemen, Rep.	Lower middle income		
Zambia	Lower middle income		
Algeria	Upper middle income		
Argentina	Upper middle income		
Azerbaijan	Upper middle income		
Belarus	Upper middle income		
Brazil	Upper middle income		
Bulgaria	Upper middle income		
China	Upper middle income		
Colombia	Upper middle income		
Cuba	Upper middle income		
Dominican Republic	Upper middle income		
Ecuador	Upper middle income		
Iran, Islamic Rep.	Upper middle income		
Iraq	Upper middle income		
Kazakhstan	Upper middle income		
Lebanon	Upper middle income		
Libya	Upper middle income		
Malaysia	Upper middle income		
Mexico	Upper middle income		
Paraguay	Upper middle income		
Peru	Upper middle income		
Romania	Upper middle income		
Russian Federation	Upper middle income		
Serbia	Upper middle income		
South Africa	Upper middle income		
Thailand	Upper middle income		
Turkey	Upper middle income		
Turkmenistan	Upper middle income		
Venezuela, RB	Upper middle income		

Table 9: Continuous Exporters of Hearing Aids SCM Sample

	Developing	RCA>1
Australia	0	1
Austria	0	1
Brazil	1	0
Canada	0	0
China	1	0
Czech Republic	0	0
Denmark	0	1
Finland	0	0
France	0	0
Germany	0	0
Greece	0	0
Hong Kong SAR, China	0	0
Hungary	0	0
India	1	0
Israel	0	0
Italy	0	0
Japan	0	0
Korea, Rep.	0	0
Malaysia	1	0
Mexico	1	0
Netherlands	0	0
Norway	0	0
Portugal	0	0
Russian Federation	1	0
Saudi Arabia	0	0
Singapore	0	1
South Africa	1	0
Spain	0	0
Sweden	0	0
Switzerland	0	1
United Arab Emirates	0	0
United Kingdom	0	0
United States	0	0

Table 10: Difference-in-difference with Synthetic Control Methods Sample (33 Countries)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Sector control	same_2dg	same_2dg	same_2dg	same_2dg	same_2dg	hightech	hightech	hightech	hightech	hightech	hightech_2dg	hightech_2dg	hightech_2dg	hightech_2dg	hightech_2dg
VARIABLES	log(exports)	log(exports)	log(exports)	log(exports)	log(exports)	log(exports)	log(exports)	log(exports)	log(exports)	log(exports)	log(exports)	log(exports)	log(exports)	log(exports)	log(exports)
(Hearing Aid 2007-)	0.782***	0.786***		0.532***		0.764***	0.765***		0.497***		0.676***	0.688***		0.446**	
	(0.176)	(0.205)		(0.185)		(0.174)	(0.203)		(0.179)		(0.171)	(0.198)		(0.186)	
(Hearing Aid 2007-)*(Dummy RCA 1995-2000 > 1)		-0.028					-0.007					-0.078			
		(0.260)					(0.259)					(0.283)			
(Hearing Aid 2007-)*(Dummy Developing)				1.177***					1.258***					1.085***	
				(0.305)					(0.292)					(0.277)	
(Hearing Aid 2007-)*(Dummy Low RCA 1995-2000 < 1)			2.151***					2.069***					1.906***		
			(0.115)					(0.088)					(0.121)		
(Hearing Aid 2007-)*(Dummy High RCA 1995-2000 < 1)			0.735***					0.717***					0.643***		
			(0.207)					(0.205)					(0.200)		
(Hearing Aid 2007-)*(Dummy Low RCA 1995-2000 > 1)			0.964***					0.952***					0.851***		
			(0.149)					(0.161)					(0.190)		
(Hearing Aid 2007-)*(Dummy High RCA 1995-2000 > 1)			0.448***					0.467***					0.248		
			(0.167)					(0.180)					(0.262)		
(Hearing Aid 2007-)*(Dummy Low income)					-					-					-
(Hearing Aid 2007-)*(Dummy Lower middle income)					0.837***					0.758***					0.741***
					(0.102)					(0.081)					(0.125)
(Hearing Aid 2007-)*(Dummy Upper middle income)					1.854***					1.921***					1.662***
					(0.235)					(0.200)					(0.192)
(Hearing Aid 2007-)*(Dummy High income)					0.532***					0.497***					0.446**
					(0.185)					(0.179)					(0.186)
Observations	105,989	105,989	105,989	105,989	105,989	170,446	170,446	170,446	170,446	170,446	52,089	52,089	52,089	52,089	52,089
R-squared	0.861	0.861	0.861	0.861	0.861	0.852	0.852	0.852	0.852	0.852	0.867	0.867	0.867	0.867	0.867
Sum coefficients	.782***	.757***	4.298***	1.709***	3.223***	.764***	.758***	4.205***	1.755***	3.176***	.676***	.609***	3.647***	1.531***	2.849***
Period	1995-2016	1995-2016	1995-2016	1995-2016	1995-2016	1995-2016	1995-2016	1995-2016	1995-2016	1995-2016	1995-2016	1995-2016	1995-2016	1995-2016	1995-2016
Country-Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Country-Product FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
% Zeroes	.4	.4	.4	.4	.4	.44	.44	.44	.44	.44	.37	.37	.37	.37	.37

Note: Robust standard errors, clustered at the country-product level, are in parentheses. Countries with population over 5mln.
*** p<0.01, ** p<0.05, * p<0.1

Table 11: 3D printable products – Imports

VARIABLES	(1) log(imports)	(2) log(imports)	(3) log(imports)	(4) log(imports)	(5) log(imports)
(3D printable 2007-)	0.033***	0.020		0.051***	
	(0.012)	(0.013)		(0.015)	
(3D printable 2007-)*(Dummy RCA 1995-2000 > 1)		0.081***			
		(0.027)			
(3D printable 2007-)*(Dummy Developing)				-0.027	
				(0.022)	
(3D printable 2007-)*(Dummy RCA 1995-2000 << 1)			0.013		
			(0.024)		
(3D printable 2007-)*(Dummy RCA 1995-2000 < 1)			0.025		
			(0.015)		
(3D printable 2007-)*(Dummy RCA 1995-2000 > 1)			0.115***		
			(0.026)		
(3D printable 2007-)*(Dummy RCA 1995-2000 >> 1)			0.074		
			(0.048)		
(3D printable 2007-)*(Dummy Low income)					-0.031
					(0.039)
(3D printable 2007-)*(Dummy Lower middle income)					0.029
					(0.024)
(3D printable 2007-)*(Dummy Upper middle income)					0.055**
					(0.024)
(3D printable 2007-)*(Dummy High income)					0.051***
					(0.015)
Observations	1,965,467	1,965,467	1,965,467	1,965,467	1,965,467
R-squared	0.908	0.908	0.908	0.908	0.908
Sum coefficients	.033***	.101***	.227***	.024	.104*
Period	1995-2016	1995-2016	1995-2016	1995-2016	1995-2016
Country-Year FE	YES	YES	YES	YES	YES
Country-Product FE	YES	YES	YES	YES	YES
SITC 2dg-Year FE	NO	NO	NO	NO	NO
% Zeroes	.26	.26	.26	.26	.26

Note: Robust standard errors, clustered at the country-product level, are in parentheses. Countries with population over 5mln.
*** p<0.01, ** p<0.05, * p<0.1