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3D PRINTING AND INTERNATIONAL TRADE

WHAT IS THE EVIDENCE TO DATE?

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3D printing and International Trade: What is the evidence to date?

Andrea Andrenelli and Javier López-González

3D printing technologies have attracted the attention of the trade policy community for their potential to disrupt international trade. It is argued that greater cross-border exchange in design files for local printing may lead to less trade in physical goods. New evidence presented in this paper suggests quite the opposite: that the adoption of 3D printing technologies, proxied by measures of imports of 3D printers, appears to be complementary to goods trade. On average, an increase of around USD 14 000 in imports of 3D printers is associated with a USD 3.3 million increase in the value of exports of 3D printable goods. Similar dynamics are found for imports of 3D printable goods. Overall, this implies that the wider adoption of the technology has, at present, limited implications for the ongoing debate on the renewal of the WTO Moratorium on customs duties on electronic transmissions as it is unlikely to result in loss of goods trade and traditional tariff revenue.

Keywords: Additive manufacturing; system GMM; WTO Moratorium; electronic transmissions; digital trade; 3D printable goods

JEL codes: F13, F14, O33

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Key messages

What is the issue?

3D printing technologies have attracted the attention of the trade policy community for their potential to disrupt international trade. It is argued that greater cross-border exchange in design files for local printing may lead to less trade in physical goods. However, the nature and capabilities of 3D printing technologies are not well understood, and actual evidence on its impact remains scarce. This paper aims to contribute to the nascent empirical literature in this field by i) providing a technical review of existing capabilities of 3D printing technologies and relating these to possible trade outcomes; ii) highlighting what existing data can tell us about current trends in global adoption; and iii) empirically identifying some of the linkages between the use of 3D printing technologies and trade in 3D printable goods.

What are the key messages?

- 3D printing is a versatile technology with many potential applications across a range of specific tasks and sectors (from parts and components in the aerospace industry to architecture, healthcare and food). The technology has also played a role during COVID-19 in strengthening the resilience of value chains, including for medical products and manufacturing parts.
- While 3D printing may transform specific industries, it is unlikely to have large-scale and cross-sector implications for international trade over the short to medium term. This is because the scope of products that can be 3D printed remains limited. Moreover, cost, speed and quality advantages of traditional manufacturing, including economies of scale, are likely to remain for a large number of products.
- Measuring trade in 3D printers, 3D printable goods and the materials used in 3D printing processes is complex. However, looking at proxy measures suggests that, while the international adoption of 3D printing is growing, trade in 3D printable goods has generally kept pace with total trade. This indicates that there is little prima facie evidence that the adoption of 3D printing is replacing goods trade.
- The econometric analysis reveals that there is a positive and statistically significant relationship between proxy measures of imports of 3D printers and exports of 3D printable products. A 1% increase in the value of imports of 3D printers corresponds to a +0.02% increase in the value of exports of 3D printable items. While this coefficient may look small, in dollar terms it implies that, all else equal and evaluated at the mean, an increase of around USD 14 000 in imports of 3D printers (as proxied by an above average unit-value measure) is associated with an increase of about USD 3.3 million in the aggregate value of 3D printable exports. The impact is higher for more complex items like orthopaedic appliances, aircraft parts, medications and machine parts, and is significant for developing countries. Similar dynamics are found with respect to imports of 3D printable goods. This provides evidence of trade complementarities between 3D printing adoption and trade in goods.

What does this mean for policy makers?

3D printing can act as a “factory in a box”, giving access to productivity and scope enhancing manufacturing capabilities, allowing firms to increase their competitiveness and product offering. Existing evidence suggests that it is premature to say that the technology will ‘replace’ international trade. Not only is there little evidence of this happening to date, but the relationship between the technology and international trade is likely to be multifaceted, including through positive impacts on trade in raw materials (e.g. plastic filament, metal powders) and in design services. Although policy-makers are advised to think about 3D printing as a productivity enhancing technology, it will be important to continue monitoring progress in adoption to better understand the longer term consequences of the technology.

The paper shows that concerns raised under the debate on the renewal of the Moratorium on Customs Duties on Electronic Transmissions might be premature. The results presented point to a complementary relationship between the technology and goods trade, implying that wider adoption might even lead to increases in the value of goods crossing borders in the short run.

1. Introduction

3D printing (or additive manufacturing – AM)[1] has attracted the attention of the trade policy community for its potential to significantly affect international trade. However, evidence on the actual impact of the technology remains scarce, in part because the nature and capabilities of additive manufacturing are still not well understood. Indeed, while additive manufacturing has clear potential to cause disruption across a wide range of specific applications, its overall impact on trade can easily be overstated, particularly in the short to medium-term.

Against this backdrop, this paper provides an analysis of the likely implications of 3D printing technologies for trade and trade-related policies. The ultimate aim is to help policy makers better understand the technology to allow them to take advantage of the opportunities that 3D printing can offer, while preparing for potential challenges.

To this end, this paper is organised as follows. The next section reviews the engineering and business literature to provide an overview of the technical characteristics of the technology, exploring how these might relate to potential changes in trade patterns. Section 3 draws on available proxy measures to map different aspects of the evolving international 3D printing landscape. Section 4 then provides an empirical analysis of the links between 3D printing and international trade, focusing on how access to 3D printing technology via imports can affect trade in 3D printable products. A last section discusses emerging trade policy implications.

It is worth noting that, ultimately, the impact of 3D printing on trade will depend not only on the speed of uptake, but also on how the technology evolves and diffuses and how it changes existing business models – issues which are hard to establish ex-ante. That said, policy discussions on digital trade and 3D printing are ongoing, largely in an empirical vacuum. In this context, this paper aims to increase the evidence base, providing an updated understanding of existing capabilities and adoption that can be used to feed into ongoing discussions, informing policy makers about potential impacts.

[1] In this report, the terms 3D printing and additive manufacturing are used interchangeably. In technical terms, 3D printing can be seen as referring specifically to techniques involving 3D printers, while 'additive manufacturing' more generally differentiates the production technique from traditional manufacturing, which is subtractive (i.e. materials are removed to obtain the object) (Cavedagna and Lamperti, 2017[14]).

2. What do we know about 3D printing technology and trade?

3D printing refers to a manufacturing process that operates through the successive super-imposition of layers of materials (e.g. plastics, metals) to produce goods from 3D model data (computer aided design (CAD) files) using a 3D printer.[2] Given its potential to disrupt manufacturing processes, the implications of 3D printing have been the subject of wide speculation. Indeed, some have argued that 3D printing has the potential to replace as much as 22% of world trade by 2060 (Leering, 2017[1]).[3] Others have provided more conservative estimates, suggesting that it might replace between 1 and 2% of physical trade by 2030 (McKinsey Global Institute, 2019[2]). By contrast, it has also been argued that 3D printing adoption could increase trade. For instance, in the medical technology industry, the wider use of 3D printing technology has been found to increase exports of hearing aids by 58% (Freund, Mulabdic and Ruta, 2019[3]).

The wide differences in these estimates reflect the degree of uncertainty about the nature and evolution of the technology.[4] Indeed, relatively little is still known about the challenges and opportunities that 3D printing raises for trade.[5] Understanding the nature and evolution of 3D printing technologies is key to assessing their possible implications for trade and trade-policy. To this end, this section reviews key aspects of the technology, highlighting the technical determinants of the potential impact of additive manufacturing on trade.

2.1. What is it, how does it work? The main characteristics of 3D printing technology

Debates on the potential impact of 3D printing technology rarely distinguish between the different technologies, manufacturing processes and modalities of adoption that underpin 3D printing. Instead, they consider 3D printing as a homogenous technology. However, the *what* and the *how* of 3D printing are central to understanding the potential impact it may have on trade. The next section reviews the *what* of 3D printing technologies identifying what they are and what they are currently being used for.

There are many different 3D printing technologies

While additive manufacturing processes all share the feature of producing objects layer upon layer from 3D model data, they differ significantly in the methods they employ.

- Most widespread is **material extrusion**, traditionally associated with Fused Deposition Modelling (FDM). This involves materials (e.g. thermoplastics) being selectively dispensed through a nozzle to create an object through the superposition of layers (Figure 1a).
- **Powder bed fusion**, associated with Selective Laser Sintering (SLS), is also a commonly used technique. Here, thermal energy is used to selectively fuse regions of a powder bed composed of

[2] For a technical definition of additive manufacturing: “[it is] a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies, such as traditional machining” (ASTM International, 2012[5]).

[3] This is based on the assumption that, since 3D printing allows for the production of objects from a digital file, design files would be transferred across borders and substitute for the goods themselves, leading to the replacement of physical trade with digital trade. The estimate has been recently revised to -4.5% of global trade by 2040 (Leering, 2017[1]; Leering, 2021[52]).

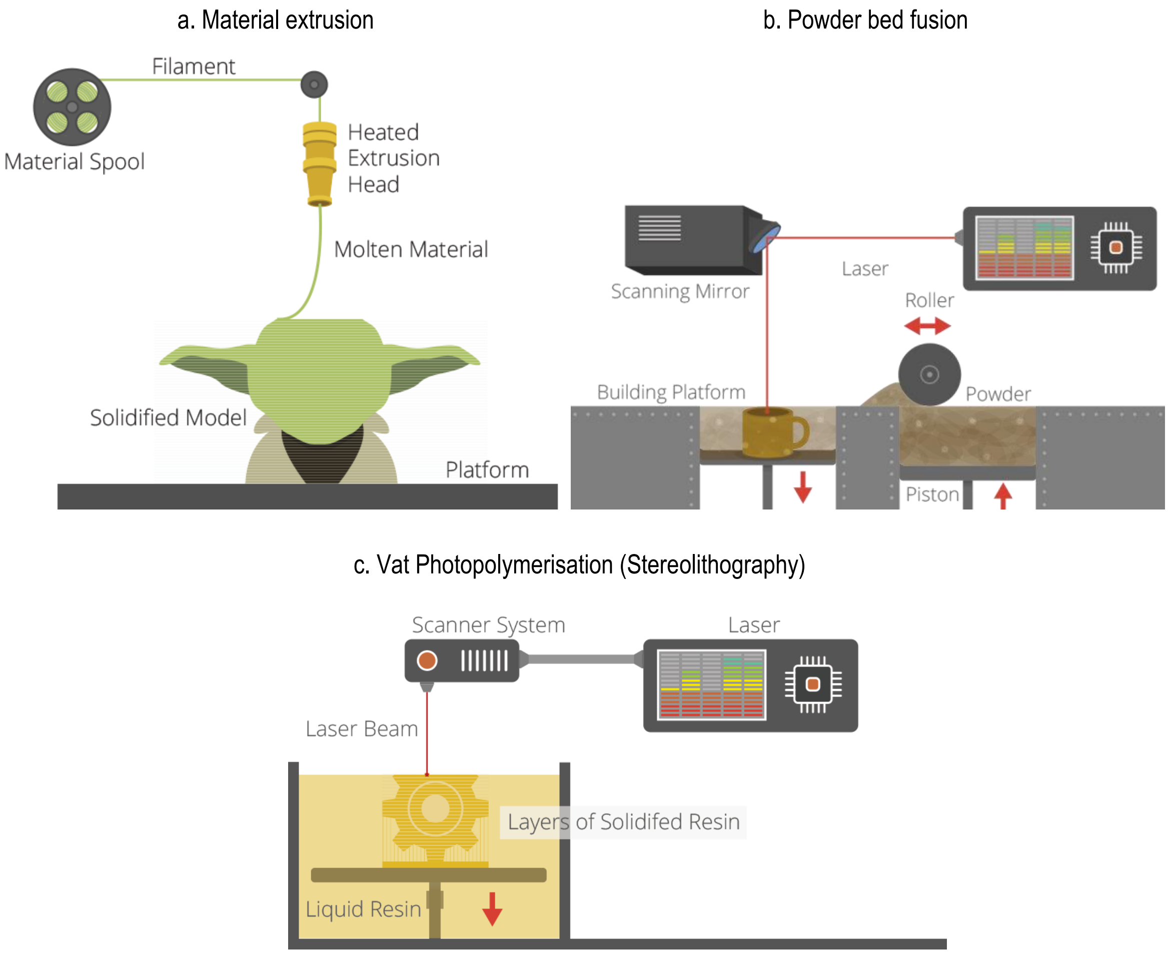
[4] As well as considerable differences in the methods used for capturing the impact of the technology.

[5] The Swedish National Board of Trade (2016[87]) provided an early and insightful analysis of the implications of 3D printing for trade.

materials such as polymers or metals. This is then lowered to allow for the superposition of another layer of powder, again, fused using a laser with the object in-the-making (Figure 1b).

- Another popular 3D printing technology is **stereolithography**, a type of vat Photopolymerisation technique credited as the first 3D printing process to be commercialised (Box 1). This process uses liquid resin and ultraviolet light to harden specific parts, creating solid elements of an object. A platform helps move the object after superimposition of layers (Figure 1c).

Figure 1. Examples of 3D printing techniques



Source: (3D Printing Industry, 2021[4]).

Overall, there are seven broad categories of additive manufacturing technologies, each using different machines and having different material requirements (ASTM International, 2012[5]; Loughborough university, 2021[6]) (Table 1). The processes and manufacturing techniques they rely on are markedly different from more traditional manufacturing methods such as *injection moulding,* which involves injecting heated plastics, rubber or metals into moulds, or *subtractive manufacturing,* which includes shaping or removing materials from solid items by boring, cutting, drilling or grinding (see World Economic Forum (2020[7])).

Table 1. Seven categories of additive manufacturing

Technology	What is it?
Material extrusion	Fuse deposition modelling (FDM) is a common material extrusion process and is trademarked by the company Stratasys. Material is drawn through a nozzle, where it is heated and is then deposited layer by layer. The nozzle can move horizontally and a platform moves up and down vertically after each new layer is deposited.
Material jetting	Material jetting creates objects in a similar method to a two dimensional ink jet printer. Material is jetted onto a build platform using either a continuous or Drop on Demand (DOD) approach.
Binder jetting	The binder jetting process uses two materials; a powder based material and a binder. The binder is usually in liquid form and the build material in powder form. A print head moves horizontally along the x and y axes of the machine and deposits alternating layers of the build material and the binding material.
Vat photopolymerization	Vat polymerisation uses a vat of liquid photopolymer resin, out of which the model is constructed layer by layer.
Sheet lamination	Sheet lamination processes include ultrasonic additive manufacturing (UAM) and laminated object manufacturing (LOM). The Ultrasonic Additive Manufacturing process uses sheets or ribbons of metal, which are bound together using ultrasonic welding.
Powder bed fusion	The Powder Bed Fusion process includes the following commonly used printing techniques: Direct metal laser sintering (DMLS), Electron beam melting (EBM), Selective heat sintering (SHS), Selective laser melting (SLM) and Selective laser sintering (SLS).
Directed energy deposition	Directed Energy Deposition (DED) covers a range of terminology: 'Laser engineered net shaping, directed light fabrication, direct metal deposition, 3D laser cladding' It is a more complex printing process commonly used to repair or add additional material to existing components.

Source: (Loughborough university, 2021[6]).

Box 1. A brief history of additive manufacturing technology

The invention of additive manufacturing is generally attributed to American engineer Charles 'Chuck' Hall who, in 1983, printed a cup using a system where light was shone into a vat of photopolymer – a material that changes from liquid to solid when light shines on it – and by superposing successive layers of this material to form the object.[1] The system was patented three years later.

Improvements in the technology led to the development of the first 3D printers, which came into commercial use in 1988. Starting in the early 1990s, additive manufacturing began to be used to manufacture prototypes and for secondary manufacturing techniques (e.g. forming tools for traditional manufacturing techniques like injection moulding). This early stage of development was characterised by relatively high costs of 3D printing machines and a relatively small number of firms operating in the additive manufacturing market – limiting the prospects of wider adoption at the manufacturing and household level.

Things changed drastically in 2004 when a group of UK-based researchers launched an open-source 3D printer project called the 'RepRap', based on 3D printers working by material extrusion of thermoplastics. A key objective of the project was to build machines that would be able to replicate their own parts, with the more recent versions of RepRap machines replicating as much as 50% of their components.

The years 2008 and 2009 marked further important steps in the history of 3D printing. In 2008 a small company called Makerbot launched the website 'Thingiverse' – that allowed designers to upload their 3D models for others to download for free and print at home. At the tail end of 2008 and the beginning of 2009, the patent owned by Stratasys for Fused Deposition Modelling technology expired, opening the door to wider 3D printing adoption. This is considered by some the second most important event in the history of 3D printing after the launch of the RepRap project.

Open-source innovation led to the involvement of an increasing number of participants in the 3D printing space, with continuous improvement and a greater and greater number of free design files being offered online. At the same time, greater competition in the market for 3D printing through material extrusion led to a decrease in the cost of FDM (Fused Deposition Modelling) machines, which fell below USD 1 000.

In parallel, various additive manufacturing companies started offering 3D printing services to the wider public, allowing users to commission the production of 3D printed parts. The 2010s also saw the emergence of Stereolithography as another 3D printing technique available to the wider public, the expiry of patents for SLS and SLA 3D printing (Table 1), and significant progress in the field of 3D printing with metals and resins. This period also saw the first applications of 3D printing in the construction industry.

Today, 3D printing based on material extrusion of thermoplastics remains the most common form of additive manufacturing. In terms of volume, parts produced from prototyping plastics with extrusion-based 3D printers (FDM/FFF) account for approximately two thirds of the total demand for 3D printed parts on the popular platform 3D Hubs, while the demand for metal parts is almost 100 times smaller than that for plastic parts (3D Hubs, 2020[8]). Polymers are also estimated to account for 82% of the materials market (Ultimaker, 2019[9]; AMFG, 2020[10]).

At the firm level, a survey conducted by Ernst and Young (2019[11]) reported that 72% of survey respondents – a 19 percentage point increase from 2016 –used a polymer system in 2019, compared with the 49% (2016: 44%) that used metal. Sculpteo's annual *State of 3D Printing* report tells a similar story, with more than 80% of surveyed companies using polymers for 3D printing (Sculpteo, 2021[12]). This preference is largely price-driven, as the wide availability of low-cost desktop polymer systems means they are much more affordable (AMFG, 2020[10]).

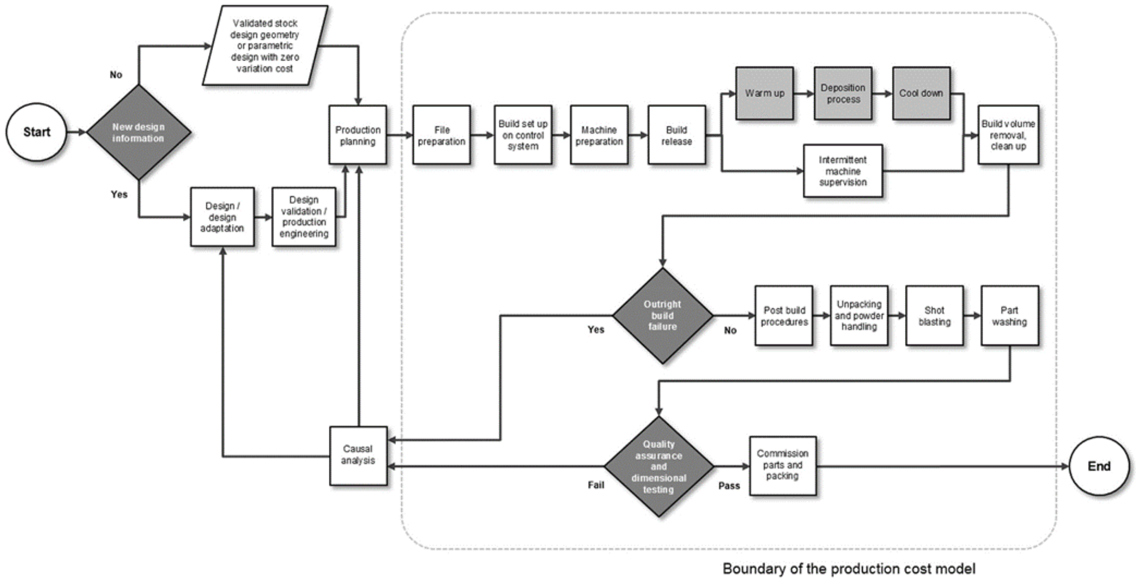
1. Important inventions in stereolithography by the Japanese inventor Kodama and French engineers Le Méhauté, de Witte, and André preceded the birth of the first 3D printer, but these inventions were either not patented or quickly abandoned because of perceived lack of business perspectives.

Source: (Laplume, Petersen and Pearce, 2016[13]; Cavedagna and Lamperti, 2017[14]; ALL3DP, 2018[15]; 3DSourced, 2021[16]).

Additive manufacturing is more complex than one might think

Additive manufacturing is not just a simple *click and print* process; it involves different steps requiring specialised personnel, materials and machinery. In the context of manufacturing activities, there are many steps in the 3D printing process, including: validation of designs; preparation of materials and machine; supervision of production; and a range of post-build procedures which include polishing and washing (Figure 2). As with other manufacturing processes, there are also a number of ancillary activities needed to maintain the machinery.

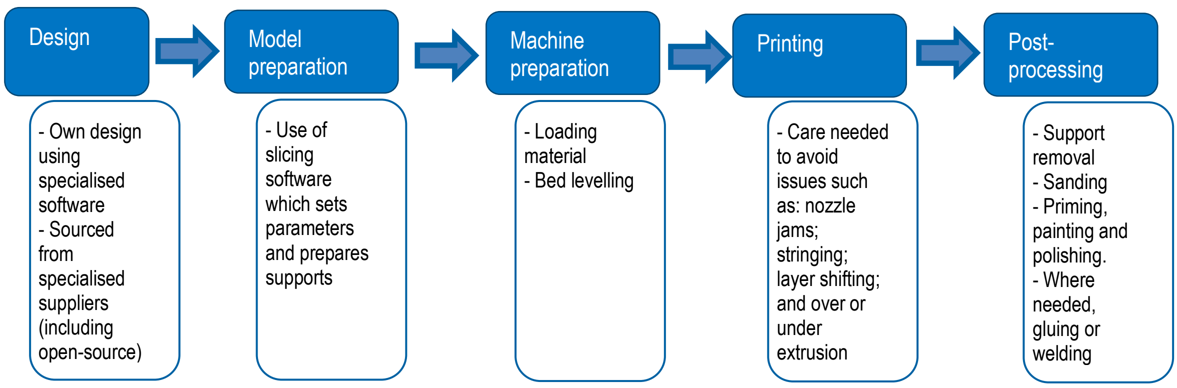
Figure 2. Process map for industrial 3D printing



Note: This figure represented the process map for polymeric laser sintering.
Source: (Baumers and Holweg, 2019[17]).

When printing at home, there are also a number of processes before a product is finalised (Figure 3), many of which share similarities with manufacturing processes. 3D printers require careful calibration, as well as use of specialised software, including what is known as a 'slicer'. These specify how a model is to be printed by taking into consideration the specific printer and material being used and setting the appropriate temperature and sequence. There are also a range of post-processing steps, often tied to the specific technology used (including generating 'supports' for parts with severe overhangs). These can include: support removal (which refers to removing the supporting infrastructure that is used when printing); sanding (to remove the rough surfaces of the original print); welding or gluing (to tie different components together); and priming, painting, smoothing or polishing.[6] 3D printing is also not without complications, and problems such as 'warping', which arise when there is uneven cooling of an object, or 'layer adhesion', where extra layers may need to be added, can arise.

Figure 3. Process map for home 3D printing



Note: Schematic representation, processes can vary according to the 3D printing technology employed.
Source: Author's elaboration based on ALL3DP (2021[18]).

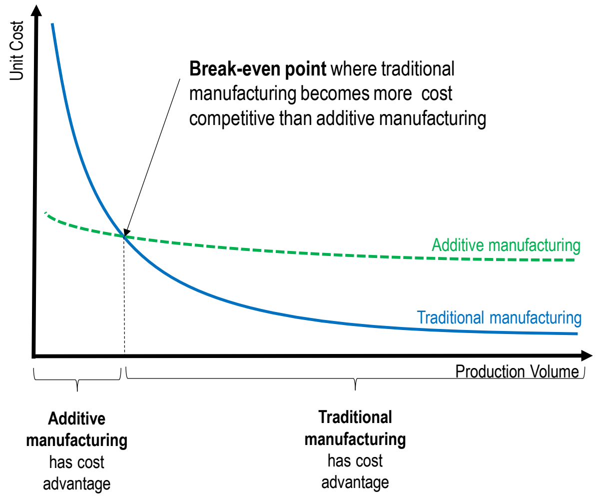
[6] See ALL3DP (2021[18]).

Additive manufacturing is best suited for production of fewer but more geometrically complex items

A number of studies in the engineering literature compare the costs of producing goods using additive manufacturing techniques against those of producing the same items with more traditional manufacturing techniques (e.g. injection moulding).[7] Traditional injection moulding techniques see a downward sloping unit cost curve, that is, as the number of units produced grows, the cost of each unit decreases, highlighting benefits from economies of scale. By contrast, unit costs for 3D printing remain relatively constant (Figure 4).

This means that, depending on the number of units produced, one technology has a cost advantage over another. Fewer units are produced more cost effectively using 3D printing technologies; however, at scale, more traditional technologies gain cost advantage. The *breakeven point*, where the unit costs are equal to each other, depends on the size of the object and complexity of production, among other factors, and is realised much later for more geometrically complex items (Hopkinson and Dickens, 2003[19]; Ruffo, Tuck and Hague, 2006[20]; Costabile et al., 2016[21]).[8] While technological progress, lower material costs, and decreases in prices for 3D printers may push the boundary of this breakeven point, the inherent cost structures of the two manufacturing techniques are unlikely to change in the near future.

Figure 4. Fewer units are produced more cost effectively using 3D printing technologies



Note: The figure shows an approximation of hypothetical cost curves for a particular good produced using additive manufacturing technologies and more traditional technologies such as injection moulding. The downwards sloping traditional manufacturing curve reflects presence of economies of scale where the more units produced the lower the unit cost, something that is not as apparent in additive manufacturing. See Costabile et al. (2016[21]) for a review of the literature of additive manufacturing cost models.
Source: Author's elaboration based on Ruffo, Tuck and Hague (2006[20]).

[7] See Costabile et al. (2016[21]) for a comprehensive review of the literature, as well as Atzeni and Salmi (2012[77]), and NIST (2014[34]).

[8] Hopkinson and Dickens, (2003[19]) and Ruffo, Tuck and Hague (2006[20]) compute the estimated unit value cost of producing an object with injections moulding vs. additive manufacturing techniques. This does not include a consideration of printing multiple parts in one session and fully utilising build volumes. However, Baumers et al. (2012[83]) includes the possibility of producing several parts per print session and, amidst methodological differences with previous studies, finds that the observations derived from the previous cost model (see Ruffo, Tuck and Hague (2006[20])) are still valid (Costabile et al., 2016[21]).

The range of products that can currently be 3D printed is somewhat limited

The type of products that can be manufactured using 3D printing techniques depends on a number of factors. These include the size and capabilities of the printers as well as the materials used to print. While large-scale 3D printers now operate in the architecture industry (OECD, 2017, p. 178[22]) and can be used to 'print' houses or bridges (Nature, 2020[23]), the technology is most often associated with smaller objects, owing to the more widespread use of smaller sized printers. In a similar vein, the existing scope of 3D printing micro- or nano-sized items remains somewhat limited (OECD, 2017[22]; Li et al., 2011[24]). However, advances are being made in digital laser micro- and nanoprinting (see, for example (Li et al., 2018[25]) and (Ulrich et al., 2020[26])) with nanotechnology researchers now able to 3D print microbatteries (Drews et al., 2020[27]).

Additionally, 3D printing is, at present, restricted to certain materials which are more malleable and adapted to the technology. These generally include plastics, but also metals, ceramics and paper. 3D printing is also less likely to be useful for printing objects that require many different materials, including electronic items such as monitors, mobile phones or household appliances (OECD, 2017, p. 179[22]).[9] That said, recent advances are enabling rapid switching between different polymer inks allowing for objects with both flexible and rigid parts (Nature, 2020[23]).

In the context of specialised manufacturing, 3D printing is used to produce parts and components in the aerospace industry (see Khajavi, Partanen and Holmström, (2014[28])). In the healthcare and pharmaceutical industry there are different applications, including in the production of anatomical models, medical implants, pharmacological design and medical apparatus and instruments (see Aimar, Palermo and Innocenti (2019[29]) and Fan et al. (2020[30])). The technology is also increasingly being used to 3D print food using chocolate, cookie dough, and sugar powder (Dankar et al. (2018[31])) and even meat (Dick, Bhandari and Prakash (2019[32])). But the technology is also often associated with producing materially simple consumption items, such as phone accessories, kitchen utensils or keyrings (Wittbrodt et al., 2013[33]). One key advantage of the technology is that it especially well-suited for producing custom designs with intricate patterns which would otherwise be costly to manufacture (Nature, 2020[23]).

Other manufacturing considerations: Inventory, resilience and timeliness

Additive manufacturing is also a versatile technology that can help limit some of the consequences of value chain disruptions and reduce 'ill-structured costs', such as those associated with build failure or management of inventory.[10] Indeed, additive manufacturing can help firms reduce the need to hold inventories of parts and reduce risks associated with production downtime (NIST, 2014[34]). Similarly, it can help respond to time-bound value chain disruptions in particular products and components by providing an avenue for maintaining rapid access to replacements.

A prominent example of the use of additive manufacturing to address value chain disruptions occurred during the COVID-19 pandemic – where, in difficult supply conditions, hospitals were experiencing shortages of particular components of ventilators. Additive manufacturing was key to producing the missing components in a limited timeframe, helping maintain intensive care capacity. Similarly, 3D printing is used to produce a range of medical equipment like Nasopharyngeal swabs, face shields or masks (Box 2). There

[9] This does not mean that the technology cannot be used in manufacturing plants to print polymer or metal components of a mobile phone that can then be assembled.

[10] As discussed by Young (1991[80]), the costs of production can be categorized in two ways. The first involves those costs that are "well-structured" such as labour, material, and machine costs. The second involves "ill-structured costs" such as those associated with build failure, machine setup, and inventory. In the literature, there tends to be more focus on well-structured costs of additive manufacturing than ill-structured costs; however, some of the more significant benefits and cost savings in additive manufacturing may be hidden in the ill-structured costs (NIST, 2014[34]).

are also a number of applications of additive manufacturing in the context of disaster relief, medical sciences and development, many of which are documented on the World Economic Forum's website.[11]

Box 2. 3D printing in support of COVID-19

There are a number of applications of 3D printing technology that have been useful in the context of COVID-19, from the production of finished items, to the production of personal protective equipment and parts and components of medical machinery.

- Belgian 3D printing company, Ziggzagg received a CE certification for their 3D printed nasopharyngeal swabs which means these meet EU standards for health, safety, and environmental protection and can be sold and used for testing.

Nasopharyngeal swabs

- At the same time, there are a number of designs that have been made freely available which can be used to produce personal protective equipment, from 3D printable face shields, to mask adjusters, hands-free door openers to wrist covers.

Face Shield

Stopgap Face Mask

- The technology has also been used to produce different components, such as connectors for materials for administering advanced oxygen therapy and ventilation components for field respirators. These have allowed health systems to access needed parts and components during shortages of medical equipment.

Source: (HP, 2021[35]).

[11] See https://www.weforum.org/agenda/archive/3d-printing/

2.2. How might the wider adoption of 3D printing technology affect trade?

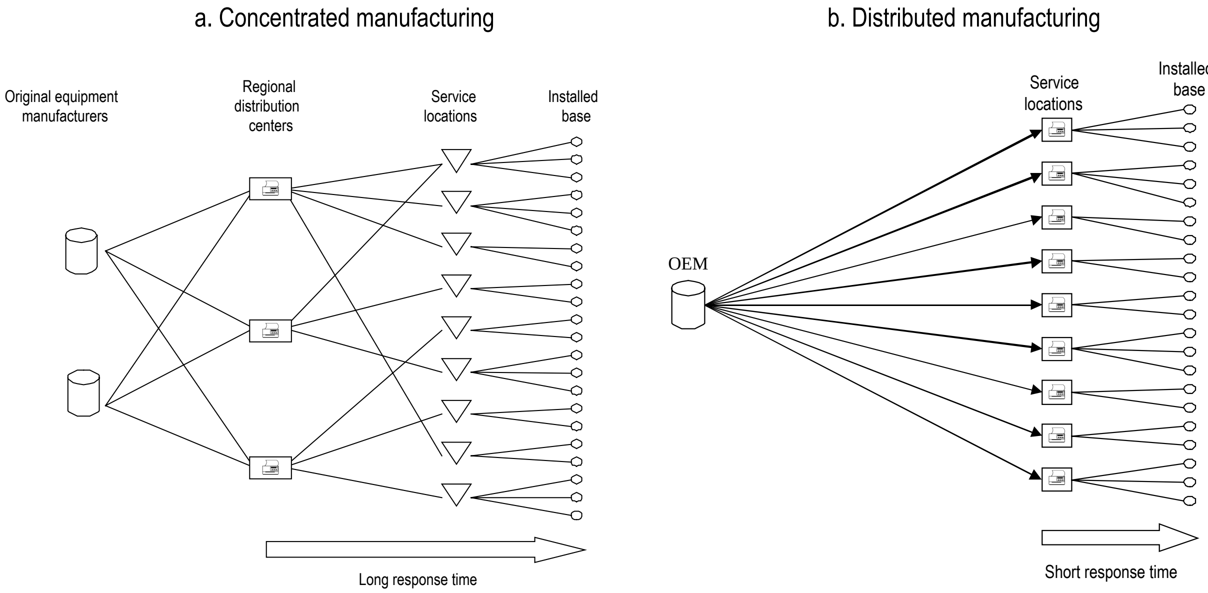
Beyond the technical capabilities and characteristics of the technology, a factor that will play a key role in determining potential impacts on international trade is *how* the technology will be used.

Concentrated versus distributed manufacturing

Broadly speaking, there are two different models of adoption that matter from an international trade perspective. These are referred to in the technical literature as 'concentrated manufacturing' and 'distributed manufacturing' (Figure 5, Holmström et al. (2010[36])). As the name suggests, differences between these two types of manufacturing relate to whether 3D printing activities are geographically concentrated or dispersed. In the case of the former, manufacturing is concentrated in hubs, with products then shipped to final destination. By contrast, distributed manufacturing takes place closer to final destination.

The existence of these competing models underscores that the transmission of digital files for local printing does not always constitute the most cost-effective means of 3D printing deployment. Indeed, there can be advantages in centralising additive manufacturing production and then shipping 3D printed goods to different destinations. Which method is used is the result of trade-offs including: (i) cost-advantages from operating fewer machines at full capacity versus having several machines functioning at less-than-optimal capacity; (ii) issues related to centralising specialised personnel; (iii) the ability to source and store material for production; and (iv) issues around speed of delivery and agility in the value chain.

Figure 5. Alternative deployment models of additive manufacturing in the value chain



Source: From Holmström et al. (2010[36]).

Existing studies on the aircraft spare parts supply chain show that high costs of additive manufacturing machines and personnel tend to outweigh the benefits of distributed deployment (Khajavi, Partanen and Holmström, 2014[28]). Case study evidence for medical parts shows that distributed manufacturing with more localised supply chain configurations, while significantly reducing the delivery time from about 54 to 27 hours, come at a 4.3-fold increase in cost (Verboeket et al., 2021[37]).[12] This balance may, however, change in the future, as increased automation and lower machine costs can alter underlying cost structures.

Overall, and for international trade, the wider adoption of concentrated rapid manufacturing is likely to lead to more trade along the supply chain than distributed rapid manufacturing. Indeed, the closer the location of 3D printing to final consumers, the fewer the times finished goods might have to cross borders. However, it is worth noting that benefits of 3D printing are likely to be multifaceted and, to some extent, independent of whether they generate more or less trade. They are also likely to materialise in developed and developing countries alike, including through lower obstacles to entrepreneurship, lower entry-barriers in manufacturing, and improved product quality (OECD, 2017, p. 183[22]).

Material inputs

Although debates about additive manufacturing are often couched in the context of the de-materialisation of international trade, this only holds true under certain circumstances and with respect to specific parts of the value chain. Indeed, 3D printing still requires the use of material inputs which are often accessed through international trade. They include polymers (plastics) and metals, but also a range of other materials used across different 3D printing techniques (Table 2).

Table 2. Additive manufacturing technologies use a range of materials as inputs

Materials / processes	Material extrusion	Vat photopoly-merization	Material jetting	Powder bed fusion	Binder jetting	Sheet lamination	Directed energy deposition
Polymers and polymer blends	x	x	x	x			
Composites (materials reinforced with carbon fibres)		x	x	x	x		
Aluminium alloys				x	x	x	x
Nickel alloys			x	x	x		x
Stainless steel				x	x	x	x
Titanium				x	x	x	x
Ceramics	x	x	x	x	x		
Paper						x	

Source: Adapted from NIST (2014[34]), Wohlers (2014[38]) and updated using Bourrel et al. (2017[39]) and AMFG (2020[10]).

It is also worth noting that 3D printers do not operate with unprocessed raw inputs. Material inputs must exhibit certain properties (e.g. in terms of strength, stiffness, malleability etc.) and be compatible with the specific 3D printing technology for which they are being used (Bourell et al., 2017[39]).

[12] The cost difference between the localized and centralized scenarios can be reduced when state-of-the-art additive manufacturing machines are utilized, demand volumes increase, and the distances between the supply chain network nodes expand (Verboeket et al., 2021[37]).

At present, processing materials for additive manufacturing can be costly, with only few firms marketing specific inputs for 3D printing technology.[13] However, as adoption of additive manufacturing becomes more widespread, lower material costs could arise due to greater benefits from scale and from more firms entering the market (NIST, 2014[34]; Stoneman, 2002[40]). Overall, a wider adoption of 3D printing could therefore lead to more upstream trade in material inputs.

Household use versus use in manufacturing processes

While much of the business literature focuses on the use of 3D printing within the value chain, it is important to highlight that desktop-based household 3D printing is also likely to be an important market. According to industry reports (Grand View Research, 2021[41]),[14] the industrial printer segment of the market accounted for 76% of the share of global revenue in 2020, with the desktop 3D printer market segment accounting for the remaining 24% of total revenue.[15]

3D printing offers new opportunities, particularly for individuals with limited manufacturing skills or equipment, to print new and more geometrically complex items. Indeed, an economic analysis of the life-cycle of a RepRap machine (a low-cost 3D printer) highlights the possible cost savings accruing to users in the production of a basket of materially simple consumption items, including an iPhone dock, a garlic press and a key chain (see Wittbrodt et al. (2013[33])). With open-source 3D printing, the economic gains of using a RepRap machine were estimated to be between USD 300 to USD 2 000 per year for a typical American household. Investment in material costs of the 3D printer were found to be recovered in less than one year.

The implications of household use versus use in manufacturing processes for international trade in goods are ambiguous. If households are predominantly printing items that are made domestically, then it is likely that there will be little to no effect on trade in goods.[16] However, if they print items that are originally made abroad, then there could potentially be an impact on goods trade. In this instance, household use is similar to 'distributed manufacturing' and is therefore likely to be associated with less trade in goods, notwithstanding trade arising from access to raw materials.[17] This could also entail a corresponding increase in trade in services in the form of more design services (CAD files) crossing borders.[18]

[13] Material costs are indeed often identified as a key barrier to broader 3D printing adoption: A number of 3D printers are designed to work exclusively with materials developed in-house by the manufacturing company, which limits the opportunities for their customers to use third-party materials (AMFG, 2020, p. 17[10]). In a survey conducted by Ernest and Young, 90% of companies report that the high cost of materials is the key barrier to adopting 3D printing or expanding their use of the technology (AMFG, 2020, p. 16[10]).

[14] According to Grand View Research's: *3D Printing Market Size, Share & Trends Analysis Report* https://www.grandviewresearch.com/industry-analysis/3d-printing-industry-analysis accessed on 8 September 2021.

[15] It is, however, difficult to estimate the size of the household 3D printing market, as desktop 3D printers are also used in education and increasingly by small businesses. Many at-home 3D printed items are also likely to be own designs or accessed via open-source pages such as Thingiverse. Assigning a monetary value to these can be difficult. Nevertheless, existing proxy measures suggest that household 3D printing is growing. See the analysis based on Google searches in Section 3.

[16] Cost savings from home printing may also have secondary impacts on demand for domestic and traded goods and services, including inputs.

[17] Similar implications would arise for local 'print-shops' offering manufacturing services in close proximity to customers.

[18] To the extent that the design is not accessed through and open-source platform and it originates from abroad.

2.3. What do we learn from this review of the literature?

Overall, the literature suggests that 3D printing is a versatile technology with many potential applications across a range of specific tasks and sectors. Additive manufacturing displays key cost advantages for production of low-volumes of geometrically complex and materially simple objects and provides unprecedented design freedom for customisation and prototyping. The technology also offers valuable opportunities to strengthen resilience in value chains, especially in manufacturing sectors where spare-part inventories can be costly.

However, the idea that additive manufacturing is likely to have large-scale and cross-sector repercussions on international trade over the short to medium term may be misplaced. Cost and quality advantages of traditional manufacturing are likely to remain for the vast majority of products traded. At the same time, materials strongly condition the scope of products that can be printed and the extent to which goods are 3D printable in all their components.

Moreover, even if 3D printing were to revolutionise manufacturing processes in specific sectors, adoption of 'concentrated manufacturing' in the value chain may actually contribute to increases in the value of trade through productivity gains (Freund, Mulabdic and Ruta, 2019[3]). In these instances, 3D printing can be *trade enhancing*.

Where 3D printing is used as a technology to produce closer to final destination, as is the case of 'distributed manufacturing' or 3D printing at home, the implications of wider adoption are not clear cut. While producing at destination is likely to reduce the need to ship intermediate or final goods across borders, the extent to which 3D printing is *trade substituting* for goods will depend on the products that can be 3D printed and the extent of adoption. Any reduction in goods trade would also need to be assessed in the context of positive changes in trade in raw materials and design services (associated with the wider adoption of 3D printing technologies irrespective of the type of manufacturing, whether concentrated or distributed).

As regards possible future development of the technology, trade impacts are likely to be contingent on how additive manufacturing technologies are adopted and how they evolve and diffuse. The debate should perhaps be less about whether 3D printing results in more or less trade but rather about how 3D printing might change the composition of trade: spurring more trade in the materials used as 'ink'; enabling new trade in customised products (with implications for trade in parcels); stimulating demand for 3D printing-related services; and leading to greater cross-border data flows in 3D model data. At the same time, the geography of trade may also be affected, including in the context of greater specialisation in design and production of raw materials.[19]

Overall, the review of the literature suggests that the impact of this technology on trade is likely to be much more complex and function-specific than foreseen in ongoing discussions.

[19] Implications might also arise in the form of where trade is recorded in official statistics. Products that were previously captured in goods trade might be, in the future, captured in services trade statistics. Or indeed, low-value products that are 3D printed using 'concentrated manufacturing' may not be recorded if they fall below *de minimis* thresholds.

3. Using existing data to map the evolving 3D printing landscape

As has been shown, the 3D printing landscape is complex, involving different technologies, modes of deployment and material uses. Moreover, since this is an emerging technology, capturing international diffusion and adoption is difficult. Although measurement efforts in digital trade are ongoing (OECD-WTO-IMF, 2019[42]), there is no comprehensive, internationally comparable, and publicly available data on 3D printing technology, nor is there clear-cut data on trade in 3D printers, 3D printable items and the materials that are used to print these items. Yet there is an urgent need to better understand the emerging 3D printing landscape, especially in the context of ongoing discussions on digital trade, including in regional trade agreements and at the WTO.

Specialised industry reports, such as the Wohler's report, can provide some insights into the current use of the technology. The platform *3D Hubs* reports that more than 500 000 3D printed parts were ordered on its platform in 2019, with North America and Europe cumulatively accounting for more than 95% of global demand (3D Hubs, 2020, p. 19[8]).[20] In terms of industry demand, over 65% comes from professional users working in the development of Industrial, Electrical or Consumer Goods. The overwhelming majority of all orders (more than 80%) included less than 20 parts, which suggests that prototyping might still be the primary use of 3D printing (3D Hubs, 2020[8]).

At the firm level, knowledge and adoption of 3D printing technologies appears to be growing. A survey conducted by Ultimaker found that out of 2 500+ companies, 67% of respondents were aware of the terms '3D printing' or 'Additive Manufacturing' in 2019, but only 35% were actually applying it—which is, however, a significant increase from 10% in 2014 (Ultimaker, 2019[9]; 3D Hubs, 2020, p. 17[8]). Ernst and Young report that, between 2015 and 2018, the number of attendees at *Formnext*, an annual industrial 3D printing trade show, rose by 300%, from 8 982 to 27 400, and the number of exhibitors increased by 34%, from 470 to 632 (Ernst & Young, 2020[43]).

However informative as this data might be, there is very little information on cross-border 3D printing activities. In the absence of official, public, complete and comparable statistics, more needs to be done to identify the international evolution of the technology.[21] This section uses a range of indicators and proxy measures to capture different facets of the evolving 3D printing environment. These include trade-based measures, firm level relationships and patent statistics, to better identify international adoption and diffusion of the technology, as well as more innovative measures of 3D printing activity based on Google trends data[22] and Thingiverse, an open-source repository of 3D printable objects.

3.1. What do trade statistics tell us about the evolving 3D printing landscape?

While the value of trade in 3D printers is currently captured in trade statistics, there is no single, dedicated, customs code for 3D printers as yet, meaning that these are not separately identified (Box 3). There are also a number of uncertainties related to the types of products that can or cannot be 3D printed. In addition, even if 3D printable products were easy to identify, trade statistics would not separately capture whether these items were produced using 3D printing or other manufacturing techniques. Nevertheless, and in the

[20] Demand for 3D printed parts is most often geographically associated with technologically innovative regions, hardware manufacturers or general manufacturing hubs, such as Silicon Valley, Los Angeles and San Diego in the United States and the United Kingdom, the Netherlands, Germany and France in Europe.

[21] For example, the World Economic Forum is mapping the evolution of 3D printing technology through a series of indicators to measure 3D printing adoption across a wide range of areas (e.g. government programmes, training, sales of 3D printers). (World Economic Forum, 2020[7]).

[22] Google Trends is an online tool that allows reporting data on internet searches on Google for particular words, 'Topics' (collection of words) and categories over time and across regions. See https://trends.google.com/trends/.

absence of comparable statistics, a number of important insights can be gleamed from looking at various indicators, particularly in terms of trying to understand emerging and potential supply and demand conditions.

Box 3. Measuring international trade in 3D printers with existing data

A metric by which to assess the global spread and adoption of additive manufacturing is international trade in additive manufacturing machines. However, as of today, 3D printers are not separately identifiable in the commodity classification of the Harmonised System (HS) nomenclature.[1] Nevertheless, there are relatively clear indications as to where these should be classified today and where they will be classified in future revisions of the HS code (World Customs Organisation, 2019[44]).

In order to identify the HS code that would best identify 3D printers today, Abeliansky, Martínez-Zarzoso, and Prettner (2015[45]; 2020[46]) undertook a range of interviews with customs authorities. Although there were some inconsistencies in classification among different national authorities, the authors concluded that the HS code 8477.80 is best suited to capturing trade in 3D printers. The use of this code is also justified on the basis of WCO guidance (World Customs Organisation, 2019[44]).[2]

This HS code captures different items under a broad heading of 'Machinery for working rubber or plastics or for the manufacture of products from these materials, not specified or included elsewhere in this Chapter.' As such, it largely covers 3D printers that use plastic or rubber materials, which are some of the most commonly used materials across different additive manufacturing processes (Box 1 and Table 1), but potentially also other machines with similar functions.

The measurement difficulties around trade in 3D printers will be eased with the 2022 revision of the Harmonised System nomenclature, which is set to include a separate heading for additive manufacturing systems. Heading 84.85 – Machines for additive manufacturing – will distinguish 3D printers based on whether they operate by metal deposit, by plastics or rubber deposit, by plaster, cement, ceramics or glass deposit, as well as other 3D printers and parts thereof (World Customs Organisation, 2019[44]).

While the revision of the Harmonised System will allow for more precise measurement of trade in additive manufacturing machines, it will take time before a snapshot of trade in 3D printers becomes available through internationally comparable trade data, at best near the end of 2023 – and more time will be needed to observe the evolution of such trade over time. This motivates the adoption of proxy measures in this report before more accurate measurement becomes possible, noting the caveats of this approach.

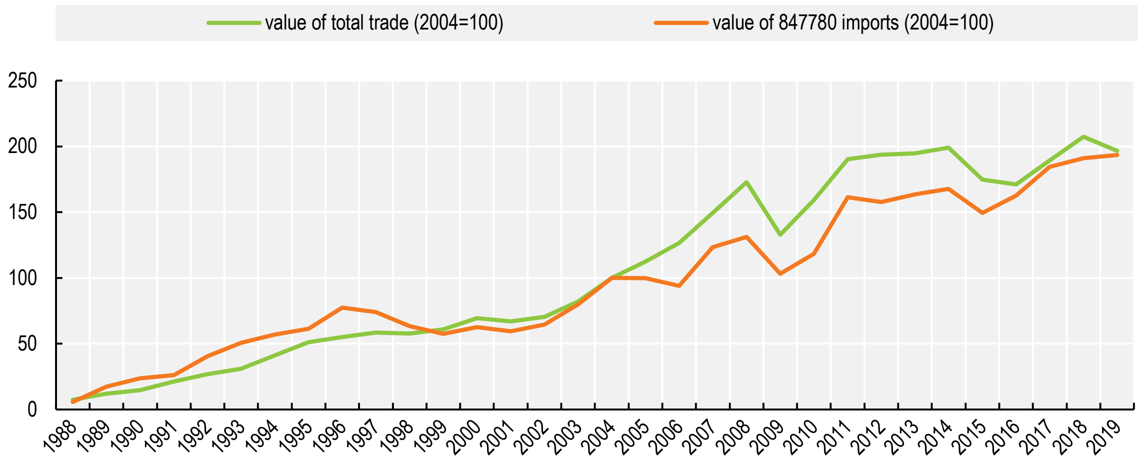
Notes:
1. A case brought before the United States Court of International Trade in 2013 shows the complexity of classifying 3D printers in trade nomenclature today. The case led to the classification of laser sintering systems working with thermoplastic powder in the HS category 8477.80, as machinery for working rubber or plastics not specified or included elsewhere in the chapter. The court concluded instead that laser sintering systems working with metal powder would best be classified under 8479.89.98, as machines having individual functions not specified or included elsewhere in the chapter. The similar technologies were classified in distinct codes by virtue of the different materials they used in the production process (Hodes and Mohseni, 2014[58]).
2. The correspondence table between the current and future version of the harmonised system classification confirms that part of HS2017 8477.80 (ex) matches in a one-to-one relationship machines for additive manufacturing operating by plastic or rubber deposit (8485.20) in HS2022. A number of other codes are also identified as potentially classifying other 3D printer techniques today. See http://www.wcoomd.org/-/media/wco/public/global/pdf/topics/nomenclature/instruments-and-tools/hs-nomenclature-2022/table-i_en.pdf?la=en and http://www.wcoomd.org/-/media/wco/public/global/pdf/topics/nomenclature/instruments-and-tools/hs-nomenclature-2022/ng0262b1.pdf?db=web.

Proxy measures of trade in 3D printers suggest falling concentration in supply

Since 2004, trade in 3D printers, as proxied using HS code 847780, has more than doubled in value – a pace just short of that witnessed by global trade overall (Figure 6). The data suggest a degree of concentration in terms of supply, with the top 10 exporters, many of which are OECD countries, representing 83% of global exports in 2019 (Figure 7a). However, there are indications that export concentration has been falling, suggesting that the technology could be diffusing with more *producers* entering the market (Figure 8).[23]

In terms of importers, concentration is lower – the top 10 importers represent 61% of total imports (Figure 7b). These include a number of non-OECD countries such as the People's Republic of China (hereafter "China"), Viet Nam, India and Indonesia. To the extent that importing patterns can give an indication of the extent of existing adoption, there are signs of greater diversification in terms of the users of 3D printing technology (relative to suppliers). However, there are few indications of falling concentration, suggesting that, beyond these countries, adoption of 3D printing technology might currently not be spreading more widely (Figure 8).

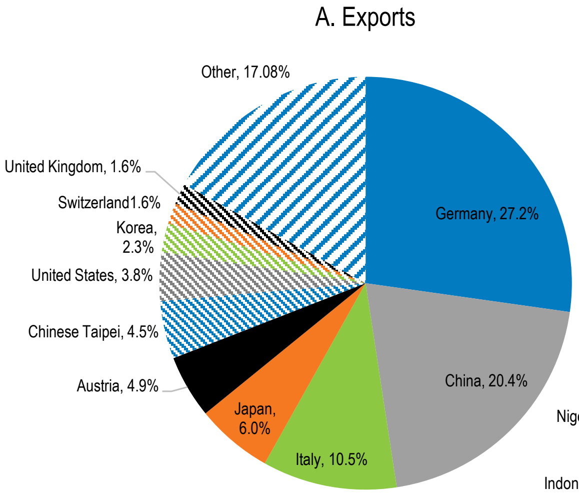
Figure 6. Potential trade in 3D printers, 1988 to 2019

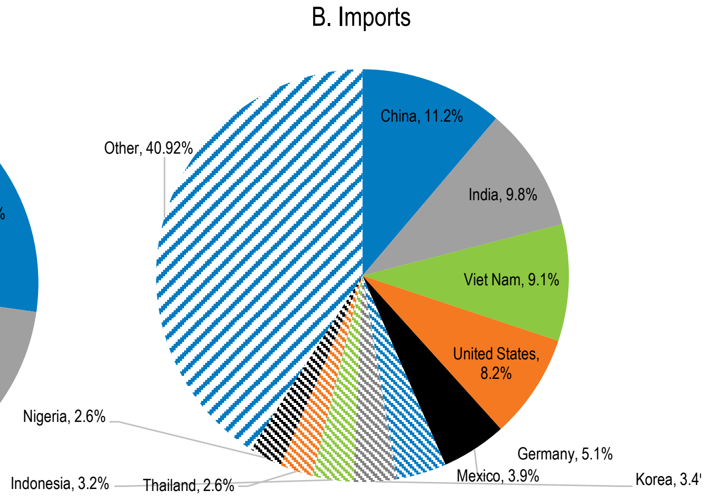


Note: 3D printers are identified using HS code 847780 referring to "Machinery; for working rubber or plastics or for the manufacture of products from these materials". See Abeliansky, Martínez-Zarzoso, and Prettner (2015). The data is normalised to 2004 – which corresponds to the launch of the RepRap project.
Source: Own calculation using COMTRADE.

[23] It is worth noting that different measures of adoption – such as 3D printing systems sold by region or installed units by country – are likely to paint a slightly different picture, with the United States playing a more prominent role as adopter of the technology. The discrepancy could be explained by: (i) the difference between selling 3D printers for domestic use vs. exporting them and (ii) the code 8477.80 including other machinery than just 3D printers. The role of the United States in this area is however still captured by statistics on innovation (see section below).

Figure 7. Distribution of potential exports and imports of 3D printers by country, 2019

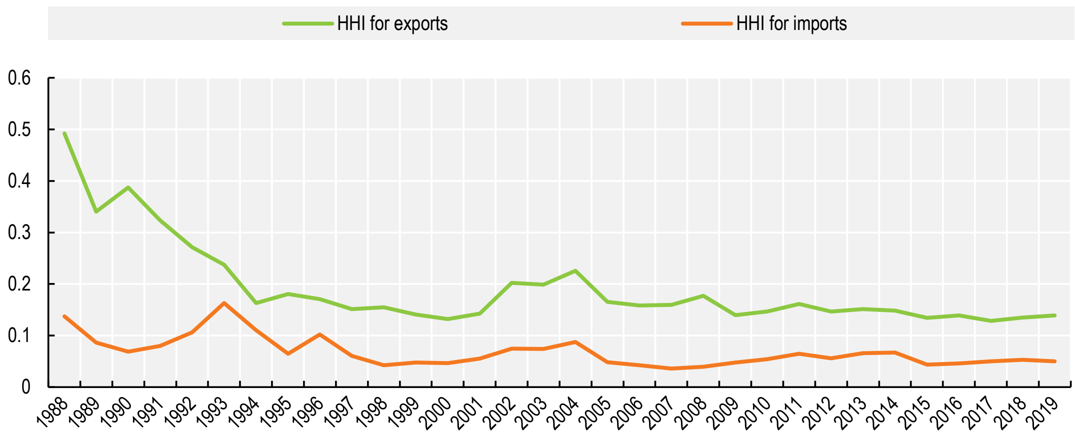




Note: 3D printers identified as HS code 847780 referring to "Machinery; for working rubber or plastics or for the manufacture of products from these materials – Other machinery". See Abeliansky, Martínez-Zarzoso, and Prettner (2015).
Source: Own calculation using COMTRADE.

Figure 8. Concentration of potential 3D printer exporters and importers, 1988 to 2019

Herfindahl-Hirshman Index (HHI)



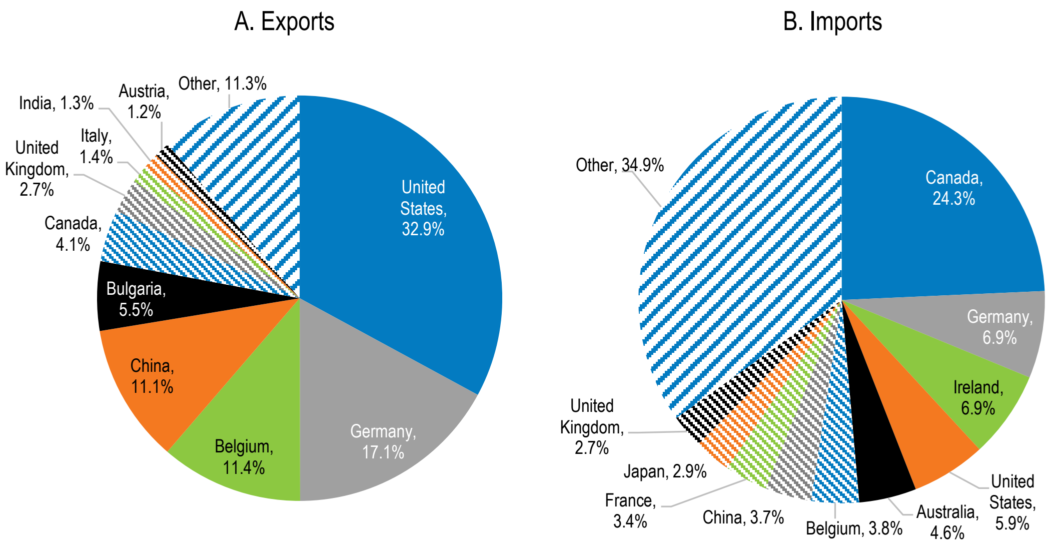
Note: 3D printers identified as HS code 847780 referring to "Machinery; for working rubber or plastics or for the manufacture of products from these materials – Other machinery". The HHI captures the degree of concentration in a market. Higher values imply more concentration.
Source: Own calculations using COMTRADE data.

Trade in materials used for 3D printing

As was the case for 3D printers, material inputs used for 3D printing are not separately identified in trade statistics. However, measures for materials traditionally associated with additive manufacturing may help identify potential trade. For instance, HS code 391610 identifies *monofilament of polymers of ethylene exceeding 1mm of size*, a processed material that can be associated with feedstock for material extrusion 3D printers.[24] In this product, OECD countries are the main suppliers and users. The trade data also reveals similar patterns in terms of distribution of exporters and importers to those for 3D printers: a relatively concentrated supply, but a slightly more diversified demand (Figure 9).[25] Other specific feedstock materials that are growing, and diversifying rapidly, are different types of metal powders, for which proxy measures of international supply and demand are provided in Figure A.3 in Annex A.

However, in terms of the raw materials used to produce 3D printed items, which include other polymers as well as metals, ceramics and paper, the suppliers are more varied (Table 3). The United States appears as the leading exporter across a number of materials such as Titanium, Polymers and Ceramics (clay), but China and Russia are the top exporters of Aluminium and Nickel in primary forms. It is, however, important to highlight that, while this information can shed light on the broad supply conditions for primary materials in this market, participation in production of 3D printing material inputs requires further processing of materials to make them compatible with processes across different additive manufacturing activities (see Section 2).

Figure 9. Trade in monofilament of polymers of ethylene, 2019



Note: HS code 3916.10: monofilament of polymers of ethylene exceeding 1mm of size.
Source: Author's calculations based on trade data extracted from COMTRADE.

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[24] As for the HS classification of 3D printers, it is important to note that this category is likely to include other items than just 3D printing feedstock.

[25] It is worth noting that metal powders are also diversifying rapidly, however it is difficult to identify a single 6-digit HS code for metal powders used as feedstock for 3D printers.

Table 3. Top 10 exporters of the primary forms of 3D printing materials, 2019

Polymers		Metals										Ceramics		Paper	
		Stainless steel		Titanium		Aluminium		Cobalt		Nickel					
USA	12.6%	CHN	12.0%	USA	30.8%	CHN	12.3%	CAN	14.7%	RUS	12.5%	USA	21.7%	USA	19.3%
DEU	7.9%	IDN	8.5%	RUS	10.6%	DEU	9.6%	USA	12.6%	USA	12.4%	CHN	15.4%	BRA	17.3%
KOR	7.6%	BEL	8.3%	JPN	10.4%	USA	6.2%	NOR	7.8%	CAN	12.4%	DEU	9.8%	CAN	13.9%
BEL	7.5%	ITA	7.7%	DEU	10.1%	CAN	6.1%	DEU	6.8%	DEU	6.6%	IND	5.7%	IDN	6.4%
SAU	6.5%	KOR	6.9%	GBR	8.7%	RUS	4.7%	GBR	6.6%	GBR	5.9%	ESP	5.7%	CHL	6.3%
CHN	6.1%	DEU	6.1%	CHN	8.4%	ARE	4.4%	BEL	6.2%	NOR	5.3%	TUR	5.3%	FIN	6.2%
NLD	5.2%	FIN	5.7%	FRA	3.5%	IND	3.6%	CHN	5.3%	FIN	4.3%	FRA	4.6%	NLD	3.0%
OAS	4.6%	OAS	5.6%	KAZ	2.9%	FRA	3.1%	AUS	5.1%	CHN	3.9%	NLD	4.4%	DEU	3.0%
SGP	4.5%	JPN	4.9%	ITA	2.2%	NOR	3.1%	RUS	4.8%	JPN	3.6%	ZAF	3.1%	RUS	2.6%
JPN	4.1%	FRA	4.4%	CAN	1.5%	ITA	2.9%	JPN	4.8%	NLD	3.5%	ITA	2.8%	PRT	1.7%

Note: OAS stands for 'Other Asia, not elsewhere classified'. Polymers: HS 39.01 to 39.14; Stainless steel: 72.18 to 72.23; Titanium: 81.08; Aluminium: 76.01 to 76.07; Cobalt: 81.05; Nickel: chapter 75; Ceramics: 'other clays' – 25.08; Paper: chapter 47.
Source: Author's calculation from COMTRADE data.

Trade in 3D printable goods

Using a list of 3D printable goods found in (Freund, Mulabdic and Ruta, 2019[3]) and constructed by Arvis et al. (2017[47]) based on expert opinion (Table A.3, Annex A, for the list of goods covered), it is possible to gain some insights into how trade in a range of manufacturing product categories, which have witnessed growing use of 3D printing technology, has evolved.

Changes in trade in 3D printable items largely kept pace with changes in total trade over the period 2002-2019 (Figure 10). However, trade in orthopaedic appliances (e.g. hearing aids, artificial joins, dental instruments) grew faster, quadrupling in value since the base year (growing nearly twice as much as total trade). By contrast, trade in machine parts grew at a slightly lower pace than total trade. Overall, the data suggest that trade in higher tech 3D printable products has grown at a faster or similar pace than total trade. There is therefore little prima facie evidence that the adoption of 3D printing is associated with less trade in items that can be 3D printed.

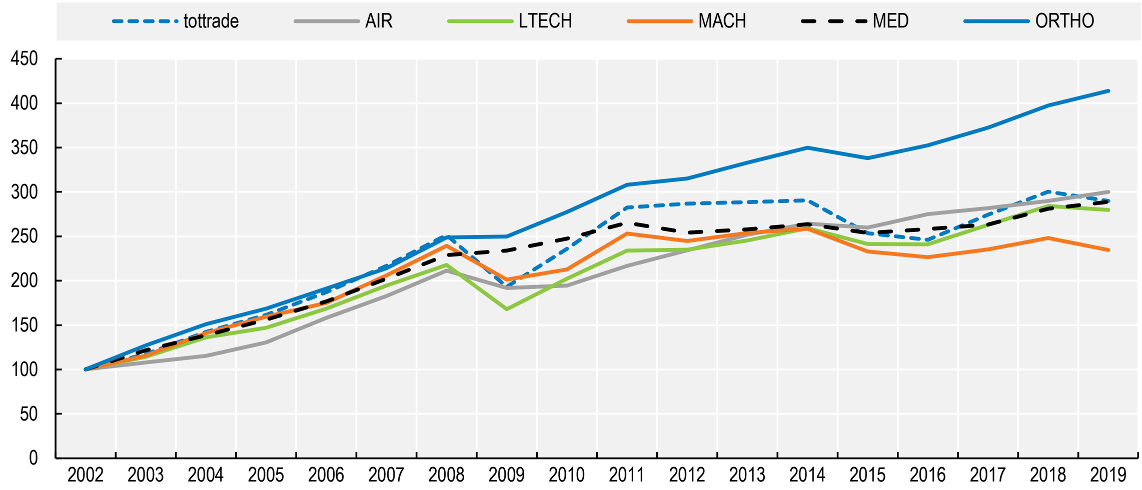
As regards main exporters and importers, the United States is the leading exporter in aircraft parts and orthopaedic appliances, while Germany leads in 3D printable machine parts, and medications & pharmaceuticals. Both are strong innovators in 3D printing technologies. By contrast, China appears to lead in exports of lower-tech 3D printable goods (Table A.4 in Annex A).

Capturing services associated with 3D printing, including trade in design (CAD) files, is complex. A classification issue arises, with these files likely classified across a range of different services sectors in the Balance of Payments accounts. For example, transactions involving CAD files/blueprints could potentially be classified as *charges for the use of intellectual property* in the EBOPS classification, but also as *sale of proprietary rights arising from research and development* (business services) when there is an outright transaction.[26] However, trade occurring in these categories would still be invisible as it would be grouped with other unrelated transactions. Similarly, design services that are digitally delivered, such as CAD files sent across borders, will not be separated from non-digitally delivered design services.[27] 3D printing-related services could also potentially be classified as architectural, engineering or computer services. Overall, this implies that capturing the impact of 3D printing on services trade is difficult but remains an important area for future research.

[26] I.e. the owners may license their IP rights or certain IP rights can be exhausted at first sale.

[27] Although digital delivery is likely to account for the lion's share of these transactions.

Figure 10. Trade in 3D printable items



Note: 2002=100. Totrade = total trade; AIR=aircraft parts; LTECH= low-tech 3D printable items (e.g. knives, handtools, candles); MACH= machine parts; MED= medications & pharmaceuticals; ORTHO= Orthopaedic appliances (e.g. hearing aids, artificial joins, spectacles, dental instruments). In 2019, AIR accounted for 18.9% of the total value of 3D printable trade; LTECH for 27.9%; MACH for 6%, MED for 38%; ORTHO for 9.1%.
Source: CEPII BACI database; Arvis et al. (2017). Data translated from SITC3 to the HS2002 nomenclature.

3.2. Insights from patents and firm-level data

While trade data can help shed light on the role that trade can play as a channel for the international adoption of 3D printing (and in turn its implications for trade), the technology also has a key domestic and firm-to-firm dimension which cannot be captured using trade statistics. This calls for the use of complementary data to paint a more nuanced picture of the current adoption and use of additive manufacturing.[28]

Patent data can help proxy innovation trends in developing additive manufacturing technologies, helping identify the role of different countries in this area.[29] Over the period 2013-17, the United States accounted for 32% of total additive manufacturing patents filed, followed by Japan (21%) and Germany (13%). Chinese Taipei and China also account for an important share of total patents filed (6% and 5% respectively) (Figure 11).

Data on firm-level interactions can also be used to provide insights into the current adoption of 3D printing technology at the sectoral level, especially in the context of existing supply-chain relationships. Using a sample of major 3D printing companies from the Factset dataset, the industry distribution of customers of additive manufacturing firms can be identified.[30] This can serve as a proxy measure for the *adoption* of this technology across different industries (Figure 12). The results show a degree of concentration across a number of high-tech sectors like Electronic Equipment/Instruments, Industrial Machinery and Medical Specialties.

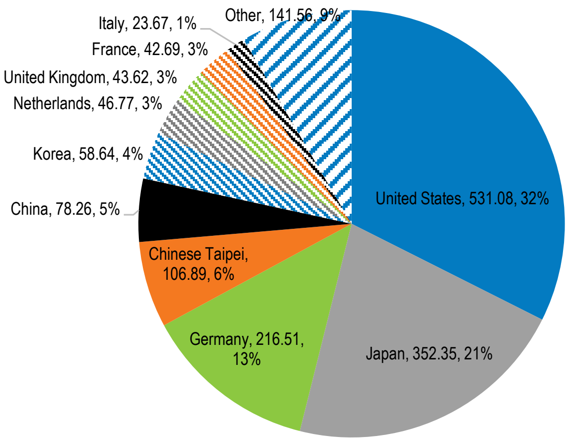
[28] Other data sources, such as patent statistics, also have the advantage of separately identifying additive manufacturing technologies in their nomenclatures, which helps provide a more accurate measurement of this evolving technology.

[29] A specific category to classify additive manufacturing in patent statistics only emerged in 2013 within the Cooperative Patent Classification (CPC) system, and was followed in 2015 by the establishment of a patent code in the International Patent Classification (IPC).

[30] The sample includes: Stratasys Ltd. (United States), Materialise NV Sponsored ADR (Belgium), Proto Labs, Inc. (United States), 3D Systems Corporation (United States), SLM Solutions Group AG (Germany), Nano Dimension Ltd. (Israel), ExOne Co. (United States), Organovo Holdings, Inc. (United States), Arcam AB (Sweden).

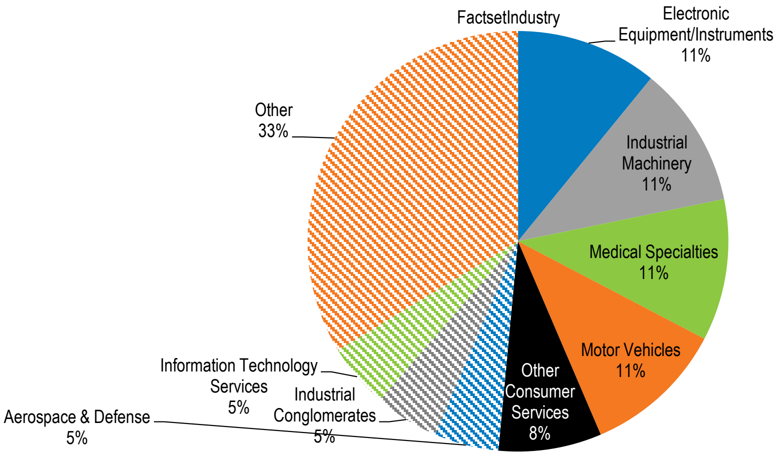
Figure 11. OECD countries are the leading innovators in Additive Manufacturing technology

Total number and share in total stock of patents filed, by applicant's location, 2013-17



Note: The absolute number of patents filed can be different from integer values because the patents are shared between applicants from several countries. IP5 patents, by application priority date. Additive manufacturing first obtained a separate classification in patent statistics in 2013, with its inclusion in the Cooperative Patent Classification (CPC) classification. Since 2015, additive manufacturing technologies are also separately identifiable in the International Patent classification (IPC), under the heading B33: Additive Manufacturing Technology (List and Tietze, 2017, p. 30[48]).
Source: OECD patent statistics.

Figure 12. Industry distribution of customers of major 3D printing companies

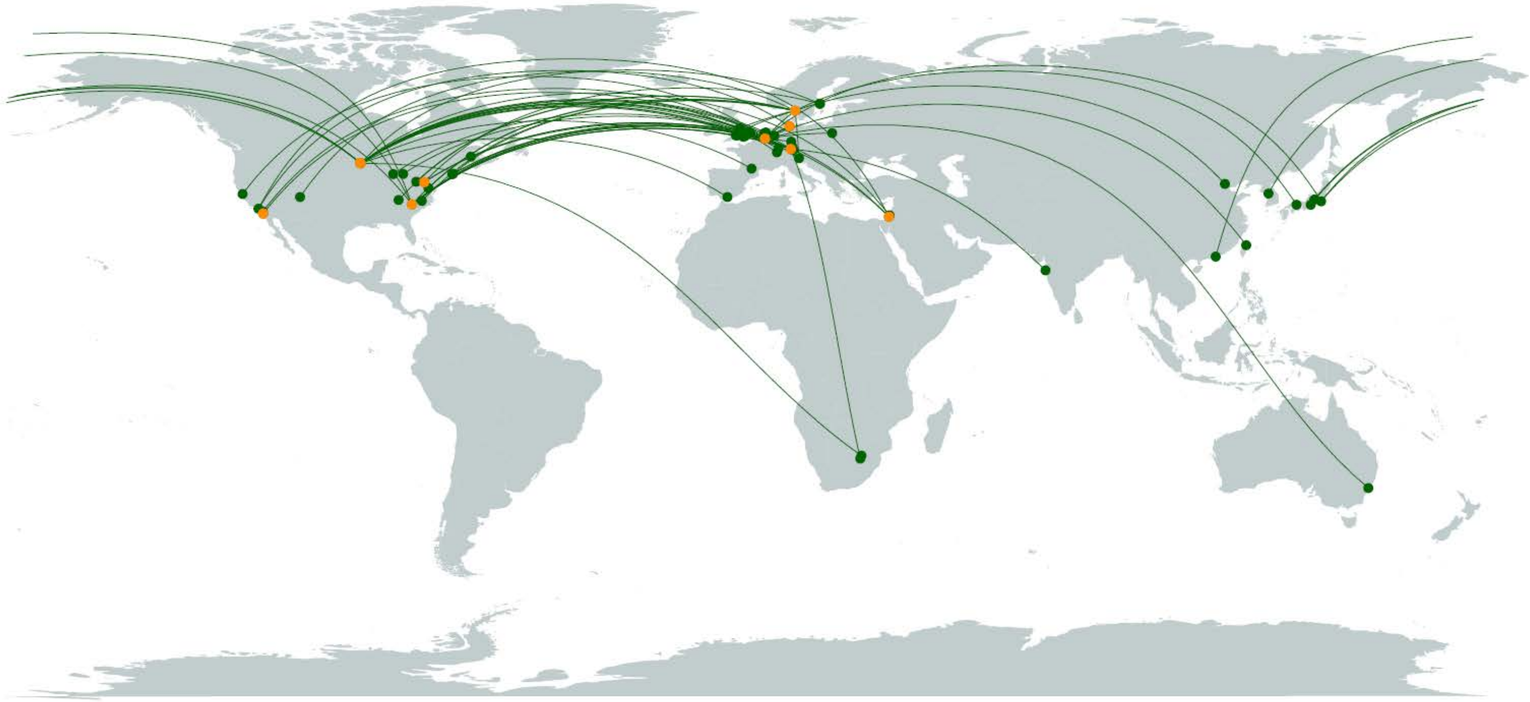


Note: Based on a sample of 101 company relationships. The figure reflects the number of business relationships and not their economic value. Data extracted in 2019.
Source: Author's calculations using Factset.

The geographical distribution of cross-border customer relationships between 3D printing companies and their business partners provides insights into ongoing international value chain interactions (Figure 13). The data shed light on customer relationships, i.e. those involving entities sourcing from 3D printing firms.

Figure 13. Customer networks of major 3D printing companies

Customer relationship of major 3D printing companies



Note: Customers are "Entities to which the source company sells products/services" (Factset, 2015[49]). The orange dots identify the supplying companies.
Source: Own calculations using Factset. Data extracted in 2019.

There is, however, little information on how these interactions are taking place. These could involve the transmission of digital files to 3D printing companies for them to print an object, which could then be exported back to the customer in physical form – a form of outsourced 'concentrated manufacturing'. Or it could involve an interaction where the source company might be providing the design for 3D printing which might then take place locally – outsourced 'distributed manufacturing'. Which form dominates can be important in determining whether 3D printing could complement or substitute for trade in goods.

3.3. Using new sources of data to map household use of 3D printing technology

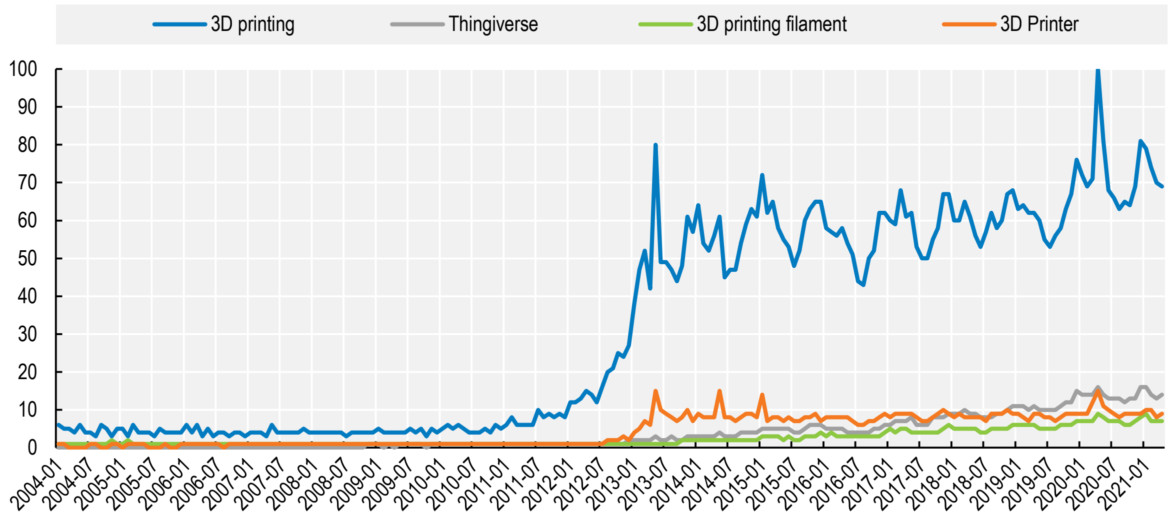
Data extracted from the internet can also provide important insights on the nature and evolution of 3D printing technology, including in identifying which products are being 3D printed by individuals.

Interest in 3D printing is growing, although there are signs that adoption is lagging

Google Trends data shows that interest in 3D printing peaked in April 2020, when many countries faced COVID-19 lockdowns (Figure 14).[31] However, searches related to 'Topics' such as '3D printing filament' (i.e. polymer materials used in 3D printing), '3D printers' or 'Thingiverse' (one of the most popular repository for 3D model files), which are likely to be more closely associated with adoption, have remained a fraction of overall searches related to the technology. This may be illustrative of a gap between interest in 3D printing and its actual adoption, notwithstanding that, overall, searches related to adoption also grew relative to their initial values.

Figure 14. Interest in 3D printing is growing, but adoption might not be keeping the same pace

Worldwide searches from January 2004 to April 2021.



Note: Google searches for 3D printing (Topic), Thingiverse (Website), 3D printing filament (Topic) and 3D Printer (Topic).
Source: Google Trends.

[31] The data shows Google Trends 'Topics'. Topics address the ambiguity problem of keywords as well as of searches in different languages. For example, the topic "Apple (company)" allows to single out searches related to the company and distinguishes them from those for apples (the fruit), by combining searches for keywords such as "applewatch", "ipad", and "macbook". However 'Topics' also have drawbacks, including opacity, as the full list of keyword included in 'Topics' is not fully transparent and could be assigned arbitrarily by algorithms. (Woloszko, 2020, p. 9[79]). Care also needs to be taken in interpreting Google trends based indicators, as unrelated events can impact changes in trends (Jaax, Gonzales and Mourougane, 2021[88]).

An online repository of 3D printable objects helps us understand what is currently being 3D printed by households

While expert judgement can help identify items that are 3D printable, and typically produced with 'industrial 3D printing' by firms, such as aircraft fuel nozzles or dental implants (Arvis et al., 2017[47]; Freund, Mulabdic and Ruta, 2019[3]), relatively little information is available on 3D printable items typically made by households and hobbyists.

Online repositories of 3D printable objects, i.e. websites that offer 3D printable design files for users to download, can provide information on the objects that tend to be produced through open-source 3D printing. The Thingi10k dataset contains information on 10 000 'featured' design files, that relate to 2 011 'things' or objects, that were culled from the popular website Thingiverse from September 2009 to November 2015 (Zhou and Jacobson, 2016[50]).[32] These 10 000 models form a sample of top-quality designs available to users on Thingiverse.[33] As such, these are items more likely to be in the "at home" or retail end of the market.

The designs are identified by names, accompanied by user-created tags, and are classified across categories and sub-categories, helping identify the nature and intended use of the printable objects. A word cloud[34] of the 4 892 available user-created tags and the names of the objects reveals the great variety of items found online (Figure 15). It also show the high frequency for items such as toys, models, games, art, ornaments, containers, lamps or boxes – suggesting the use of open-source 3D printing in the context of printing materially simple consumer items.

Figure 15. Frequency of names and tags in the Thingi10k website

Note: Tags and names. 'Makerbot' is the company that launched the Thingiverse website in 2008 (Box 1). 'Openscad' is a software application for creating CAD (Computer-Aided-Design) three dimensional objects. A 'parametric' design is a design that can be adjusted (for instance in size) to fit the needs of the person who is printing it.
Source: (Zhou and Jacobson, 2016[50]).

[32] See https://ten-thousand-models.appspot.com/

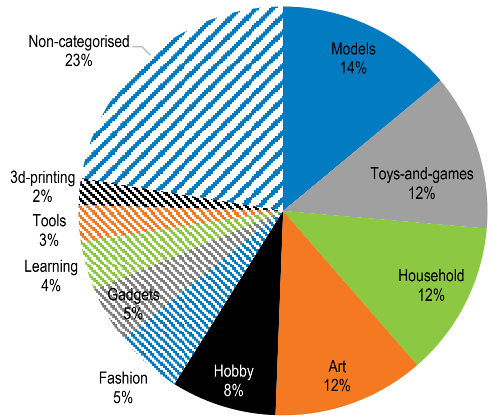
[33] Featured things are entirely and independently selected by Thingiverse staff based on their design, beauty and manufacturability, which provided a degree of certainty as to their quality and printability (Zhou and Jacobson, 2016[50]). As such, they are however not necessarily the most downloaded items.

[34] I.e. a graph where more frequent text is displayed with larger size.

The distribution of 3D printable objects within the available categories of the Thingiverse website helps identify those objects that tend to be more frequently featured. Models (e.g. representing vehicles, buildings, or animals), toys and games, household items and art (e.g. signs and logos, sculptures) together account for about 50% of the total objects in the repository. About 23% of the objects are also not categorised in a particular category (Figure 16).

In terms of the average dimensions of 3D printable objects, the vast majority are small to medium sized.[35] That is, if the median object were a perfect cube, each side would have a length of 13.4 cm. If it were a perfect pyramid with a square base, it would have a height of 13.5 cm and a base side length of 20cm (Figure 17). However, these dimensions refer to the size of final objects which can result from the assembly of many individual pieces. Objects printed with individual production processes (i.e. individual design files) tend to be several times smaller than the objects they make up (Figure 17) smaller cube and pyramid). The median object in the distribution indeed has three different components, which highlights that assembly is very common when 3D printing.

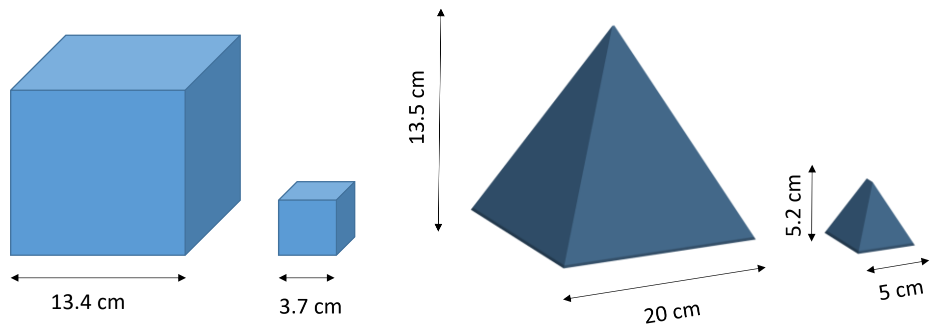
Figure 16. Categories of products that can be 3D printed from the Thingiverse website



Source: Author's compilation using Thingi10K, based on 2 010 products.

Figure 17. Finished 3D printable objects and their component elements tend to be small

Visualisation of the median total surface area of 3D printable objects and their individual components



Note: Scaling of size was necessary for 95 of the 2 011 objects available in Thingi10k (corresponding to 496 design files of the available 10 000) due to some objects being too small or too big to be realistically printed. Scaling was most often carried out from the imperial to the metric system or by a factor of 10 000 or 1 000. Scaling however has no impact on the median size of 3D printable objects, although it would affect their average size.
Source: Author's compilation using Thingi10k.

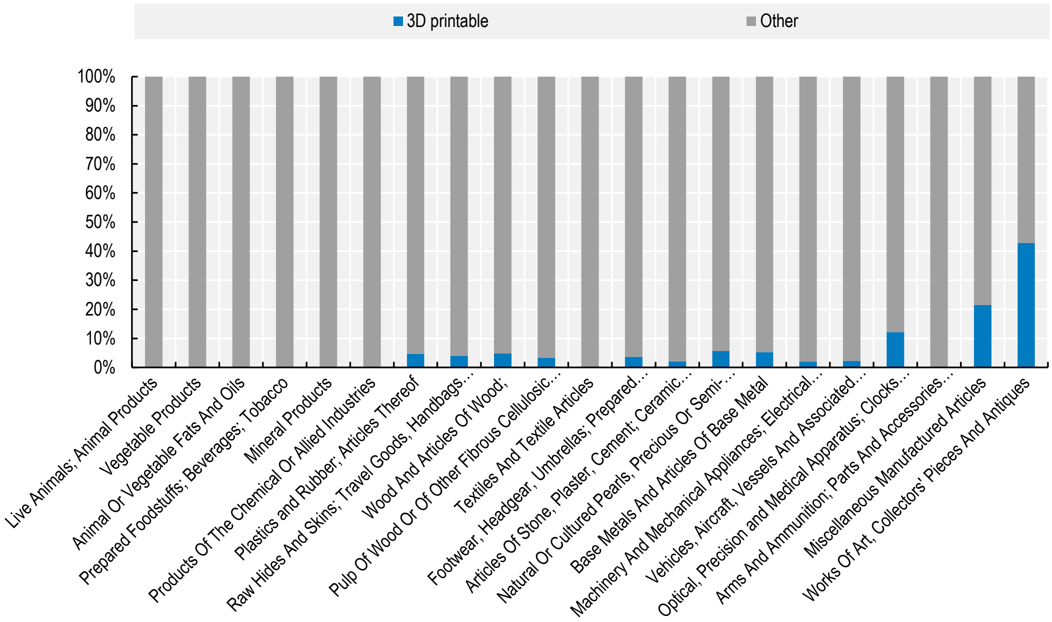
35 Ranging between 14.91 cm² (5th percentile) and 10 554 cm² (95th percentile) in total surface area, with a median surface area of 1 073 cm².

On the basis of the available information, a correspondence between the 3D printable objects in Thingi10k and internationally traded products in the Harmonised System nomenclature is built (see Annex B for an explanation of the methodology). This helps identify which particular items might be susceptible to being affected by the wider adoption of the technology, and identify in which sections of the HS system these articles might be found (Figure 18).

Overall, the HS category with the most potentially 3D printable items is 'works of art' (HS Section XXI) where about 43% of the total HS lines, three out of seven, include 3D printable items. This is followed by miscellaneous manufactured articles (HS Section XX), at 21.5% of total codes, and HS Section XVIII with 12.1% of total HS lines comprising potentially 3D printable objects, including clocks, watches and musical instruments.

Figure 18. Open-source 3D printable items concentrate in few product categories

Share of 3D printable items over total HS lines by section of the Harmonised System nomenclature



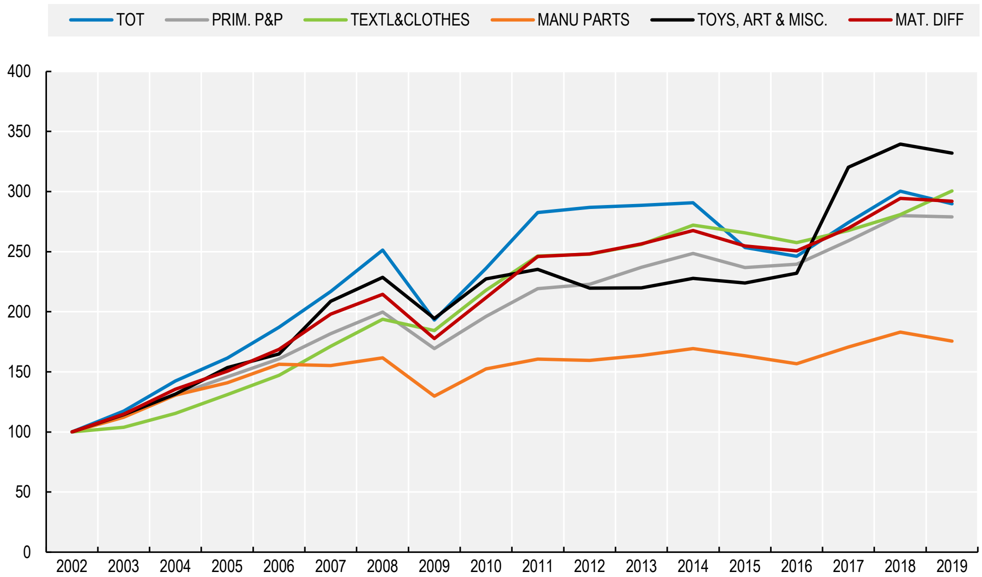
Note: Includes items whose functions can be performed by 3D printed products while being classified in the Harmonised System in different materials (e.g. tool handles normally made of wood, but that can be 3D printed in polymers). See Annex B for a discussion.
Source: Authors' calculation based on Thingi10k.

It is important to highlight that this corresponds to objects found within the Thingi10k dataset – and is hence representative of items that tend to be open-sourced on the internet. Different models of 3D printing adoption, for instance at the firm-level, are allowing for the production of an increasing number of items in the medical products sector or for spare parts, for instance, that are rarely found in an open-source repository of 3D printing design files like Thingiverse (Section 3.1). This highlights that the list of 3D printable objects constructed provides an indication of the particular products that are likely to be affected by 'household type' 3D printing adoption only (see the literature review). [36]

[36] The HS correspondence to the 34 unique 3D printable items identified by Arvis et al. (2017[47]; Freund, Mulabdic and Ruta, 2019[3]) in SITC3 includes a total of 184 HS2002 codes. A total of 143 unique HS2002 codes were identified using Thingi10k. Only 14 HS codes appear in both lists.

Trade in 'household' 3D printable products has moved at a similar pace as total trade over the last decades – with the exception of 3D printable items in the category of manufacturing parts, which has fallen,[37] and trade in toys, works of art and miscellaneous manufacturing articles (e.g. furniture, illuminated signs) which has outpaced total trade in recent years (Figure 19). Overall, this suggests that, to date, there is little prima facie evidence of large changes in trade as a result of wider adoption of 3D printing technologies by households.

Figure 19. International trade in 'household' 3D printable items



Note: 2002=100. The figure is obtained by collapsing products identified as 3D printable belonging to similar sections of the HS nomenclature. TOT=total trade; PRIM. P&P: Plastic and Paper products in primary forms (HS sect. VII and X); TEXTL & CLOTHES: Textile and clothing articles (HS sect. XI and XII); MANUPARTS: manufactured parts (HS sect. XVI, XVII, XVIII); TOYS, ART & MISC.: toys, works of art, and miscellaneous manufactured articles (HS sect. XX and XXI); MAT.DIFF: materially different 3D printable products, i.e. products that can be 3D printed as substitutes for certain goods like iron rivets, kitchen glassware or leather belts, but that were not found in such material in the Thingi10k dataset (e.g. a replacement rivet in polymers instead of iron, belt parts not made of leather). In 2019, PRIM. P&P accounted for about 16.1% of total trade in Thingi10k products; TEXTL&CLOTHES for 3.4%; MANU PARTS for 52.8%; TOYS, ART & MISC. for 14.6%; MAT.DIFF for 13.1%.
Source: Thingi10k dataset and BACI CEPII database.

[37] The slower growth in this category is mainly attributable to the fall in the value of trade in digital processing units for computers (HS2002 847330), of which related plastic elements (e.g. cases) are printed by hobbyists. The value of trade in the category accounted for 50.3% of total trade in MANU PARTS in 2002, and 25.6% in 2019. The quantity of trade in this item, however, has kept pace with the quantity of overall trade, reflecting that price effects are likely to be driving the decrease in manufactured parts. Other products that have grown less than total trade include sounds recordings and reproducing apparatus, a number of watch and clock parts, drawing, marking-out, and mathematical calculating machines, items related to photographic apparatus, or automatic banknote dispensers. Technological obsolesce is hence more likely to explain the changes observed in this category than large-scale home 3D printing, though more research on the exact drivers of this change may be needed.

4. 3D printing adoption and trade in goods: What is the evidence to date?

As noted in the previous sections, the impact of 3D printing on trade is likely to be multifaceted and depend on a number of factors, particularly the speed of adoption, *how* the technology is used (e.g. whether home printing or distributed or concentrated manufacturing) and for *what* purposes it is used (e.g. what items are being printed). However, data on these elements are not readily available. As discussed in the previous section, international trade nomenclatures do not, at present, separately identify trade in 3D printing machines (Box 3), nor do they classify goods according to whether or not they have been 3D printed (or identify trade in 3D printing services). Moreover, publicly available and reliable indicators on the adoption of additive manufacturing technologies, whether by firms or individuals, are not widely available. This implies that empirical analysis in this area needs to be approached with caution. Identifying the extent to which 3D printing technologies might be *trade substituting* for goods, as suggested in Leering (2017[1]), or *trade enhancing* for goods as posited by Freund, Mulabdic and Ruta (2019[3]) will remain a challenge until reliable statistics become available.

Notwithstanding the data limitations, there is a need to provide greater insights on the emerging relationship between 3D printing and international trade, given increasing discussions in trade policy circles. While some insights into existing linkages are starting to appear in the economic literature (Box 4), more analysis is needed. This is especially important in the context of ongoing discussions on issues that will affect the future of 3D printing in regional trade agreements and under the WTO's Joint Statement Initiative on e-commerce. It is also important in the context of discussions related to the renewal of the WTO Moratorium on Customs Duties on Electronic Transmissions (Andrenelli and López González, 2019[51]). All these discussions would benefit from a stronger empirical evidence base.

Box 4. What is the evidence on the impact of 3D printing on international trade?

Only a handful of studies have sought to empirically assess the impact of additive manufacturing technology on international trade flows, each using different approaches to capture 3D printing adoption.

- An early report by Leering (2017[1]), based on strong assumptions about a rapid adoption and strong substitution with respect to trade, estimated that 3D printing would reduce trade by as much as 22% by 2060.[1] This estimate was later revised to a 4.5% reduction in world trade by 2040 (Leering, 2021[52]).
- Cavedagna and Lamperti (2017[14]) used patent statistics from the United States Patent and Trademark Office (USPTO) to proxy for additive manufacturing adoption.[2] They found that ICT infrastructure and protection of property rights were important determinants of innovation in AM technologies which was, in turn, correlated with higher domestic value added in exports in the machinery and equipment sector. The authors also found evidence that greater AM adoption was related to lower shares of re-exported inputs and total imported inputs in selected industries.[3]
- Abeliansky, Martinez-Zarzoso, and Prettner (2015[45]; 2020[46]) used a gravity model to estimate the impact of trade costs on the quantity of imports of additive manufacturing machines (as proxied by the HS code 847780). They found that 3D printers were mostly imported in large economies where high transport costs prevailed. In terms of the effects of trade in 3D printable goods, the authors reported a negative correlation between the one-year lag of sales of

industrial 3D printers and the volume of imported hearing aids (classified in tariff line 9021.40) in a sample of 17 countries.

- Freund, Mulabdic and Ruta (2019[3]) adopted a difference-in-difference approach to empirically assess whether international trade in hearing aids followed different patterns in the post-3D printing adoption period (2007-2016) compared to the period 1995-2007.[4] The authors found that 3D printing adoption had a strong and positive impact on trade flows of hearing aids – resulting in a 58% percentage increase in exports and a 104% increase in imports relative to similar products (p.9).
- Freund, Mulabdic and Ruta (2019[3]) also estimated the impact of 3D printing adoption for a basket of 34 3D printable products beyond hearing aids (the list – in the SITC nomenclature – builds on Arvis et al. (2017[47]). The authors found a positive impact of 3D printing adoption on trade, albeit smaller than that identified for hearing aids. The authors also show some evidence that additive manufacturing technology could result in the substitution of trade in heavier products and increases of trade in lighter products, in light of differences between trade costs for the two types of goods, which would condition the type of additive manufacturing deployment.

Notes

1. The study, however, builds on strong assumptions on the pace at which investment in AM would grow, on the substitution between mass manufacturing and additive manufacturing, and on the linear and negative relationship between adoption of 3D printing and cross-border trade in goods. The fall in trade is a combination of a hypothetical reduction in the level of trade in goods as well as in those services related to trade in goods (e.g. transport).
2. The authors classified relevant patents by filtering through keywords found in patent applications (a separate classification for additive manufacturing patents was not yet available).
3. These industries are fabricated metal products (ISIC C28), machinery and equipment (C29) and motor vehicles (C34) (Cavedagna and Lamperti, 2017[14]).
4. With 2007 being the year in which hearing aids production was disrupted by additive manufacturing adoption (Brans, 2013[81]).

4.1. Are imports of 3D printers linked to higher exports of 3D printable items?

One of the facets that has not been explored in the existing literature is the extent to which access to imported 3D printers, or adoption of additive manufacturing via international channels, enables firms to engage more widely in the production of 3D printable items. This is likely to be an important channel through which the benefits of 3D printing materialise, especially for countries which might not have the knowhow to produce 3D printers but which can position themselves as users of the technology to produce 3D printable items more competitively. The benefits of adoption via this channel are likely to be similar to those that are discussed in the context of GVC participation, where countries gain access to more sophisticated inputs and technologies to enhance domestic production and exports (see OECD (2013[53]), Kowalski (2015[54]), and Lopez-Gonzalez (2017[55])).

Identifying proxy measures for imports of 3D printers and exports of 3D printable items

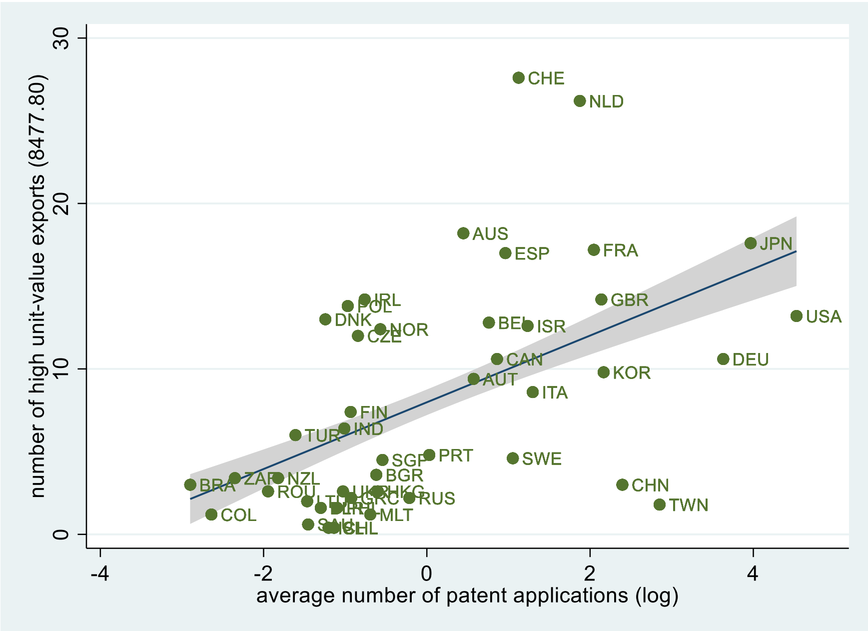
To assess the extent to which adoption of 3D printing technology through imports is associated with exports of 3D printable items, proxy measures for these variables are needed.[38] For imports of 3D printers, HS code 847780 is used based on WCO recommendations for classifying existing trade in 3D printers (Box 3)

[38] An alternative methodological approach involves the use of difference-in-difference techniques which compare trends before and after the adoption of 3D printing to draw observations on its impact on the period following adoption (Freund, Mulabdic and Ruta, 2019[3]). While this sidesteps the need for proxy measures, it requires a relatively fast adoption and strong knowledge of when 3D printing was widely adopted in specific sectors.

and on the basis of recent empirical analysis providing supporting evidence for this choice (see Abeliansky, Martinez-Zarzoso, and Prettner (2015, pp. 26-28[45]; 2020[46])). However, in order to more accurately capture trade in 3D printers, only the value of trade that is above the global average unit value is considered (see Annex B for further details).

The motivation behind this choice is that, within this HS-code, various items are likely to be captured, some of which are not 3D printers. Selecting only trade that is above the average global unit-value aims to ensure that 3D printers, which tend to be higher tech items and likely to command higher prices, are more precisely identified. This proxy measure is strongly correlated with measures of domestic innovation, such as the number of patent applications in additive manufacturing technologies (which are available for a reduced sample of countries and time) (Figure 20).

Figure 20. High unit-value exporters of product 847780 are strong innovators in AM technologies



Note: This figure shows the correlation between the frequencies with which countries export at higher than average unit values (y-axis) and the average number of patent applications in additive manufacturing technologies in the years for which information is available (2013-2017). For example, Korea exported high unit value machinery in the code 847780 to ten different destinations per year in the period 2013-2017, while also featuring among the top innovators in additive manufacturing technologies (behind the United States, Japan, Germany, Chinese Taipei, and China).
Source: OECD Patent Statistics and CEPII BACI database.

Identifying exports of 3D printed items is also complex. Trade nomenclatures do not break down goods or services by method of production. That is, while trade data will capture physical trade in goods that have been 3D printed, it also captures trade in similar goods that have not been 3D printed.[39] Although little can be done about this in the absence of more detailed information about trade in 3D printed goods, it is likely that changes in trade for specific 3D printable products are at least, to some extent, related to the use of

[39] Moreover, while some products (such as hearing aids) have been overwhelmingly affected by additive manufacturing technology (Brans, 2013[81]), others may be little affected by the technology, with traditional manufacturing techniques still playing an important if not prominent role in their production and exchange. The timing at which different items were affected by 3D printing also varies from good to good.

3D printing technology (Freund, Mulabdic and Ruta, 2019[3]), providing the opportunity to capture some variation arising from 3D printing adoption, especially when controlling for other confounding factors.[40]

This paper uses a list of 3D printable items identified in a recent World Bank study (see Arvis et al. (2017[47]) as referenced in Freund, Mulabdic and Ruta (2019[3])). Based on expert judgement, the list includes 34 unique customs codes containing a range of products including pharmaceuticals, manufacturing equipment, aircraft parts and medical products, as well as other lower-technology 3D printable items such as knives, handtools and candles (see Section 3 and Table A.3, Annex A). [41]

Modelling the links between imports of 3D printers and exports of 3D printable items

The role of international adoption of 3D printing on exports of 3D printable items is modelled via a dynamic panel estimation where changes in exports of 3D printable goods are a function of:

- *Past performance,* captured by way of lagged dependent variables of exports to reflect dynamic changes and export persistence
- *Structural parameters* which include per capita GDP, R&D expenditure and inward FDI flows and capture supply capacity variables
- Measures of *adoption of 3D printing technology*, in this case via proxy measures of imports of 3D printers
- Controls for *overall import demand*, captured by way of total imports (excluding the proxy measures for imports of 3D printers). This will help control for determinants of imports that may affect export performance (allowing the variable on import of 3D printers to capture variance specific to that particular product). This variable would also control for the prevailing trade policy environment.

Further details on the model and the regressors are provided in Box 5 and Annex C.

The estimations are undertaken across two different sample periods: 2002-2009 and 2010-2018. This is, first, to capture differences between periods where the speed of adoption was different (with the earlier period characterised by slow 3D printing adoption and the more recent period by more rapid adoption; see for instance Wohlers (2019[56]), as reported in World Economic Forum (2020, p. 8[7])) and, second, for technical reasons related to the GMM specification.[42] The year 2010 is taken as a cut-off period since the start of the decade marked fuller deployment of 3D printing technologies, notably thanks to the expiry of key patents and the wider availability of different AM techniques (Box 1).[43]

[40] Confounding factors are variables that affect the dependent and/or independent variables causing spurious associations.

[41] A concordance is used to translate the product codes from SITC into the HS nomenclature, in order to work with the BACI database. The sensitivity of results is also tested to using trade data as extracted through the original SITC nomenclature from COMTRADE (Table C.4, Annex C).

[42] With GMM techniques best suited for situations with 'large N, small T', and in light of the double lag structure of the main model for the dependent variable, limiting the number of years over which hypotheses are tested allows to contain instrument proliferation (Roodman, 2009[57]) and improve the reliability of the model.

[43] Noting, however, that some product markets like hearing aids started to be affected a few years prior to this date (e.g. 2007-2008) (Freund, Mulabdic and Ruta, 2019[3]).

Box 5. Identifying changes in patterns of 3D printable trade

The empirical strategy is based on a production function where determinants of exports of 3D printable items at the country level are a function of past realisations of exports of 3D printable goods, a range of structural variables capturing technological capacity, foreign investment and factor endowments, a measure of the prevailing trade policy environment and a measure for international adoption of 3D printers. This is synthesised into the following reduced form equation:

$$X_{it} = \beta_1 X_{it-1} + \beta_2 X_{it-2} + \beta_3 M3DP_{it} + \beta_4 TotImp_{it} + \beta_5 GDPcap_{it} + \beta_6 R\&Dexp_{it} + \beta_7 inward\,FDI_{it} + \partial_i + \delta_t + \varepsilon_{it}$$

Where X_{it} is the natural logarithm of the sum of exports of 3D printable items of country *i* at time *t* and X_{it-1} and X_{it-2} are the lagged dependent variables used to capture dynamics and controlling for omitted variables and autocorrelated residuals arising from persistence in the series. $M3DP_{it}$ is the log of the proxy measure for imports of 3D printers, our variable of interest, while $TotImp_{it}$, the log of total imports net of measures of imports of 3D printers, is a control measure capturing determinants of overall imports, including the prevailing trade policy environment. $GDPcap_{it}$ is the natural log of per-capita GDP, $R\&Dexp_{it}$ is R&D expenditure as a share of GDP and $inward\,FDI_{it}$ is existing inward foreign investment as a share of GDP. These last three variables are used to control for, among others things, capital labour ratios, technological capacity, innovation expenditure and realised foreign investment. A set of country (∂_i) and year (δ_t) fixed effects are also used to control for country and time specific effects.

A dynamic, system Generalised Method of Moments (GMM), specification is used to help deal with potential problems arising from endogeneity (see Annex C for a brief discussion of GMM estimators).[1] The number of lags is chosen to remove second-order serial correlation and improve instrument validity (Sargan-Hansen test).

Note: 1. The use of systems GMM over difference GMM is justified on the basis of Bond, Hoeffler and Temple (2001[63]), as detailed in Annex C.

The results support the hypothesis that imports of 3D printers had a positive and statistically significant impact on exports of 3D printable products for the period 2010-2018, but not for the decade prior to 2010 (Table 4).[44] In the baseline model, a 1% increase in the value of imports of 3D printers corresponds to a +0.02% increase in the value of exports of 3D printable items. While this coefficient may look small, in dollar terms it implies that, all else equal, an increase of around USD 14 000 in imports of 3D printers (as proxied by the above average unit-value measure) is associated with an increase of about USD 3.3 million in the aggregate value of 3D printable exports. The impact is therefore not only statistically significant, but also economically important and suggests new evidence of complementarities between 3D printing adoption and trade in goods.

A series of sensitivity and falsification tests were run as robustness checks (Annex C). These include: using alternative econometric techniques (pooled OLS and Fixed effect regressions); testing the results to instrument reduction (Roodman, 2009[57]); using different export data (in SITC instead of HS nomenclature); using alternative measures of imports of 3D printers (i.e. HS code 8479.89 (Hodes and Mohseni, 2014[58]), both including the whole value of trade in the product line as well as by only considering the above average unit value of trade); and running a series of placebo tests using imports of unrelated

[44] The fact that the relationship is statistically significant only for the period associated with more rapid adoption of 3D printing technologies is reassuring as it suggests that the model might not be capturing a spurious relationship.

goods (to ensure that correlation is not driven by common factors which explain exports more broadly).[45] The statistical relationship between indicators of imports of 3D printers and exports of 3D printable items remains robust to these tests.

Table 4. Imports of 3D printers and exports of 3D printable items

	2002-2018	2002-2009	2010-2018
Dependent variable:	3D printable exports	3D printable exports	3D printable exports
3D printable exports (N-1)	0.661***	0.771***	0.647***
	(0.0803)	(0.0657)	(0.0902)
3D printable exports (N-2)	0.0939	0.103	0.238
	(0.115)	(0.0793)	(0.145)
Proxy for 3D printer imports	**0.00638**	**-0.0111**	**0.0224****
	(0.00674)	**(0.00729)**	**(0.00873)**
Total imports	0.281*	0.173*	0.100
	(0.162)	(0.0879)	(0.0789)
GDP per capita	0.0382	0.0402	-0.000965
	(0.0420)	(0.0376)	(0.0302)
R&D expenditure	0.0917	0.0109	0.0622
	(0.0563)	(0.0426)	(0.0396)
Inward FDI	0.000662	0.000632	0.000783
	(0.000557)	(0.000532)	(0.000727)
Observations	1284	519	765
Number of instruments	37	42	74
Number of groups	129	113	124
AR1 (p-value)	0.00265	0.0278	0.0375
AR2 (p-value)	0.726	0.631	0.405
Hansen-J (p-value)	0.339	0.00408	0.253

Note: The table shows results for the model described in Box 5. It uses a system GMM estimator across different time periods. The instrument matrix is collapsed for the period 2002-2018 in order to contain instrument proliferation and maintain the number of instruments below the number of groups (Roodman, 2009). All variables are in log except R&D expenditure and Inward FDI (shares). Standard errors in parentheses (* p<0.10; ** p<0.05; ***; p<0.010).
Source: Own calculations.

To identify differences across product categories, 3D printable items are divided into two subsets, one including higher tech items (namely aircraft parts; machine parts; medications & pharmaceuticals; and orthopaedic appliances) and one including lower tech 3D printable items (e.g. knives, hand tools, candles).[46] The results suggest that the impact of importing 3D printers remains statistically significant across both types of items, but it is more positive for high-tech exports (Table 5).

[45] The goods used in these placebo tests include unrelated items like apples, locomotives and explosives, but also all capital goods (as identified through the OECD BTDIx correspondence, excluding HS code 8477.80) and injection moulding machines.

[46] These accounted, on average, for 72.1% and 27.9% of the value of 3D printable trade respectively in the period 2010-2018 (Figure 10).

Table 5. Impact of importing 3D printers on exports of high and low tech 3D printable goods exports (2010-2018)

	Low-tech 3D printable exports	High-tech 3D printable exports
Low-tech 3D printable exports(N-1)	0.581***	
	(0.1000)	
Low-tech 3D printable exports(N-2)	0.223***	
	(0.0637)	
High-tech 3D printable exports(N-1)		0.571***
		(0.122)
High-tech 3D printable exports(N-2)		0.261*
		(0.145)
Proxy for 3D printer imports	**0.0218***	**0.0269*****
	(0.0111)	**(0.00982)**
Total imports	0.236*	0.151**
	(0.140)	(0.0632)
GDP per capita	-0.0142	0.0430
	(0.0358)	(0.0399)
R&D expenditure	0.0676	0.0860*
	(0.0497)	(0.0469)
Inward FDI	-0.000330	0.00133
	(0.00109)	(0.000954)
Observations	765	765
No. of instruments	74	74
No. of groups	124	124
AR1 (p-value)	0.0402	0.0516
AR2 (p-value)	0.487	0.369
Hansen-J (p-value)	0.406	0.130

Note: The table shows results for the model described in Box 5 across different types of 3D printed items, whether high tech or low tech. High-tech 3D printable exports includes aircraft parts; machine parts; medications & pharmaceuticals; and orthopaedic appliances. Low-tech 3D printable items include knives, hand tools, candles, table glassware, fittings for plastic tubes, and industrial moulds, among other products. See Table A.3, Annex A, for the full classification. All variables are in log except R&D expenditure and Inward FDI (shares). Standard errors in parentheses (* p<0.10; ** p<0.05; ***; p<0.010).

The results also suggest some differences across levels of development for high-tech products. Indeed, when the sample is split between developing countries and high-income countries,[47] the coefficient on imported 3D printers appears to be economically stronger and statistically more significant for developing countries than for high-income countries (Table C.6 in Annex C).[48] This might suggest that access to foreign 3D printing technology to strengthen export capacity in high-tech 3D printable items is more important for developing countries than it is for high-income countries.[49]

Overall, these results suggest a complementary relationship between 3D printing and goods trade, implying that wider adoption might even lead to increases in the value of goods crossing borders in the short run, with implications for the ongoing debate on the Moratorium on customs duties on electronic transmissions.

[47] As defined in the June 2020 World Bank classification.

[48] Splitting the sample has implications for the GMM estimation, which require making adjustments to the instrument count in the baseline model. Notably, reducing the number of groups requires reducing the instrument count as well as limiting the lags used in the HENR (1988[66]) equation (Roodman, 2009[57]). In light of the relatively high number of instruments with the double lag structure, both adjustments are needed to gauge at potential differences between the country groups.

[49] By contrast, the coefficient of the same test for low-tech goods remains significant only for high-income countries, while not being significant for the developing country group.

4.2. What is the evidence of links between imports of 3D printers and imports of 3D printable items?

The relationship between the adoption of 3D printing technology and imports of 3D printable products is also important since it can help shed light on whether there might be evidence of emerging trade substitution. Indeed, if the adoption for 3D printing technology is associated with lower imports of 3D printable goods, this might mean that these items are being printed domestically instead of sourced internationally. However, if 3D printing adoption is linked with more imports of 3D printable items, this would further reinforce the preliminary evidence on existing complementarities.[50]

To test this hypothesis, a similar system GMM model is used, although based on an import demand equation rather than a production function. Demand for imports of 3D printable goods is modelled as a function of *past performance* (the lagged dependent variables), *structural parameters*, which include measures of income (per capita GDP) and human capital (human capital index)[51] to capture demand side variables, a measure of *adoption of 3D printing technology*; and controls for *overall import demand* (Box 5).

The results suggest that there is a positive relationship between imports of 3D printable goods and the international adoption of 3D printing (Table 6). While the channels of transmission can be difficult to establish, the results are in line with those in Freund, Mulabdic and Ruta (2019[3]) and corroborate the findings from the previous section showing complementarities between the adoption of 3D printing technologies and trade in goods. The results are robust to different specifications, the inclusion of different measures of adoption of 3D printing, including measures of domestic adoption constructed using Google Trends data; and different controls for the trade policy environment.[52]

The relationship between 3D printing adoption at the household level and imports of 3D printable items is also tested (Box 6). The preliminary results suggest that there is no statistically significant relationship between proxy measures of adoption of 3D printing by households and imports of desktop 3D printable items, providing some preliminary evidence to suggest that there appears to be no substitution taking place.

This further supports the view that 3D printing is unlikely to have widespread implications for the debate on the Moratorium.

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50 Noting difficulties with the analysis, (Freund, Mulabdic and Ruta, 2019[3]) find some evidence of a positive relationship between 3D printing and imports of 3D printable items.

51 The human capital index in the import demand function mirrors R&D in the export production function – aiming to capture knowledge-related dynamics behind greater demand for 3D printable goods (which are generally high-tech items).

52 The analysis also reveals interesting differences between developing and high-income countries as well as higher and lower technology goods, which would require further attention but point to complementarities being particularly important for higher technology goods (Table C.7 in Annex C).

Table 6. Imports of 3D printers and imports of 3D printable items

	2002-2018	2002-2009	2010-2018
Dependent variable	3D printable imports	3D printable imports	3D printable imports
Imports of 3DP products (N-1)	0.419***	0.674***	0.674***
	(0.131)	(0.135)	(0.0534)
Imports of 3DP products (N-2)	0.107***	0.183***	0.101***
	(0.0315)	(0.0425)	(0.0353)
Proxy for 3D printer imports	**0.00320**	**0.00176**	**0.00506****
	(0.00203)	**(0.00247)**	**(0.00234)**
Total imports	0.459***	0.138	0.217***
	(0.145)	(0.153)	(0.0474)
GDP per capita	0.0281	-0.00436	-0.00165
	(0.0199)	(0.0217)	(0.00790)
Human capital indicator	0.0138	0.00225	0.0254
	(0.0258)	(0.0249)	(0.0186)
Inward FDI	-0.000505	-0.000170	-0.000683***
	(0.000314)	(0.000109)	(0.000197)
Observations	2040	820	1220
No. of instruments	37	39	69
No. of groups	137	137	136
AR1 (p-value)	0.0000187	0.00000229	0.00000209
AR2 (p-value)	0.857	0.0143	0.336
Hansen-J (p-value)	0.354	0.198	0.370

Note: The table shows the point estimates for the determinants of imports of 3D printable goods using a system GMM estimator across different time periods. All variables are in log except the human capital index and Inward FDI (shares). Standard errors in parentheses (* p<0.10; ** p<0.05; ***; p<0.010).
Source: Own calculations.

Box 6. Adoption of 3D printing by households and imports of 3D printing items – some preliminary numbers

While the previous analysis largely focuses on industrial uses of 3D printing technology as associated with goods such as medical instruments or aircraft parts, wider adoption of the technology at the household level is also likely to have trade impacts, albeit for different types of goods. Indeed, if consumers are able to 3D print items rather than buy them, then one might expect a negative correlation between measures of household adoption and imports of 3D printable items most associated with open-source 3D printing.

Identifying household adoption of 3D printing technologies and the goods that these might print is difficult and requires the use of proxy measures.

- For household adoption of 3D printing: data from Google Trends is used were the ratio between searches of the Topic ‘3D printing filament’[1] and searches of the Topic ‘injection moulding’ (a more traditional manufacturing technique) is used. The aim is to capture variation on the relative use of these technologies.
- For data on imports of 3D printable goods as identified using a derived correspondence table between items in the Thingi10k dataset and HS codes (Annex A).

The empirical strategy used is similar to that presented in the empirical analysis and summarised in Box 3. However, instead of a production function, it is based on an import demand function. The determinants of imports of 3D printable items by country i at time t, $\boldsymbol{M_{it}}$, are a function of past realisations of these imports, $\boldsymbol{M_{it-1}}$ and $\boldsymbol{M_{it-2}}$, a range of structural variables capturing import demand, $\boldsymbol{TotImp_{it}}$, income proxied by per capita GDP, $\boldsymbol{GDPcap_{it}}$, foreign investment, $\boldsymbol{inward\ FDI_{it}}$ and human capital $\boldsymbol{HC_{it}}$ (as a demand shifter mirroring the R&D variable in the production function in Box 5, which acted as a production shifter), as well as a proxy for adoption of 3D printing technology at the household level, $\boldsymbol{A3DP_{it}}$. A set of country ($\boldsymbol{\partial_i}$) and year ($\boldsymbol{\delta_t}$) fixed effects are also used to control for time and country invariant factors.

$$M_{it} = \beta_1 M_{it-1} + \beta_2 M_{it-2} + \beta_3 A3DP_{it} + \beta_4 TotImp_{it} + \beta_5 GDPcap_{it} + \beta_6 HC_{it} + \beta_7 inward\ FDI_{it} + \partial_i + \delta_t + \varepsilon_{it}$$

This specification is tested on a reduced sample of 51 countries, given that the measure of domestic adoption was unavailable for more countries. The results show that, while all variables have the expected sign and key tests are in range (AR2 and Sargan-Hansen test), there does not seem to be a statically significant relationship between household adoption and import of 3D printing items associated with household printing (Table C.8 in Annex C). A number of sensitivity and falsification tests are run, but the results remain statistically insignificant.

Although preliminary, these results suggests that there might not be a relationship between 3D printing adoption at the household level and imports of 3D printed items, in turn suggesting that households might 3D print items that they would have not imported, or that this type of 3D printing adoption may not yet be sufficiently widespread to have consequences for aggregate trade flows. Nevertheless, more work is needed to better understand the evolving relationship between 3D printing at the household level and imports of 3D printable items.

Note: 1. Specific queries related to this topic include ‘filament 3D’ and its variants, including in different languages, as well as ‘PLA’, ‘ABS’ or ‘PETG’, which are popular materials for Fused-Deposition Modelling 3D printing. The indicator is extracted over 6 different samples and computed using a simple average to reduce the risks associated to sampling variance in Google Trends (Jaax, Gonzales and Mourougane, 2021[88]).

5. Conclusions and policy implications

This paper has highlighted that 3D printing is a versatile technology offering new opportunities for firms to increase productivity and product scope across a range of specific tasks and sectors, from parts and components in the aerospace industry to architecture, healthcare and food. 3D printing technologies display particular cost advantages in the production of low volumes of geometrically complex and materially simple objects. They also provide unprecedented design freedom for customisation and prototyping and offer valuable opportunities to strengthen resilience in value chains, especially in manufacturing sectors where spare-part inventories can be costly or time is critical.

This report also highlights a number of measurement challenges. Some of these are likely to be resolved through the creation of HS heading 84.85 to identify additive manufacturing machines in the Harmonised System Nomenclature (World Customs Organisation, 2019[44]). Efforts to better measure digital trade more generally are also advancing (OECD-WTO-IMF, 2019[42]), and a number of initiatives have been undertaken to build monitoring frameworks to map the evolution of 3D printing for trade (World Economic Forum, 2020[7]). However, comprehensive, internationally comparable, and publicly available statistics on the use or adoption of 3D printing remain unavailable, and the world of CAD design files crossing borders for 3D printing remains uncharted. Progress on measurement, and especially in the trade in services-related aspects of 3D printing, is hence important to paint a full picture of the relationship between the technology and trade.

Although identifying trade in 3D printers, 3D printable goods and the materials used in additive manufacturing processes is complex, proxy measures can provide useful insights on adoption and use of the technology. They suggest that international adoption of 3D printing is growing and that trade in high-tech 3D printable goods, such as aircraft parts and orthopaedic appliances, and trade in open source 3D printable items that can be home-printed, has generally grown at the same pace as total trade.

The econometric analysis shows a positive and statistically significant relationship between proxy measures of imports of 3D printers and exports and imports of 3D printable products, with results being robust to a large number of sensitivity checks. This provides preliminary evidence of trade complementarities between 3D printing adoption and trade in goods.

Overall, the evidence presented in this study suggests that it is premature to conclude that 3D printing technology will ‘replace’ trade. Not only is there little evidence of this happening to date, but the multifaceted relationship between the technology and international trade is likely to play out over time, including through positive impacts on trade in materials (e.g. polymers and metals) and in design services. Although policy-makers are advised to think about 3D printing as a productivity enhancing technology, it will be important to continue monitoring progress in adoption to better understand the longer term consequences of the technology on trade flows.

With respect to the ongoing debate on the renewal of the Moratorium on customs duties on electronic transmissions, the results presented herein suggest that the evidence to date does not support the view that 3D printing will have wide-ranging impacts on physical trade in the short to medium-term.

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Annex A. Identifying 3D printable goods in customs data

A.1. Using the Thingi10K database to identify goods that can be 3D printed at home

The Thingi10k dataset includes 2 011 objects representing the 'featured' design files on the popular website Thingiverse, posted between September 2009 and November 2015 (Zhou and Jacobson, 2016[50]). These objects were regularly webscraped from the website with the objective of studying the geometrical properties of their component elements: the 10 000 design files from which the website draws its name.

However, the wealth of information collected as part of this exercise can be of use also for the identification of those objects that can be or are 3D printed on the web, particularly in the context of 3D printing at home or by hobbyists. The website gathers quantitative information such as the intended size of 3D printable objects as well as qualitative information on the categories and sub-categories in which users classified their design files and the tags they included to make those objects more easily findable on the website. The open-source nature of Thingi10k allows easy access to this information.

In this report, Thingi10k is used to build a correspondence between the text variables of Thingi10k and the harmonised system classification in its 2002 nomenclature. A mix of manual and software-driven approaches were used for this purpose. A manual approach was adopted to classify those objects that were ascribed by users to particular categories and subcategories, such as 'fashion' (category) and 'accessories' (subcategory). This involved identifying a range of HS codes that could represent the mix of objects found within each subcategory (Table A.1). The manual approach was preferred for these objects because of the manageable number of things classified under subcategories, and in order to maintain supervision over the matching process, including by exploring the pictures, comments and actual 'Makes' relating to individual objects on the Thingiverse website.

Four hundred and fifty-one of the 2011 'things' included in Thingi10k, however, were not classified by users under categories and subcategories. This miscellaneous subset is much harder to classify manually into the HS system, which is why a software-driven approach using Python was adopted for its inclusion in the list of 3D printable objects. This process required a number of different steps, which included: creating one string variable containing all of the information available for particular objects (i.e. its name and tags); restricting the number of potential chapters that could match 3D printable objects in the HS (by excluding for instance live animals and vegetable products); or removing 'stopword matches' that would reflect the association of Thingi10k things and HS codes due to words like 'made', 'height' or 'size', which do not add information on the particular association between objects and HS codes. The software-driven approach led to the identification of additional products not initially included in the list of 3D printable products. Table A.2 indicates which particular HS codes were identified thanks to this text-matching technique.

An additional aspect of the correspondence regards those matches with products that fulfil the function of objects that can be 3D printed on Thingiverse, but that are classified in the HS system under materials other than those used to print them on the website. For example, a number of tools, tool parts, and screws of different sizes are available in Thingiverse, although users print those with polymers and not in metals. However, those objects are classified in the HS under heading 82, as tools of base metal. Those and other objects are included in the correspondence although they are identified with a binary variable indicating that they are materially different from those found on Thingiverse.

Table A.1. Matching Thingi10k subcategories to a range of HS2002 codes

Category	Subcategory	Quantity	HS2002
3d-printing		11	9102.21, 9102.99, 9113.90, 9504.90
3d-printing	3d-printer-accessories	10	8477.90
3d-printing	3d-printer-extruders	5	8477.90
3d-printing	3d-printer-parts	5	8477.90
3d-printing	3d-printers	5	3923.10, 8473.30, 8477.90
3d-printing	3d-printing-tests	6	3923.10
Art	2d-art	20	4911.91, 4911.99, 7118.10, 9503.20, 9503.49, 9503.70, 9503.90, 9703.00, 9705.00
Art	Art-tools	9	
Art	Coins-and-badges	9	
Art	Interactive-art	4	
Art	Math-art	20	
Art	Scans-and-replicas	38	
Art	Sculptures	56	
Art	Signs-and-logos	77	
Art		8	
Fashion		4	6204.44, 6402.99, 9003.11
Fashion	Accessories	29	4203.30, 6215.20, 6217.10, 7117.11, 9113.90, 9615.11, 9615.19, 9615.90
Fashion	Bracelets	11	7117.90, 9113.90
Fashion	Costume	18	9505.10, 9505.90
Fashion	Earrings	3	7117.90
Fashion	Glasses	9	9003.11
Fashion	Jewelry	13	7117.90
Fashion	Keychains	13	6217.10
Fashion	Rings	7	7117.90
Gadgets		13	8503.00, 9105.29, 9110.11, 9111.90, 9114.10, 9114.30, 9114.90
Gadgets	Audio	14	3923.10, 8518.90
Gadgets	Camera	20	9006.99
Gadgets	Computer	9	8473.30
Gadgets	Mobile-phone	15	8522.90
Gadgets	Tablet	8	8522.90
Gadgets	Video-games	11	9504.90
Hobby		3	3923.10, 9503.20
Hobby	Automotive	8	9503.20
Hobby	Diy	20	8714.99, 9110.19, 9111.80, 9111.90
Hobby	Electronics	22	8473.30, 8517.90
Hobby	Music	32	9202.10, 9205.10, 9205.90, 9206.00, 9208.90, 9209.91, 9209.92, 9503.80
Hobby	Rc-vehicles	24	9503.20
Hobby	Robotics	38	8473.30, 9503.20
Hobby	Sports-and-outdoors	20	6603.90, 8714.95, 8714.99, 9506.19, 9506.40, 9506.91, 9603.29, 9707.10
Household		11	4910.00, 9403.90, 9405.92
Household	Bathroom	16	3922.90
Household	Containers	25	3923.30, 3924.10, 3926.40
Household	Decor	76	3926.40, 3926.90, 9110.19, 9112.20, 9112.90, 9114.40, 9405.92, 9405.99
Household	Household-supplies	8	3926.90, 8301.10, 8708.99, 9403.90
Household	Kitchen-and-dining	43	3924.10
Household	Office	15	3926.10, 9110.19
Household	Organization	23	3923.30, 4421.10
Household	Outdoor-and-garden	21	3926.90, 7610.90, 8467.89, 9026.90
Household	Pets	7	3926.90
Household	Replacement-parts	1	
Learning		14	4905.99
Learning	Biology	18	
Learning	Engineering	15	
Learning	Math	13	
Learning	Physics-and-astronomy	18	
Models		11	9114.40
Models	Animals	43	3926.40, 9023.00, 9503.20, 9503.49, 9503.90

Category	Subcategory	Quantity	HS2002
Models	Buildings-and-structures	54	3926.40, 9023.00, 9503.20, 9503.90
Models	Creatures	34	3926.40, 9023.00, 9503.20, 9503.49, 9503.90
Models	Food-and-drink	5	3926.40, 9023.00, 9503.20, 9503.90
Models	Model-furniture	8	3926.40, 9023.00, 9503.20, 9503.90
Models	Model-robots	14	3926.40, 9023.00, 9503.20, 9503.90
Models	People	17	3926.40, 9023.00, 9502.10, 9502.99, 9503.20, 9503.90
Models	Props	32	3926.40, 9023.00, 9503.20, 9503.90
Models	Vehicles	63	3926.40, 9023.00, 9503.20, 9503.90
Tools		8	9603.29
Tools	Hand-tools	19	7315.12, 7319.90, 8204.20, 8205.10, 8205.20, 8205.40, 8212.90, 8459.70, 8466.92, 9017.20, 9017.30, 9021.39, 9021.90
Tools	Machine-tools	1	8466.30
Tools	Parts	18	3926.90, 7315.11, 7318.11, 7318.13, 7318.15, 7318.16, 7318.21, 7318.22, 7318.23, 8205.40, 8302.49, 8419.90, 8473.30, 8482.50, 8483.20
Tools	Tool-holders-and-boxes	12	7117.90, 8466.10, 8466.20
Toys-and-games		51	9502.91, 9502.99, 9503.10, 9503.50, 9503.60, 9503.80, 9504.20, 9504.30, 9505.90
Toys-and-games	Chess	6	9504.90
Toys-and-games	Construction-toys	26	9503.20
Toys-and-games	Dice	7	9504.90
Toys-and-games	Games	24	9502.10, 9503.49, 9503.70, 9504.30
Toys-and-games	Mechanical-toys	60	9503.80
Toys-and-games	Playsets	20	9503.20
Toys-and-games	Puzzles	33	9503.60
Toys-and-games	Toy-and-game-accessories	22	9504.20, 9505.90
Non-categorised	Non-categorised	451	3924.90, 3926.30, 4202.32, 4202.92, 4404.10, 4404.20, 4417.00, 7013.10, 7013.32, 7013.39, 7323.91, 7323.92, 7323.93, 7323.94, 7323.99, 7418.19, 7615.19, 8205.51, 8205.59, 8207.90, 8208.30, 8210.00, 8304.00, 8472.90, 9503.30, 9704.00

Note: The heading non-categorised things included only HS codes that were not previously classified in other categories and subcategories.
Source: Authors' calculations based on the Thingi10k dataset.

Table A.2. Household 3D printable objects

Text match	HS2002	Description	Materially different
	392290	Plastics: bidets, lavatory pans, flushing cisterns and similar sanitary ware n.e.s. in heading no. 3922	
	392310	Plastics: boxes, cases, crates and similar articles for the conveyance or packing of goods	
	392330	Plastics: carboys, bottles, flasks and similar articles, for the conveyance or packing of goods	
	392410	Plastics: tableware and kitchenware	
Yes	392490	Plastics: household and toilet articles	
	392610	Plastics: office or school supplies	
	392620	Plastics: articles of apparel and clothing accessories (including gloves, mittens and mitts)	
Yes	392630	Plastics: fittings for furniture, coachwork or the like	
	392640	Plastics: statuettes and other ornamental articles	
	392690	Plastics: other articles n.e.s. in chapter 39	
Yes	420232	Cases and containers: of a kind normally carried in the pocket or in the handbag, with outer surface of plastic sheeting or of textile materials	1
Yes	420292	Cases and containers: with outer surface of plastic sheeting or of textile materials, n.e.s. in heading no. 4202	1
	420330	Clothing accessories: belts and bandoliers, of leather or of composition leather	1
Yes	440410	Wood: coniferous, split poles, piles, pickets, stakes, pointed but not sawn lengthwise: sticks for umbrellas, tool handles etc., roughly trimmed but not turned or bent: chipwood etc., hoopwood	1
Yes	440420	Wood: non-coniferous, split poles, piles, pickets, stakes, pointed but not sawn lengthwise: sticks for umbrellas, tool handles etc., roughly trimmed but not turned or bent: chipwood etc., hoopwood	1
Yes	441700	Wood: tools, tool bodies, tool handles, broom or brush bodies and handles, boot and shoe lasts and trees, of wood	1
	442110	Wood: clothes hangers	1
	490599	Maps and hydrographic or similar charts: (printed other than in book form), including wall maps, topographical plans and similar	
	491000	Calendars: printed, of any kind, including calendar blocks	
	491110	Printed matter: trade advertising material, commercial catalogues and the like	
	491191	Printed matter: pictures, designs and photographs, n.e.s. in item no. 4911.10	
	491199	Printed matter: n.e.s. in heading no. 4911	
	620444	Dresses: women's or girls', of artificial fibres (not knitted or crocheted)	
	621520	Ties, bow ties and cravats: of man-made fibres (not knitted or crocheted)	
	621710	Clothing accessories: other than those of heading no. 6212 (not knitted or crocheted)	
	640299	Footwear: n.e.s. in heading no. 6402, (other than just covering the ankle), with outer soles and uppers of rubber or plastics	
	660390	Trimmings, accessories and parts of articles of heading no. 6601 or 6602: n.e.s. in heading no. 6603	
Yes	701310	Glassware: of a kind used for table, kitchen, toilet, office, indoor decoration or similar purposes (other than of heading no. 7010 or 7018), of glass-ceramics	1
Yes	701332	Glassware: of a kind used for table or kitchen purposes, of glass having a linear co-efficient of expansion not exceeding 5 x 10-6 per kelvin within a temperature range of 0-300 degrees C, (not of glass-ceramics)	1
Yes	701339	Glassware: used for table or kitchen purposes, (not of lead crystal or glass-ceramics or glass having a linear co-efficient of expansion not exceeding 5 x 10-6 per kelvin with a temperature range of 0-300 degrees c)	1
	711711	Jewellery: imitation, cuff links and studs, of base metal, whether or not plated with precious metal	1
	711790	Jewellery: imitation, of other than base metal, whether or not plated with precious metal	1
	711810	Coin (other than gold coin), not being legal tender	1
	731511	Chain: articulated link, roller, of iron or steel	1
	731512	Chain: articulated link, (other than roller), of iron or steel	1
	731811	Iron or steel: threaded coach screws	1
	731813	Iron or steel: threaded screw hooks and screw rings	1
	731815	Iron or steel: threaded screws and bolts n.e.s. in item no. 7318.1, whether or not with their nuts or washers	1
	731816	Iron or steel: threaded nuts	1
	731821	Iron or steel: non-threaded spring washers and other lock washers	1

Text match	HS2002	Description	Materially different
	731822	Iron or steel: non-threaded washers, excluding spring and lock	1
	731823	Iron or steel: non-threaded rivets	1
	731990	Iron or steel: knitting needles, bodkins, crochet hooks and similar articles, for use in the hand, n.e.s. in heading no. 7319	1
Yes	732391	Cast iron: table, kitchen and other household articles and parts thereof, of cast iron, not enamelled	1
Yes	732392	Cast iron: table, kitchen and other household articles and parts thereof, of cast iron, enamelled	1
Yes	732393	Steel, stainless: table, kitchen and other household articles and parts thereof	1
Yes	732394	Iron (excluding cast) or steel: table, kitchen and other household articles and parts thereof, enamelled	1
Yes	732399	Iron or steel: table, kitchen and other household articles and parts thereof, of iron or steel n.e.s. in heading no. 7323	1
Yes	741819	Copper: table, kitchen or other household articles and parts thereof, (other than pot scourers and scouring or polishing pads, gloves and the like)	1
	761090	Aluminium: structures (excluding prefabricated buildings of heading no. 9406) and parts of structures, n.e.s. in heading no. 7610, plates, rods, profiles, tubes and the like	1
Yes	761519	Aluminium: table, kitchen or other household articles and parts thereof, n.e.s. in item no. 7615.11	1
	820420	Tools, hand: interchangeable spanner sockets, with or without handles	1
	820510	Tools, hand: drilling, threading or tapping tools	1
	820520	Tools, hand: hammers and sledge hammers	1
	820540	Tools, hand: screwdrivers	1
Yes	820551	Tools, hand: household	1
Yes	820559	Tools, hand: other than household tools	1
Yes	820790	Tools, interchangeable: (for machine or hand tools, whether or not power-operated), for screw-driving or uses n.e.s. in heading no. 8207	1
Yes	820830	Tools: knives and cutting blades, for kitchen appliances or for machines used by the food industry	1
Yes	821000	Tools: hand-operated mechanical appliances, weighing 10kg or less, used in the preparation, conditioning or serving of food or drink	1
	821290	Razors: parts n.e.s. in heading no. 8212	1
	830110	Padlocks: (key, combination or electrically operated), of base metal	1
	830249	Mountings, fittings and similar articles: suitable for other than buildings or furniture, of base metal	1
Yes	830400	Office equipment: filing cabinets, card-index cabinets, paper trays, paper rests, pen trays, office-stamp stands and similar office or desk equipment, of base metal, other than office furniture of heading no. 9403	1
	841990	Machinery, plant and laboratory equipment: parts of equipment for treating materials by a process involving a change of temperature	
	845970	Machine-tools: for threading or tapping by removing metal	
	846610	Machine-tools: parts and accessories, tool holders and self-opening dieheads	
	846620	Machine-tools: parts and accessories, work holders	
	846630	Machine-tools: parts and accessories, dividing heads and other special attachments for machine-tools	
	846692	Machine-tools: parts and accessories, for the machines of heading no. 8465	
	846789	Tools: for working in the hand, (other than chain saws), hydraulic or with self-contained non-electric motor, (not pneumatic)	
Yes	847290	Office machines: automatic banknote dispensers, coin-sorting machines, coin-counting or wrapping machines, pencil-sharpening machines, perforating or stapling machines	
	847330	Machines: parts and accessories of automatic data processing, magnetic or optical readers, digital processing units	
	847790	Machinery: parts of those for working rubber or plastics	
	848250	Bearings: cylindrical roller bearings n.e.s. in heading no. 8482	
	848320	Bearing housings, incorporating ball or roller bearings	
	850300	Electric motors and generators: parts suitable for use solely or principally with the machines of heading no. 8501 or 8502	
	851790	Line telephony or telegraphy apparatus: electrical, parts of the apparatus of heading no. 8517	
	851890	Microphones, headphones, earphones, amplifier equipment: parts of the equipment of heading no. 8518	
	852290	Sound recording or reproducing apparatus: parts and accessories thereof, other than pick-up cartridges	
	870899	Vehicles: parts and accessories, n.e.s. in heading no. 8708	

Text match	HS2002	Description	Materially different
	871495	Cycles: parts thereof, saddles	
	871499	Cycles: parts thereof, n.e.s. in item no. 8714.9	
	900311	Frames and mountings: for spectacles, goggles or the like, of plastics	
	900699	Photographic flashlight apparatus: parts and accessories, for other than cameras	
	901720	Drawing, marking-out or mathematical calculating instruments	
	901730	Mathematical equipment: micrometers, callipers and gauges	
	902139	Artificial parts of the body: excluding artificial joints	
	902190	Appliances: worn, carried or implanted in the body, to compensate for a defect or disability	
	902300	Instruments, apparatus and models: designed for demonstrational purposes (in education or exhibitions), unsuitable for other uses	
	902690	Instruments and apparatus: parts and accessories for those measuring or checking the flow, level, pressure or other variables of liquids or gases (excluding those of heading no. 9014, 9015, 9028 or 9032)	
	910221	Wrist-watches: whether or not incorporating a stop-watch facility, with automatic winding	
	910299	Pocket watches and other watches, including stop-watches: (excluding wrist-watches), other than those of heading no. 9101, other than electrically operated	
	910529	Clocks: (excluding those with watch movements and instrument panel clocks), wall clocks, other than electrically operated	
	911011	Watches: complete movements, unassembled or partly assembled (movement sets)	
	911019	Watches: rough movements	
	911180	Watch cases: n.e.s. in heading no. 9111	
	911190	Watch cases and parts thereof	
	911220	Clock cases and similar cases for other goods of chapter 91: other than watch cases	
	911290	Clock cases and similar cases for other goods of chapter 91: other than watch cases, parts thereof	
	911390	Watch straps, watch bands, watch bracelets, and parts thereof: n.e.s. in heading no. 9113	
	911410	Clock or watch parts: springs, including hairsprings	
	911430	Clock or watch parts: dials	
	911440	Clock or watch parts: plates and bridges	
	911490	Clock or watch parts: n.e.s. in heading no. 9114	
	920210	Musical instruments: string, played with a bow (e.g. violins)	
	920510	Musical instruments: wind, brass (e.g. trumpets)	
	920590	Musical instruments: wind, other than brass (e.g. clarinets, bagpipes)	
	920600	Musical instruments: percussion (e.g. drums, xylophones, cymbals, castanets, maracas)	
	920890	Fairground and mechanical street organs, mechanical singing birds, musical saws and musical instruments nes in chapter 92: decoy calls of all kinds: whistles: call horns and other mouth-blown sound signalling instruments	
	920991	Musical instruments: parts and accessories for pianos	
	920992	Musical instruments: parts and accessories for string musical instruments other than keyboard instruments	
	940390	Furniture: parts	
	940592	Lamps and light fittings: parts thereof, of plastics	
	940599	Lamps and light fittings: parts thereof, of materials other than glass or plastics	1
	950210	Dolls: representing only human beings, whether or not dressed	
	950291	Dolls: representing only human beings, garments and accessories therefor, footwear and headgear	
	950299	Dolls: representing only human beings, parts and accessories, (other than garments and accessories therefor or footwear and headgear)	
	950310	Toys: electric trains, including tracks, signals and other accessories therefor	
	950320	Toys: reduced-size (scale) model assembly kits, whether or not working models, excluding those of item no. 9503.10	
Yes	950330	Toys: construction sets and constructional toys, excluding (scale) model assembly kits	
	950349	Toys: representing animals or non-human creatures, not stuffed	
	950350	Toy musical instruments and apparatus	
	950360	Toys: puzzles	

Text match	HS2002	Description	Materially different
	950370	Toys: n.e.s. in heading no. 9503, put up in sets or outfits	
	950380	Toys and models: n.e.s. in heading no. 9503, incorporating a motor	
	950390	Toys: n.e.s. in heading no. 9503	
	950420	Billiard articles and accessories	
	950430	Games: operated by coins, banknotes (paper currency), discs or other similar articles, other than bowling alley equipment	
	950490	Games: articles for funfair, table or parlour games, including pintables, tables for casino games, bowling alley equipment, n.e.s. in heading no. 9504	
	950510	Christmas festivity articles	
	950590	Festive, carnival or other entertainment articles including novelty jokes and conjuring tricks: other than Christmas festivity articles	
	950619	Snow-ski equipment	
	950640	Table-tennis articles and equipment	
	950691	Athletics and gymnastics equipment	
	960329	Brushes: shaving, hair, nail, eyelash and other toilet brushes for use on the person, including brushes as parts of appliances	
	960719	Slide fasteners: other than those fitted with chain scoops of base metal	
	961511	Combs, hair slides and the like: of hard rubber or plastics	
	961519	Combs, hair slides and the like: of other than hard rubber or plastics	
	961590	Hairpins, curling pins, curling grips, hair curlers and the like (not those of heading no. 8516) and parts thereof	
	970300	Sculptures and statuary: original, in any material	
Yes	970400	Stamps, postage or revenue: stamp-postmarks, first-day covers, postal stationery (stamped paper) and like, used or unused, other than those of heading 4907	
	970500	Collections and collectors' pieces: of zoological, botanical, mineralogical, anatomical, historical, archaeological, palaeontological, ethnographic or numismatic interest	

Source: Authors' calculations based on the Thingi10k dataset.

A.2. Industrial 3D printable goods

Table A.3. Industrial 3D printable items, in HS and SITC, with classification

HS2002	HS2002 description	SITCagg4	SITC description	High-tech	Low-tech	Type
294110	Antibiotics: penicillins and their derivatives with a penicillanic acid structure: salts thereof	5413	Antibiotics,non-medical	1	0	MED
294120	Antibiotics: streptomycins and their derivatives: salts thereof	5413	Antibiotics,non-medical	1	0	MED
294130	Antibiotics: tetracyclines and their derivatives: salts thereof	5413	Antibiotics,non-medical	1	0	MED
294140	Antibiotics: chloramphenicol and its derivatives: salts thereof	5413	Antibiotics,non-medical	1	0	MED
294150	Antibiotics: erythromycin and its derivatives: salts thereof	5413	Antibiotics,non-medical	1	0	MED
294190	Antibiotics: n.e.s. in heading no. 2941	5413	Antibiotics,non-medical	1	0	MED
300310	Medicaments: containing penicillins, streptomycins or their derivatives, for therapeutic or prophylactic uses, (not in measured doses, not packaged for retail sale)	5421	Insulin medicaments bulk	1	0	MED
300320	Medicaments: containing antibiotics other than penicillins, streptomycins and their derivatives, for therapeutic or prophylactic uses, (not in measured doses, not packaged for retail sale)	5421	Insulin medicaments bulk	1	0	MED
300390	Medicaments: (not containing antibiotics, hormones, alkaloids or their derivatives), for therapeutic or prophylactic uses, (not packaged for retail sale)	5429	Medicaments n.e.s.	1	0	MED
300410	Medicaments: containing penicillins, streptomycins or their derivatives, for therapeutic or prophylactic uses, packaged for retail sale	5421	Insulin medicaments bulk	1	0	MED
300420	Medicaments: containing antibiotics (other than penicillins, streptomycins or their derivatives), for therapeutic or prophylactic uses, packaged for retail sale	5421	Insulin medicaments bulk	1	0	MED
300450	Medicaments: containing vitamins or their derivatives, for therapeutic or prophylactic use, packaged for retail sale	5429	Medicaments n.e.s.	1	0	MED
300490	Medicaments: consisting of mixed or unmixed products n.e.s. in heading no. 3004, for therapeutic or prophylactic uses, packaged for retail sale	5429	Medicaments n.e.s.	1	0	MED
340600	Candles, tapers and the like	8993	Candles/matches/smokers	0	1	LOWTECH
360500	Matches: other than pyrotechnic articles of heading no. 3604	8993	Candles/matches/smokers	0	1	LOWTECH
360610	Fuels: liquid or liquefied-gas, in containers, of a kind used for filling or refilling cigarette or similar lighters, (of a capacity not exceeding 300cm3)	8993	Candles/matches/smokers	0	1	LOWTECH
360690	Ferro-cerium and other pyrophoric alloys in all forms: articles of combustible materials n.e.s. in chapter 36	8993	Candles/matches/smokers	0	1	LOWTECH
391740	Plastics: tube, pipe and hose fittings (e.g. joints, elbows, flanges)	5817	Fittings - plastic tubes	0	1	LOWTECH
392610	Plastics: office or school supplies	8939	Plastic articles nes	0	1	LOWTECH
392630	Plastics: fittings for furniture, coachwork or the like	8939	Plastic articles nes	0	1	LOWTECH
392640	Plastics: statuettes and other ornamental articles	8939	Plastic articles nes	0	1	LOWTECH
392690	Plastics: other articles n.e.s. in chapter 39	8939	Plastic articles nes	0	1	LOWTECH
640191	Footwear: waterproof, covering the knee, rubber or plastic outer soles and uppers (not assembled by stitch, rivet, nail, screw, plug or similar)	8513	Rub/plast footware nes	0	1	LOWTECH

HS2002	HS2002 description	SITCagg4	SITC description	High-tech	Low-tech	Type
640192	Footwear: waterproof, covering the ankle (but not the knee), rubber or plastic outer soles and uppers (not assembled by stitch, rivet, nail, screw, plug or similar)	8513	Rub/plast footware nes	0	1	LOWTECH
640199	Footwear: waterproof, n.e.s. in heading no. 6401, rubber or plastic outer soles and uppers (not assembled by stitch, rivet, nail, screw, plug or similar)	8513	Rub/plast footware nes	0	1	LOWTECH
640212	Sports footwear: with outer soles and uppers of rubber or plastics, ski-boots, cross-country ski footwear and snowboard boots	8512	Sports footwear	0	1	LOWTECH
640219	Sports footwear: (other than ski-boots, snowboard boots or cross-country ski footwear), with outer soles and uppers of rubber or plastics	8512	Sports footwear	0	1	LOWTECH
640220	Footwear: with outer soles and uppers of rubber or plastics, upper straps or thongs assembled to the sole by plugs	8513	Rub/plast footware nes	0	1	LOWTECH
640291	Footwear: n.e.s. in heading no. 6402, covering the ankle, with outer soles and uppers of rubber or plastics	8513	Rub/plast footware nes	0	1	LOWTECH
640299	Footwear: n.e.s. in heading no. 6402, (other than just covering the ankle), with outer soles and uppers of rubber or plastics	8513	Rub/plast footware nes	0	1	LOWTECH
640312	Sports footwear: with outer soles of rubber, plastics, leather or composition leather and uppers of leather, ski-boots, snowboard boots and cross-country ski footwear	8512	Sports footwear	0	1	LOWTECH
640319	Sports footwear: (other than ski-boots, snowboard boots or cross-country ski footwear), with outer soles of rubber, plastics, leather or composition leather and uppers of leather	8512	Sports footwear	0	1	LOWTECH
640411	Sports footwear: tennis shoes, basketball shoes, gym shoes, training shoes and the like, with outer soles of rubber or plastics and uppers of textile materials	8512	Sports footwear	0	1	LOWTECH
640610	Footwear: parts, uppers and parts thereof, other than stiffeners	8519	Footware parts/leggings	0	1	LOWTECH
640620	Footwear: parts, outer soles and heels, of rubber or plastics	8519	Footwear parts/leggings	0	1	LOWTECH
640691	Footwear: parts, of wood	8519	Footwear parts/leggings	0	1	LOWTECH
640699	Footwear: of materials n.e.s. in heading no. 6406	8519	Footwear parts/leggings	0	1	LOWTECH
670210	Flowers, foliage and fruit, artificial, and parts thereof: articles made of artificial flowers, foliage or fruit, of plastics	8992	Artificial flowers/fruit	0	1	LOWTECH
670290	Flowers, foliage and fruit, artificial, and parts thereof: articles made of artificial flowers, foliage or fruit, of materials other than plastics	8992	Artificial flowers/fruit	0	1	LOWTECH
690310	Refractory ceramic goods: containing by weight more than 50% of graphite or other forms of carbon or of a mixture of these products, excluding those of siliceous fossil meals or similar earths	6637	Ceramics nes	0	1	LOWTECH
690320	Refractory ceramic goods: containing by weight more than 50% of alumina or of a mixture or compound of alumina and of silica, excluding those of siliceous fossil meals or similar earths	6637	Ceramics nes	0	1	LOWTECH
690390	Refractory ceramic goods: composition of which n.e.s. in heading no. 6903, other than those of siliceous fossil meals or similar earths	6637	Ceramics nes	0	1	LOWTECH
690911	Ceramic wares: for laboratory, chemical or other technical uses, of porcelain or china	6639	Ceramic articles nes	0	1	LOWTECH
690912	Ceramic wares: for laboratory, chemical or other technical uses, articles having a hardness equivalent to 9 or more on the Mohs scale	6639	Ceramic articles nes	0	1	LOWTECH

HS2002	HS2002 description	SITCagg4	SITC description	High-tech	Low-tech	Type
690919	Ceramic wares: for laboratory, chemical or other technical uses, other than articles having a hardness equivalent to 9 or more on the Mohs scale or of porcelain or china	6639	Ceramic articles nes	0	1	LOWTECH
690990	Ceramic wares: pots, jars and similar articles of a kind used for the conveyance or packing of goods and ceramic troughs, tubs and similar receptacles used in agriculture	6639	Ceramic articles nes	0	1	LOWTECH
691410	Ceramic articles n.e.s. in chapter 69: of porcelain or china	6639	Ceramic articles nes	0	1	LOWTECH
691490	Ceramic articles n.e.s. in chapter 69: other than of porcelain or china	6639	Ceramic articles nes	0	1	LOWTECH
701010	Glass: ampoules, of a kind used for the conveyance or packing of goods	6659	Glass articles nes	0	1	LOWTECH
701310	Glassware: of a kind used for table, kitchen, toilet, office, indoor decoration or similar purposes (other than of heading no. 7010 or 7018), of glass-ceramics	6652	Table/kitchen glassware	0	1	LOWTECH
701321	Glassware: drinking glasses, of lead crystal	6652	Table/kitchen glassware	0	1	LOWTECH
701329	Glassware: drinking glasses, not of glass-ceramics or lead crystal	6652	Table/kitchen glassware	0	1	LOWTECH
701331	Glassware: of a kind used for table or kitchen purposes, (excluding drinking glasses), of lead crystal	6652	Table/kitchen glassware	0	1	LOWTECH
701332	Glassware: of a kind used for table or kitchen purposes, of glass having a linear co-efficient of expansion not exceeding 5 x 10-6 per kelvin within a temperature range of 0-300 degrees C, (not of glass-ceramics)	6652	Table/kitchen glassware	0	1	LOWTECH
701339	Glassware: used for table or kitchen purposes, (not of lead crystal or glass-ceramics or glass having a linear co-efficient of expansion not exceeding 5 x 10-6 per kelvin with a temperature range of 0-300 degrees c)	6652	Table/kitchen glassware	0	1	LOWTECH
701391	Glassware: n.e.s. in heading no. 7013, of lead crystal	6652	Table/kitchen glassware	0	1	LOWTECH
701399	Glassware: n.e.s. in heading no. 7013, other than of lead crystal	6652	Table/kitchen glassware	0	1	LOWTECH
701400	Glassware: signalling, (not optically worked)	6659	Glass articles nes	0	1	LOWTECH
701610	Glass cubes and other glass smallwares: whether or not on a backing, for mosaics or similar decorative purposes	6659	Glass articles nes	0	1	LOWTECH
701710	Glassware: laboratory, hygienic or pharmaceutical, whether or not graduated or calibrated, of fused quartz or other fused silica	6659	Glass articles nes	0	1	LOWTECH
701720	Glassware: laboratory, hygienic or pharmaceutical, whether or not graduated or calibrated, having a linear co-efficient of expansion not over 5 x 10-6 per kelvin with a temperature of 0-300 degrees C	6659	Glass articles nes	0	1	LOWTECH
701790	Glassware: laboratory, hygienic or pharmaceutical, whether or not graduated or calibrated, of glass n.e.s. in heading no. 7017	6659	Glass articles nes	0	1	LOWTECH
701810	Glass: beads, imitation pearls, imitation precious or semi-precious stones and similar glass smallwares	6659	Glass articles nes	0	1	LOWTECH
701820	Glass microspheres: not exceeding 1mm in diameter	6659	Glass articles nes	0	1	LOWTECH
701890	Glass: articles thereof, statuettes and other ornaments of lamp worked glass, other than imitation jewellery	6659	Glass articles nes	0	1	LOWTECH
702000	Glass: articles n.e.s. in chapter 70	6659	Glass articles nes	0	1	LOWTECH
71310	Vegetables, leguminous: peas (pisum sativum), shelled, whether or not skinned or split, dried	5421	Insulin medicaments bulk	1	0	MED
71390	Vegetables, leguminous: n.e.s. in heading no. 0713, shelled, whether or not skinned or split, dried	5429	Medicaments n.e.s.	1	0	MED

HS2002	HS2002 description	SITCagg4	SITC description	High-tech	Low-tech	Type
721610	Iron or non-alloy steel: U, I or H sections, hot-rolled, hot-drawn or extruded, of a height of less than 80mm	6768	Iron/st angle/shape/sect	0	1	LOWTECH
721621	Iron or non-alloy steel: L sections, hot-rolled, hot-drawn or extruded, of a height of less than 80mm	6768	Iron/st angle/shape/sect	0	1	LOWTECH
721622	Iron or non-alloy steel: T sections, hot-rolled, hot-drawn or extruded, of a height less than 80mm	6768	Iron/st angle/shape/sect	0	1	LOWTECH
721631	Iron or non-alloy steel: U sections, hot-rolled, hot-drawn or extruded, of a height of 80mm or more	6768	Iron/st angle/shape/sect	0	1	LOWTECH
721632	Iron or non-alloy steel: I sections, hot-rolled, hot-drawn or extruded, of a height of 80mm or more	6768	Iron/st angle/shape/sect	0	1	LOWTECH
721633	Iron or non-alloy steel: H sections, hot-rolled, hot-drawn or extruded, of a height of 80mm or more	6768	Iron/st angle/shape/sect	0	1	LOWTECH
721640	Iron or non-alloy steel: L or T sections, hot-rolled, hot-drawn or extruded, of a height of 80mm or more	6768	Iron/st angle/shape/sect	0	1	LOWTECH
721650	Iron or non-alloy steel: angles, shapes and sections, n.e.s. in heading no. 7216, hot-rolled, hot-drawn or extruded	6768	Iron/st angle/shape/sect	0	1	LOWTECH
721661	Iron or non-alloy steel: angles, shapes and sections, cold-formed or cold-finished, obtained from flat-rolled products	6768	Iron/st angle/shape/sect	0	1	LOWTECH
721669	Iron or non-alloy steel: angles, shapes and sections, cold-formed or cold-finished, (not obtained from flat-rolled products)	6768	Iron/st angle/shape/sect	0	1	LOWTECH
721691	Iron or non-alloy steel: angles, shapes and sections, n.e.s. in heading no. 7216, cold-formed or cold-finished, from flat-rolled products	6768	Iron/st angle/shape/sect	0	1	LOWTECH
721699	Iron or non-alloy steel: angles, shapes and sections, n.e.s. in heading no. 7216	6768	Iron/st angle/shape/sect	0	1	LOWTECH
722240	Steel, stainless: angles, shapes and sections	6768	Iron/st angle/shape/sect	0	1	LOWTECH
722870	Steel, alloy: angles, shapes and sections	6768	Iron/st angle/shape/sect	0	1	LOWTECH
730110	Iron or steel: sheet piling, whether or not drilled, punched or made from assembled elements	6768	Iron/st angle/shape/sect	0	1	LOWTECH
730120	Iron or steel: angles, shapes and sections, welded	6768	Iron/st angle/shape/sect	0	1	LOWTECH
741110	Copper: tubes and pipes, of refined copper	6827	Copper tube/pipe/fitting	0	1	LOWTECH
741121	Copper: tubes and pipes, of copper-zinc base alloys (brass)	6827	Copper tube/pipe/fitting	0	1	LOWTECH
741122	Copper: tubes and pipes, of copper-nickel base alloys (cupro-nickel) or copper-nickel-zinc base alloys (nickel silver)	6827	Copper tube/pipe/fitting	0	1	LOWTECH
741129	Copper: tubes and pipes, of copper alloys (other than copper-zinc, copper-nickel base alloys (cupro-nickel) or copper-nickel-zinc base alloys (nickel-silver))	6827	Copper tube/pipe/fitting	0	1	LOWTECH
741210	Copper: tube or pipe fittings (e.g. couplings, elbows, sleeves) of refined copper	6827	Copper tube/pipe/fitting	0	1	LOWTECH
741220	Copper: tube or pipe fittings (e.g. couplings, elbows, sleeves) of copper alloys	6827	Copper tube/pipe/fitting	0	1	LOWTECH
820110	Tools, hand: spades and shovels	6951	Hand tools agric/forest	0	1	LOWTECH
820120	Tools, hand: forks	6951	Hand tools agric/forest	0	1	LOWTECH
820130	Tools, hand: mattocks, picks, hoes and rakes	6951	Hand tools agric/forest	0	1	LOWTECH
820140	Tools, hand: axes, bill hooks and similar hewing tools, of a kind used in agriculture, horticulture or forestry	6951	Hand tools agric/forest	0	1	LOWTECH
820150	Tools, hand: one-handed secateurs (including poultry shears)	6951	Hand tools agric/forest	0	1	LOWTECH
820160	Tools, hand: hedge shears, two-handed pruning shears and similar two-handed shears	6951	Hand tools agric/forest	0	1	LOWTECH
820190	Tools, hand: n.e.s. in heading no. 8201, of a kind used in agriculture, horticulture or forestry	6951	Hand tools agric/forest	0	1	LOWTECH

HS2002	HS2002 description	SITCagg4	SITC description	High-tech	Low-tech	Type
820411	Tools, hand: hand-operated spanners and wrenches (including torque meter wrenches but not including tap wrenches), non-adjustable	6953	Wrenches and spanners	0	1	LOWTECH
820412	Tools, hand: hand-operated spanners and wrenches (including torque meter wrenches but not including tap wrenches), adjustable	6953	Wrenches and spanners	0	1	LOWTECH
820420	Tools, hand: interchangeable spanner sockets, with or without handles	6953	Wrenches and spanners	0	1	LOWTECH
820713	Tools, interchangeable: rock drilling or earth boring tools, with working part of cermets, whether or not power operated	6956	Knives/blades/tool tips	0	1	LOWTECH
820719	Tools, interchangeable: rock drilling or earth boring tools, with working part (other than of cermets), whether or not power operated, including parts	6956	Knives/blades/tool tips	0	1	LOWTECH
820720	Tools, interchangeable: (for machine or hand tools, whether or not power-operated), dies for drawing or extruding metal	6956	Knives/blades/tool tips	0	1	LOWTECH
820730	Tools, interchangeable: (for machine or hand tools, whether or not power-operated), tools for pressing, stamping or punching	6956	Knives/blades/tool tips	0	1	LOWTECH
820740	Tools, interchangeable: (for machine or hand tools, whether or not power-operated), tools for tapping or threading	6956	Knives/blades/tool tips	0	1	LOWTECH
820750	Tools, interchangeable: (for machine or hand tools, whether or not power-operated), tools for drilling (other than rock)	6956	Knives/blades/tool tips	0	1	LOWTECH
820760	Tools, interchangeable: (for machine or hand tools, whether or not power-operated), for boring or broaching	6956	Knives/blades/tool tips	0	1	LOWTECH
820770	Tools, interchangeable: (for machine or hand tools, whether or not power-operated), for milling	6956	Knives/blades/tool tips	0	1	LOWTECH
820780	Tools, interchangeable: (for machine or hand tools, whether or not power-operated), for turning	6956	Knives/blades/tool tips	0	1	LOWTECH
820790	Tools, interchangeable: (for machine or hand tools, whether or not power-operated), for screw-driving or uses n.e.s. in heading no. 8207	6956	Knives/blades/tool tips	0	1	LOWTECH
820810	Tools: knives and cutting blades, for machines or for mechanical appliances, for metal working	6956	Knives/blades/tool tips	0	1	LOWTECH
820820	Tools: knives and cutting blades, for wood working machines or mechanical appliances	6956	Knives/blades/tool tips	0	1	LOWTECH
820830	Tools: knives and cutting blades, for kitchen appliances or for machines used by the food industry	6956	Knives/blades/tool tips	0	1	LOWTECH
820840	Tools: knives and cutting blades, for agricultural, horticultural or forestry machines or mechanical appliances	6956	Knives/blades/tool tips	0	1	LOWTECH
820890	Tools: knives and cutting blades, for machines or mechanical appliances, n.e.s. in heading no. 8208	6956	Knives/blades/tool tips	0	1	LOWTECH
820900	Tools: plates, sticks, tips and the like for tools, unmounted, of sintered metal carbides or cermets	6956	Knives/blades/tool tips	0	1	LOWTECH
840290	Boilers: parts of steam or other vapour generating boilers	7119	Parts for boilers/etc.	1	0	MACH
840490	Boilers: parts of auxiliary plant, for use with boilers of heading no. 8402 and 8403 and parts of condensers for steam or other vapour power units	7119	Parts for boilers/etc.	1	0	MACH
840690	Turbines: parts of steam and other vapour turbines	7128	Stm turbine(712.1)parts	1	0	MACH
841191	Turbines: parts of turbo-jets and turbo-propellers	7149	Parts react/gas turb eng	1	0	AIR
841199	Turbines: parts of gas turbines (excluding turbo-jets and turbo-propellers)	7149	Parts react/gas turb eng	1	0	AIR

HS2002	HS2002 description	SITCagg4	SITC description	High-tech	Low-tech	Type
841490	Pumps and compressors: parts, of air or vacuum pumps, air or other gas compressors and fans, ventilating or recycling hoods incorporating a fan	7438	Parts for fans/gas pumps	1	0	MACH
843810	Machinery: industrial, for bakery and for the manufacture of macaroni, spaghetti or similar products	7272	Other food proc machines	1	0	MACH
843820	Machinery: industrial, for the manufacture of confectionery, cocoa or chocolate	7272	Other food proc machines	1	0	MACH
843830	Machinery: industrial, for sugar manufacture	7272	Other food proc machines	1	0	MACH
843840	Machinery: industrial, brewery machinery	7272	Other food proc machines	1	0	MACH
843850	Machinery: industrial, for the preparation of meat or poultry	7272	Other food proc machines	1	0	MACH
843860	Machinery: industrial, for the preparation of fruits, nuts or vegetables	7272	Other food proc machines	1	0	MACH
843880	Machinery: used in the industrial preparation or manufacture of food or drink, n.e.s. in heading no. 8438	7272	Other food proc machines	1	0	MACH
843890	Machinery: parts of those machines used in the industrial preparation or manufacture of food or drink	7272	Other food proc machines	1	0	MACH
843991	Machinery: parts of machinery for making pulp of fibrous cellulosic material	7259	Paper ind machine parts	1	0	MACH
843999	Machinery: parts of machinery for making or finishing paper or paperboard	7259	Paper ind machine parts	1	0	MACH
844190	Machinery: parts of machinery for making up paper pulp, paper or paperboard, including cutting machines of all kinds	7259	Paper ind machine parts	1	0	MACH
845090	Washing machines: parts for household or laundry-type	7249	Washing/etc. machine part	1	0	MACH
845190	Machinery: parts, of the machinery of heading no. 8451	7249	Washing/etc. machine part	1	0	MACH
846011	Machine-tools: flat-surface grinding machines, in which positioning in any one axis can be set up to an accuracy of 0.01mm or better, numerically controlled	7316	Sharpen/grind. mac tool	1	0	MACH
846019	Machine-tools: flat-surface grinding machines, in which positioning in any one axis can be set up to an accuracy of 0.01mm or better, other than numerically controlled	7316	Sharpen/grind. mac tool	1	0	MACH
846021	Machine-tools: grinding machines (other than flat-surface), in which positioning in any one axis can be set up to at least an accuracy of 0.01mm, numerically controlled	7316	Sharpen/grind. mac tool	1	0	MACH
846029	Machine-tools: grinding machines (other than flat-surface), in which positioning in any one axis can be set up to at least an accuracy of 0.01mm, other than numerically controlled	7316	Sharpen/grind. mac tool	1	0	MACH
846031	Machine-tools: sharpening (tool or cutter grinding) machines, numerically controlled	7316	Sharpen/grind. mac tool	1	0	MACH
846039	Machine-tools: sharpening (tool or cutter grinding) machines, other than numerically controlled	7316	Sharpen/grind. mac tool	1	0	MACH
846040	Machine-tools: for honing or lapping	7316	Sharpen/grind. mac tool	1	0	MACH
846090	Machine-tools: for deburring, polishing or otherwise finishing metal, sintered metal carbides or cermets by means of grinding stones, abrasives or polishing products, n.e.s. in heading no. 8460	7316	Sharpen/grind. mac tool	1	0	MACH
847920	Machinery: for the extraction or preparation of animal or fixed vegetable fats or oils	7272	Other food proc machines	1	0	MACH
848010	Moulding boxes: for metal foundry	7491	Moulds (exc metal ingot)	0	1	LOWTECH
848020	Mould bases: for metal, metal carbides, glass, mineral materials, rubber or plastics	7491	Moulds (exc metal ingot)	0	1	LOWTECH

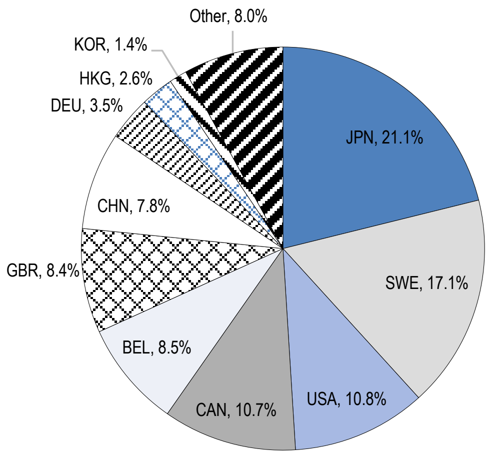
HS2002	HS2002 description	SITCagg4	SITC description	High-tech	Low-tech	Type
848030	Moulding patterns: of metal, metal carbides, glass, mineral materials, rubber or plastics	7491	Moulds (exc metal ingot)	0	1	LOWTECH
848041	Moulds: for metal or metal carbides, injection or compression types	7491	Moulds (exc metal ingot)	0	1	LOWTECH
848049	Moulds: for metal or metal carbides, other than injection or compression types	7491	Moulds (exc metal ingot)	0	1	LOWTECH
848050	Moulds: for glass	7491	Moulds (exc metal ingot)	0	1	LOWTECH
848060	Moulds: for mineral materials	7491	Moulds (exc metal ingot)	0	1	LOWTECH
848071	Moulds: for rubber or plastics, injection or compression types	7491	Moulds (exc metal ingot)	0	1	LOWTECH
848079	Moulds: for rubber or plastics, other than injection or compression types	7491	Moulds (exc metal ingot)	0	1	LOWTECH
848420	Seals: mechanical	7499	Machine parts non-el nes	1	0	MACH
848510	Ships' propellers and blades therefor	7499	Machine parts non-el nes	1	0	MACH
848590	Machinery: parts, not containing electrical connectors, insulators, coils, contacts or other electrical features, n.e.s. in chapter 84	7499	Machine parts non-el nes	1	0	MACH
880310	Aircraft and spacecraft: propellers and rotors and parts thereof	7929	Aircraft etc. parts	1	0	AIR
880320	Aircraft and spacecraft: under-carriages and parts thereof	7929	Aircraft etc. parts	1	0	AIR
880330	Aircraft and spacecraft: parts of aeroplanes or helicopters n.e.s. in heading no. 8803	7929	Aircraft etc. parts	1	0	AIR
880390	Aircraft and spacecraft: parts thereof n.e.s. in chapter 88	7929	Aircraft etc. parts	1	0	AIR
900311	Frames and mountings: for spectacles, goggles or the like, of plastics	8842	Spectacles/frames	1	0	ORTHO
900319	Frames and mountings: for spectacles, goggles or the like, of materials other than plastics	8842	Spectacles/frames	1	0	ORTHO
900390	Frames and mountings: parts for spectacles, goggles or the like	8842	Spectacles/frames	1	0	ORTHO
900410	Sunglasses: corrective, protective or other	8842	Spectacles/frames	1	0	ORTHO
900490	Spectacles, goggles and the like: (other than sunglasses) corrective, protective or other	8842	Spectacles/frames	1	0	ORTHO
901841	Dental instruments and appliances: dental drill engines, whether or not combined on a single base with other dental equipment	8721	Dental instruments	1	0	ORTHO
901849	Dental instruments and appliances: other than dental drill engines	8721	Dental instruments	1	0	ORTHO
902110	Orthopaedic or fracture appliances	8996	Orthopaedic appliances	1	0	ORTHO
902121	Dental fittings: artificial teeth	8996	Orthopaedic appliances	1	0	ORTHO
902129	Dental fittings: other than artificial teeth	8996	Orthopaedic appliances	1	0	ORTHO
902131	Artificial parts of the body	8996	Orthopaedic appliances	1	0	ORTHO
902139	Artificial parts of the body: excluding artificial joints	8996	Orthopaedic appliances	1	0	ORTHO
902140	Hearing aids (excluding parts and accessories)	8996	Orthopaedic appliances	1	0	ORTHO
902150	Pacemakers: for stimulating heart muscles (excluding parts and accessories)	8996	Orthopaedic appliances	1	0	ORTHO
902190	Appliances: worn, carried or implanted in the body, to compensate for a defect or disability	8996	Orthopaedic appliances	1	0	ORTHO
960110	Ivory and articles thereof: worked	8991	Carvings/mouldings	0	1	LOWTECH
960190	Bone, tortoise shell, horn, antlers, coral, mother-of-pearl and other animal carving material and articles thereof (including articles obtained by moulding)	8991	Carvings/mouldings	0	1	LOWTECH
960200	Vegetable, mineral carving material and articles of these materials, moulded or carved articles of wax, stearin, natural gums, resins or modelling pastes,	8991	Carvings/mouldings	0	1	LOWTECH

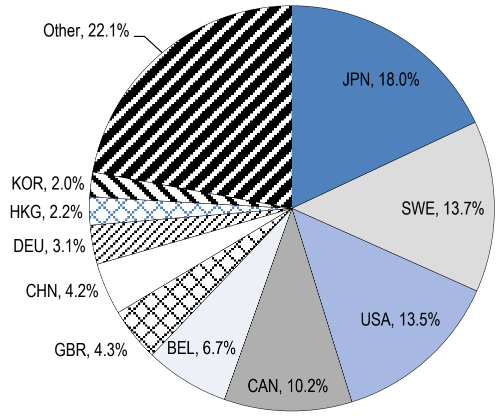
HS2002	HS2002 description	SITCagg4	SITC description	High-tech	Low-tech	Type
	worked unhardened gelatin (not heading no. 3503)					
961310	Lighters: pocket, cigarette, gas fuelled, non-refillable	8993	Candles/matches/smokers	0	1	LOWTECH
961320	Lighters: pocket, cigarette, gas fuelled, refillable	8993	Candles/matches/smokers	0	1	LOWTECH
961380	Lighters: whether or not mechanical or electrical, n.e.s. in heading no. 9613	8993	Candles/matches/smokers	0	1	LOWTECH
961390	Lighters: parts for cigarette lighters and other lighters, whether or not mechanical or electrical, other than flints and wicks	8993	Candles/matches/smokers	0	1	LOWTECH
961420	Pipes and pipe bowls and parts	8993	Candles/matches/smokers	0	1	LOWTECH
961490	Cigar, cigarette holders and parts thereof	8993	Candles/matches/smokers	0	1	LOWTECH

Source: Own classification, based on Arvis et al. (2017[47]) as reported in (Freund, Mulabdic and Ruta, 2019[3]), BACI and COMTRADE database;

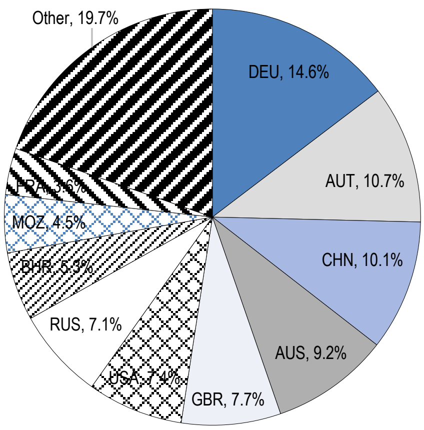
Figure A.3. Top traders in metal powders associated with 3D printing feedstock (2019)

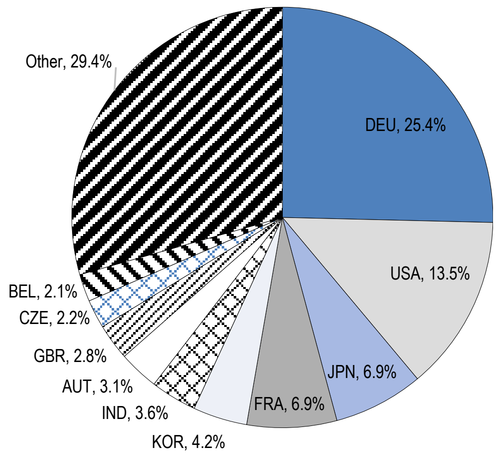
Powders of alloy steel (HS: 7205.21). Top 10 exporters (left) and importers (right)



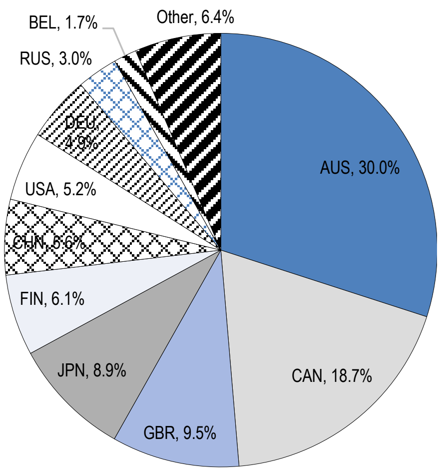


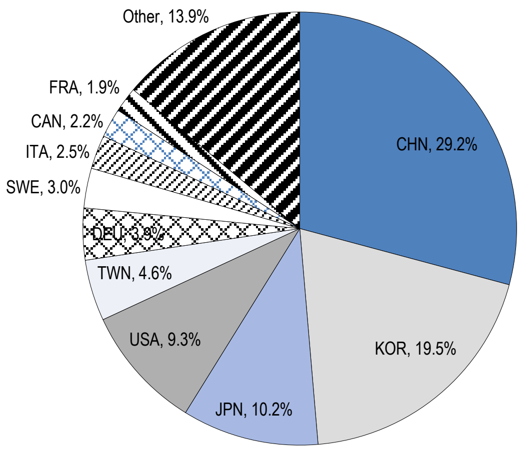
Aluminium powders of non-lamellar structure (HS: 7603.10). Top 10 exporters (left) and importers (right)





Nickel powders and flakes (HS: 7504.00). Top 10 exporters (left) and importers (right)





Note: HS2017 nomenclature. Titanium powders are identified by the code 8108.20 yet not separated by unwrought Titanium at the 6-digit level. The same applies to cobalt powders (HS 8105.20).
Source: CEPII BACI data.

Table A.4. Top exporters and importers in 3D printable product categories

Export and import shares in global exports and imports, 2019

Aircraft parts				Low-tech goods				Machine parts				Medicaments & pharmaceuticals				Orthopaedic appliances			
EXP		IMP		EXP		IMP		EXP		IMP		EXP		IMP		EXP		IMP	
USA	27.4%	USA	22.0%	CHN	28.0%	USA	14.2%	DEU	15.4%	USA	11.3%	DEU	13.6%	USA	18.4%	USA	17.3%	USA	19.0%
FRA	11.5%	FRA	10.0%	DEU	10.4%	DEU	8.3%	CHN	13.6%	CHN	7.3%	CHE	11.9%	DEU	8.0%	CHN	12.0%	DEU	8.3%
GBR	10.9%	DEU	9.4%	USA	6.4%	FRA	4.2%	ITA	8.4%	DEU	6.4%	USA	9.2%	BEL	5.4%	DEU	8.9%	NLD	8.3%
DEU	10.3%	SGP	6.3%	VNM	6.0%	MEX	3.8%	USA	8.2%	MEX	3.5%	IRL	8.1%	CHE	5.0%	CHE	8.7%	FRA	5.6%
JPN	5.5%	GBR	5.5%	JPN	4.3%	CHN	3.8%	JPN	7.5%	FRA	3.2%	ITA	6.5%	GBR	4.6%	IRL	8.5%	CHN	5.3%
ITA	3.7%	CAN	4.9%	ITA	4.1%	JPN	3.5%	NLD	4.2%	JPN	2.9%	FRA	5.7%	CHN	4.5%	ITA	6.2%	JPN	4.5%
CHN	3.3%	JPN	3.4%	KOR	3.1%	GBR	3.5%	CHE	3.5%	KOR	2.7%	NLD	5.4%	ITA	4.1%	NLD	5.7%	ITA	4.0%
CAN	3.3%	CHN	3.4%	FRA	2.5%	ITA	3.2%	FRA	3.3%	IDN	2.5%	IND	4.8%	JPN	3.9%	MEX	3.4%	GBR	3.9%
MEX	2.5%	HKG	2.8%	POL	2.2%	NLD	2.8%	GBR	2.6%	GBR	2.5%	GBR	4.7%	FRA	3.7%	FRA	3.3%	BEL	3.9%
POL	1.7%	ARE	2.3%	NLD	2.0%	BEL	2.3%	KOR	2.5%	IND	2.4%	BEL	4.1%	NLD	2.9%	SGP	3.1%	CHE	2.8%

Note: Based on the SITC correspondence with the HS2002 nomenclature.
Source: BACI CEPII database.

Annex B. Proxy measure of 3D printing adoption

B.1. Constructing the indicator for imports of additive manufacturing machines

In order to construct a measure of high unit-value imports in HS code 8477.80, the global average unit value of machinery traded in this HS line is computed for the sample period 2002-2018. When a country imports machinery under the code 847780 at a higher unit value than average, the value of this bilateral trade flow is considered in the total sum of imports of ‘additive manufacturing machines’, whereas imports below the average unit value are discarded from the total sum.

For greater clarity, filtering for high-unit value trade in 8477.80 is done via a three step procedure that is based on annual bilateral trade data. First, a baseline average unit value for all bilateral trade flows in 8477.80 is calculated for all trading countries between 2002 and 2018. Second, country imports are classified according to whether they are above or below this baseline average unit value, taking into account partner and year dimensions. For instance, for a given year, if country A imports item 8477.80 at above average unit value from country B this will be counted. However, if it imports product 8477.80 from county C below this unit value, it will not be counted (see Table B.1 for descriptive statistics on the countries that most frequently exported and imported at above average unit value in 2010-2018). Third, the sum of all imports at above average unit value is computed by importing country. This provides the proxy measure for imports of 3D printers at a country and year level.

Beyond allowing for a filter in trade in the generic HS code, focusing on high-unit value imports in the data helps reduce the correlation between the indicator of imports of additive manufacturing machines and total imports (net of 847780), which is included in the model as a control variable potentially explaining changes in exports of 3D printable products. In the period 2002-2018, the log of the unadjusted value of imports of 847780 displayed a 0.88 correlation with total imports, while the log of high-value imports showed a 0.68 correlation with total trade. A range of other adjusted variables were considered to proxy for additive manufacturing imports (e.g. imports weighted by patent applications in the exporter country, imports from the top ten innovators in AM technologies, the volume of imports under 847780) but these indicators displayed a higher correlation with total trade as well as with the unfiltered measure of 3D printer imports (HS 847780). Using this variable hence also helps reduce the risk of multicollinearity.

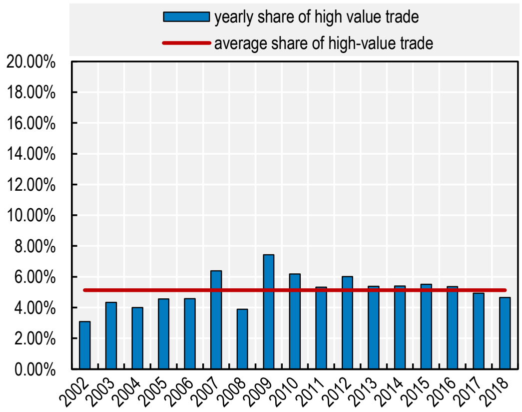
The global average unit value used as benchmark is computed across all countries and once for the entire sample period 2002-2018 (i.e. it is not an indicator of yearly average unit value in the HS code). Maintaining a single benchmark for the entire sample period helps capture the expected effect on greater trade in 3D printers. As more and more 3D printers enter the HS code 847780 as adoption grows, and with 3D printers assumed to have a higher unit value than machinery typically traded in the HS code, the average unit-value of those bilateral trade flows involving exporting innovators is expected to increase relative to the past. Using a yearly indicator of average unit-value would imply that 3D printers entering HS code 847780 would influence the average unit value of trade in that given year – making the distinction between 3D printers and other machinery more subject to ‘jumpiness’ from year to year (Figure B.1). Results of the regressions are nevertheless tested to this alternative measure and are robust to the different indicator, although less statistically significant.

As reporter in Figure B.1., the value of trade in ‘additive manufacturing machines’ represents on average 5.12% of total trade in HS code 8477.80, with the share being generally above average in the 2010-2018 period. Out of the total 48, 940 total bilateral trade flows taking place in HS 8477.80 from 2002 to 2018, 5, 108 qualify as above average in unit value.

The most frequent exporters of high unit-value machinery in 8477.80 in the period 2010-2018 include Switzerland, the Netherlands, France, Japan and Australia (Table B.1). The most frequent importers include South Africa, Germany, Japan, India and China, and generally the machinery appears to be imported by a mix of developing and developed countries.

Figure B.1. Using a single benchmark for average unit value helps improve the stability of the main regressor

Value of trade captured as high-value (i.e. 3D printers' trade) using a single benchmark for average unit value (left) vs. a yearly benchmark of average unit-value (right) as a share of trade in 8477.80



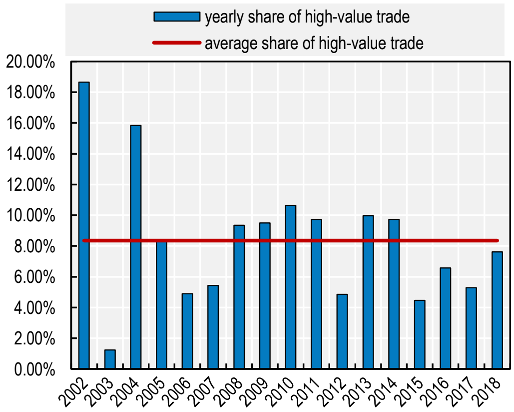


Table B.1 Top 25 exporters and importers of high unit-value machinery in 8477.80 (2010-2018)

	Top 25 exporters of high unit-value machinery (8477.80)				Top 25 importers of high unit-value machinery (8477.80)			
#	Exporter	Number of high-value exports	Share of high-value EXP in total EXP	Average value of HV EXP (USD thousands)	Importer	Number of high-value imports	Share of high-value IMP in total IMP	Average value of HV IMP (USD thousands)
1	CHE	227	35.30%	3628.673	ZAF	66	18.49%	6796.38
2	NLD	210	32.23%	2703.85	DEU	63	14.44%	11670.57
3	FRA	132	17.40%	2977.981	JPN	63	18.38%	19376.23
4	JPN	130	22.44%	4416.228	IND	62	12.02%	20604.83
5	AUS	129	28.98%	4114.061	CHN	61	12.07%	16710.43
6	IRL	123	38.70%	3571.6	CHE	58	27.04%	3364.389
7	ESP	115	15.39%	3157.181	CZE	57	22.51%	3978.168
8	DNK	111	19.73%	4703.361	KOR	53	19.71%	7097.711
9	GBR	110	14.59%	2538.792	MEX	52	8.54%	14634.45
10	BEL	99	17.02%	3476.048	FRA	51	13.34%	1864.213
11	USA	96	9.02%	3553.085	VNM	50	15.16%	10713.14
12	NOR	95	33.57%	4817.253	ITA	47	13.17%	1280.99
13	ISR	87	23.61%	6125.275	HUN	47	15.06%	22223.15
14	DEU	87	12.30%	1669.478	AUT	47	15.00%	6533.562
15	THA	86	16.24%	4955.864	RUS	45	13.06%	9207.171
16	CZE	79	14.80%	4008.878	BRA	44	12.38%	9260.586
17	POL	77	16.75%	3720.021	ARG	44	15.79%	1607.432
18	KOR	75	11.22%	2920.897	IDN	44	13.71%	7281.972
19	HUN	71	26.72%	4896.687	IRL	44	19.96%	14215.54
20	AUT	71	9.15%	3898.976	POL	44	16.66%	5134.498
21	ITA	70	6.87%	1728.423	GBR	43	10.91%	3781.943
22	CAN	69	11.60%	3754.425	AUS	42	15.23%	1750.422
23	FIN	53	21.60%	4807.984	ESP	42	10.67%	2440.677
24	IND	51	5.32%	3551.881	USA	42	8.96%	8476.901
25	SVK	41	10.76%	5124.852	BEL	41	13.12%	12106.38

Note: The total number of high-value exports denotes the number of times a bilateral trade relationship was classified as above average unit-value. For example, Switzerland exported at above average unit value 227 times, including 8 times to Korea in the 9-year period from 2010 to 2018, 5 times to Brazil, 3 times to Bolivia, as well as with a wide range of other import partners. The share of high-value EXP in total EXP denotes the average number of exports that is classified as above average unit-value. For example, Switzerland exported 8 times high-value machinery to Korea, and 9 times in the code 8477.80 in general (i.e. once at below average unit value). About 88% of its exports to Korea were high value. An average of this number is then computed across all import partners. The average value of HV EXP indicate the average value in thousand USD exported for the trade flows classified as above high-unit value. Indicators for imports mirror those of exports.
Source: CEPII BACI data.

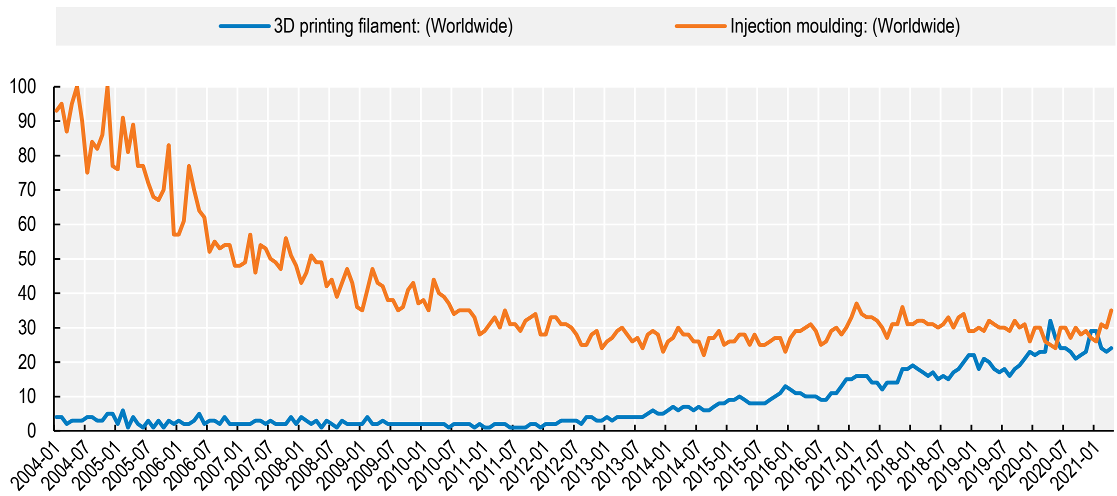
B.2. Using Google trends to proxy 3D printing adoption

A potential instrument to proxy the use of 3D printing are web searches for 3D printing filament, likely to be associated with wider 3D printing adoption, in light of the strong links between the technology and the web. Worldwide searches for this Topic have grown significantly over the past decades, and reached in 2020 similar volumes to those for Injection Moulding (Topic) globally (i.e. the competing manufacturing technique most often compared to 3D printing) (Figure B.2.). In light of the characteristics of the technology discussed in the review of the literature, more searches for 3D printing filament may not necessarily imply less-cross border trade, but they can provide a useful measure of 3D printing use across countries and over time.

There are also limitations related to using internet searches to proxy for 3D printing adoption. The data is available only for 51 countries (excluding 'low-search volume' regions) and internet searches may not well reflect adoption of AM technologies by firms, which are likely to use information networks other than Google.[53] Nevertheless, this measure can provide some insights into use of 3D printing at the country level, and potentially on the presence of active 3D printing communities within regions. In some European countries like Poland, Sweden and the Czech Republic, 3D printing filament (Topic) was searched in 2018 around 5 to 3 times more than Injection Moulding (Topic) (Figure 19). For most countries, and especially non-OECD countries, however, searches related to Injection Moulding remained more voluminous than searches for 3D printing filament in 2018 and subsequent years.

The variable of searches for 3D printing filament used for estimation (see Box 6) is the ratio of searches for 3D printing filament (Topic) to searches for Injection Moulding (Topic), by country and across the years 2004-2018.

Figure B.2. Worldwide searches for 3D printing filament (Topic) and Injection Moulding (Topic) converged over the last decade

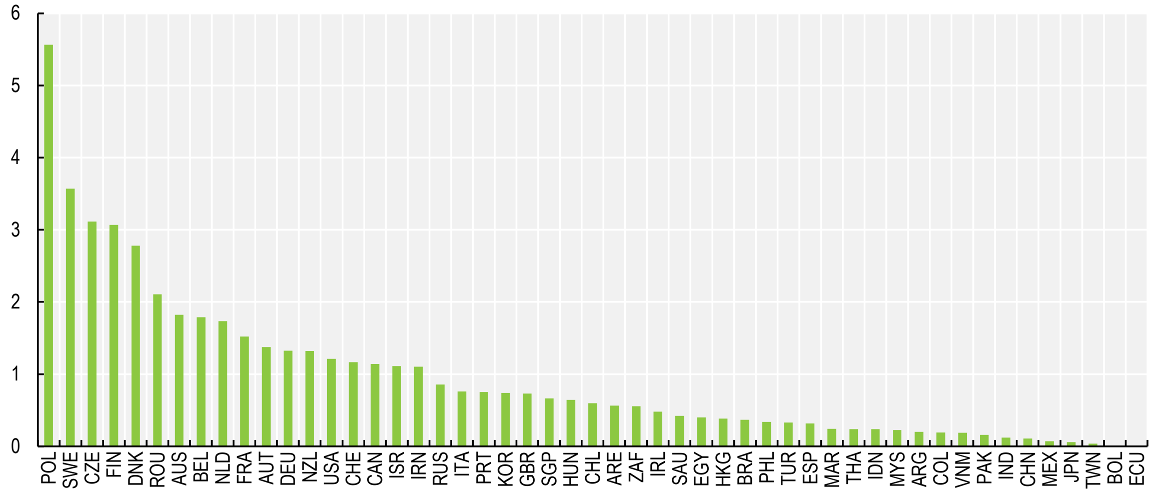


Source: Google trends: https://trends.google.com/trends.

53 For a discussion of the strengths and limitations of Google Trends, see Woloszko (2020).

Figure B.3. Ratio of searches for 3D printing filament (Topic) to searches for Injection Moulding (Topic)

2018



Note: 2018 refers to the latest available year for harmonised trade data in the CEPII BACI database.
Source: Google Trends: https://trends.google.com/trends.

Annex C. Estimations

C.1. GMM estimation

Control variables in the main model

As reported in Box 3, the model used to estimate the impact of importing additive manufacturing machines on exports of 3D printable products is:

$$X_{it} = \beta_1 X_{it-1} + e\beta_2 X_{it-2} + \beta_3 M3DP_{it} + \beta_4 TotImp_{it} + \beta_5 GDPcap_{it} + \beta_6 R\&Dexp_{it} + \beta_7 inward\ FDI_{it} + \partial_i + \delta_t + \varepsilon_{it}$$

Where $\boldsymbol{X_{it}}$ is the natural logarithm of the sum of exports of 3D printable items of country *i* at time t and $\boldsymbol{X_{it-1}}$ and $\boldsymbol{X_{it-2}}$ are the lagged dependent variables used to capture dynamics and controlling for omitted variables and autocorrelated residuals arising from persistence in the series. $\boldsymbol{M3DP_{it}}$ is the log of the proxy measure for imports of 3D printers, our variable of interest, while $\boldsymbol{TotImp_{it}}$, the log of total imports net of 3D printers, is a control measure capturing determinants of overall imports, including the prevailing trade policy environment. $\boldsymbol{GDPcap_{it}}$ is the natural log of per-capita GDP, $\boldsymbol{R\&Dexp_{it}}$ is R&D expenditure over GDP and $\boldsymbol{inward\ FDI_{it}}$ is existing inward foreign investment as a share of GDP. These last three variables are used to control for, among others things, capital labour ratios, technological capacity, innovation expenditure and realised foreign investment. A set of country ($\boldsymbol{\partial_i}$) and year ($\boldsymbol{\delta_t}$) fixed effects are also used.

The choice of control variables was driven by three main factors: ensuring theoretical consistency by selecting variables that affect production and exports; allowing for the ***widest*** possible country coverage in order to satisfy the condition of 'large N' necessary for reliable GMM estimations; limiting correlation between the different regressors to reduce the risks of multicollinearity, and capture different aspects of the production/exports function. Table C.1 and Table C.2 below provide a summary of these variables as well as their correlation coefficients, for both the export and import models presented in Section 4.

Table C.1. Summary statistics for the main regressors (export and import models)

	Obser-vations	Mean	Standard deviation	Min	Max	Source
3D printable exports	3608	122489.1	441290.3	.0131134	4384990	CEPII BACI database (2020 version)
3D printable imports	3621	3259993	1.04e+07	7.599	1.60e+08	CEPII BACI database (2020 version)
Proxy for 3D printer imports	1751	2301.582	5321.659	1.003	51131.27	CEPII BACI database (2020 version)
Total imports	3621	6.54e+07	1.93e+08	1009.614	2.46e+09	CEPII BACI database (2020 version)
GDP per capita	3163	14028.33	18978.26	194.8731	113236.1	World Bank World Development indicators (2020)
R&D expenditure	1481	.9532535	.9800393	.00544	4.95278	World Bank World Development indicators (2020)
Inward FDI	3049	8.189543	53.54034	-40.41425	1704.59	World Bank World Development indicators (2020)
Human capital index	2329	2.521667	.6942297	1.088122	4.154454	Penn World Table 10.0 (2021) (Feenstra, Inklaar and Timmer, 2015[59])
3DP filament searches	765	.2398205	.4522901	0	5.485185	Google Trends (2021)

Note: GDP per capita in current prices (NY.GDP.PCAP.CD) is gross domestic product divided by midyear population. R&D expenditure (GB.XPD.RSDV.GD.ZS) is research and development expenditure (% of GDP). Inward FDI (BX.KLT.DINV.WD.GD.ZS) is foreign direct investment, net inflows (% of GDP). The human capital index is based on years of schooling and returns to education – see Penn World Table 9.0 for more information. See Section II, III and Annex B for a description of how the other variables were constructed.

Table C.2. Correlation matrix for the model regressors (export and import models)

	3DP exports	3DP exports (N-1)	3DP exports (N-2)	3DP imports	3DP imports (N-1)	3DP imports (N-2)	Proxy for 3D printer imports	Total imports	GDP per capita	R&D expen-diture	Inward FDI	Human capital index	3DP filament searches
3DP exports	1												
3DP exports (N-1)	0.99	1											
3DP exports (N-2)	0.98	0.99	1										
3DP imports	0.87	0.88	0.88	1									
3DP imports (N-1)	0.87	0.88	0.88	0.99	1								
3DP imports (N-2)	0.86	0.87	0.88	0.99	0.99	1							
Proxy for 3D printer imports	0.23	0.23	0.23	0.14	0.14	0.14	1						
Total imports	0.89	0.88	0.87	0.91	0.90	0.88	0.22	1					
GDP per capita	0.38	0.39	0.39	0.40	0.41	0.41	-0.1	0.29	1				
R&D expenditure	0.37	0.38	0.37	0.33	0.33	0.33	0.00	0.32	0.70	1			
Inward FDI	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	0.22	-0.0	1		
Human capital index	0.34	0.35	0.35	0.40	0.40	0.40	-0.0	0.32	0.69	0.67	0.09	1	
3DP filament searches	0.06	0.07	0.07	0.09	0.10	0.11	-0.0	0.03	0.23	0.20	-0.0	0.29	1

Note: 3DP stands for 3D printable. Missing values of 3DP exports, proxy for 3D printer imports and total imports are replaced by zeros.

Why use a system GMM estimation?

The generalised method-of-moments estimators are dynamic panel estimators designed for situations with 1) 'small T, large N', meaning few time periods and many individuals; 2) a linear functional relationship; 3) one left hand-side variable that is dynamic, depending on its past realisations; 4) independent variables that are not strictly exogenous, meaning they are correlated with past and possibly current realisations of the error; 5) fixed individual effects; and 6) heteroscedasticity and autocorrelation within individuals but not across them (Roodman, 2009[60]).[54]

In the international trade literature, GMM estimators have notably been used to study the phenomenon of export-persistence at the firm-level: despite adverse productivity shocks or exchange rate fluctuations, it is estimated that over 80% of exporters continue to export the following period (Timoshenko, 2015[61]). Potential explanations are that more productive firms self-select into an exporting status, or because of the "learning by exporting" hypothesis, suggesting a causal effect from a firm's export status to productivity (Andersson and Lööf, 2009[62]). In light of the high correlation between exports and their past realisations at the country level, GMM estimations are used as a particularly useful option to control for endogeneity as well as a range of unobserved variables likely to be captured by past export performance.

Following the rule-of-thumb approach suggested by Bond, Hoeffler and Temple (2001[63]; Adeleye, Adedoyin and Nathaniel, 2021[64]), the main model is estimated using pooled OLS, fixed effects and difference GMM regressions to identify whether difference or system GMM would be most appropriate for estimation, in both the 2002-2009 period and the 2010-2018 period. Table C.3 reports the results. The first results is that, for the period 2010-2018, the difference GMM coefficient for the first lagged dependant

[54] The difference and system GMM were developed by Holtz-Eakin, Newey, and Rosen (1988[66]), Arellano and Bond (1991[84]), Arellano and Bover (1995[86]), and Blundell and Bond (1998[85]).

variable (N-1) is not between the pooled OLS coefficient (0.663 – upper bound) and the fixed effect regression coefficient (0.299<0.338, lower bound), showing that the estimation suffers from downward bias and that the use of system GMM is recommend.[55] Second, the proxy indicator for imports of 3D printers is robust to the use of different empirical specifications.[56]

Table C.3. Model results across pooled OLS, Fixed effects, and Difference GMM estimations

	Pooled OLS		Fixed effects		Difference GMM	
	2002-2009	2010-2018	2002-2009	2010-2018	2002-2009	2010-2018
3D printable exports (N-1)	**0.777*** **	**0.663*** **	**0.115**	**0.338** **	**-0.0652**	**0.299**
	(0.0758)	**(0.0955)**	**(0.0814)**	**(0.147)**	**(0.180)**	**(0.222)**
3D printable exports (N-2)	0.153*	0.283***	-0.113	-0.0203	-0.103	0.0386
	(0.0827)	(0.0973)	(0.0737)	(0.124)	(0.0644)	(0.114)
Proxy for 3D printer imports	**-0.0129* **	**0.0223*** **	**-0.00835**	**0.0169** **	**0.00682**	**0.0126** **
	(0.00765)	**(0.00677)**	**(0.00761)**	**(0.00688)**	**(0.00625)**	**(0.00632)**
Total imports	0.112**	0.0324	0.600**	0.553***	0.247	0.532**
	(0.0459)	(0.0277)	(0.256)	(0.198)	(0.311)	(0.206)
GDP per capita	0.00892	-0.00518	-0.169	-0.0209	0.154	0.00630
	(0.0309)	(0.0270)	(0.231)	(0.175)	(0.362)	(0.204)
R&D expenditure	0.00844	0.0362*	0.0850	0.0385	0.116	0.0824
	(0.0245)	(0.0198)	(0.161)	(0.0831)	(0.166)	(0.0987)
Inward FDI	0.000844***	0.000580	0.000173	-0.000731	-0.0000144	0.000130
	(0.000311)	(0.000553)	(0.000415)	(0.00107)	(0.000647)	(0.00110)
Observations	519	765	519	765	406	641
R-squared	0.979	0.978	0.408	0.207	-	-
No. of instruments	-	-	-	-	30	57
No. of groups	-	-	-	-	100	105
AR1 (p-value)	-	-	-	-	0.233	0.164
AR2 (p-value)	-	-	-	-	0.442	0.835
Hansen-J (p-value)	-	-	-	-	0.321	0.0194

Note: Standard errors in parentheses (* p<0.10; ** p<0.05; ***; p<0.010).
Source: Own calculations.

Model options include: two-step estimation to improve the efficiency of the GMM estimator and the accuracy of the associated tests; a robust option to request Windmeijer's (2005[65])finite-sample correction, to correct for downward biased standard errors arising from heteroskedasticity and autocorrelation; and forward orthogonal deviations instead of differencing.

When trade flows are missing they are replaced by zero to run the estimations on the largest possible number of groups and observations. Results are robust to replacing zero trade flows with missing values.

[55] System GMM is also recommended when the dependent variable (i.e. exports of 3D printable items) shows a high degree of persistence.

[56] Pooled OLS and Fixed effects regressions are also run without lagged dependant variables – the statistical significance of imports of 3D printers remains the same in 2010-2018 while being absent in 2002-2009, for both pooled OLS and Fixed effects.

Testing the robustness of results to sensitivity checks, instruments' reduction, and placebo regressions

A first sensitivity check consists in using export data extracted from COMTRADE in the SITC nomenclature, as the original list developed by Arvis et al. (2017[47]) was developed in this nomenclature. Results in the main model are robust to the change in export data, including for the split between sample periods and high-tech and low-tech goods (Table C.4).

Table C.4. Robustness of results to the use of SITC exports data

	3DP exports (2002-2009)	3DP exports (2010-2018)	3DP low-tech exports (2010-2018)	3DP high-tech exports (2010-2018)
3DP exports (N-1)	0.486***	0.360***		
	(0.150)	(0.107)		
3DP exports (N-2)	0.138***	0.220**		
	(0.0483)	(0.0845)		
3DP low-tech exports (N-1)			0.408***	
			(0.122)	
3DP low-tech exports (N-2)			0.249***	
			(0.0778)	
3DP high-tech exports (N-1)				0.353***
				(0.101)
3DP high-tech exports (N-2)				0.207**
				(0.0804)
Proxy for 3D printer imports	**0.0159**	**0.115****	**0.0874***	**0.126****
	(0.0230)	**(0.0544)**	**(0.0495)**	**(0.0554)**
Total imports	0.570*	0.427**	0.411**	0.370**
	(0.297)	(0.189)	(0.194)	(0.174)
GDP per capita	0.108	-0.0287	-0.159	0.0525
	(0.115)	(0.162)	(0.124)	(0.159)
R&D expenditure	0.154	0.482**	0.329*	0.571**
	(0.142)	(0.215)	(0.168)	(0.239)
Inward FDI	0.00188	0.00582**	0.00265	0.00639**
	(0.00135)	(0.00230)	(0.00168)	(0.00266)
Observations	519	765	765	765
No. of instruments	42	74	74	74
No. of groups	113	124	124	124
AR1 (p-value)	0.137	0.121	0.123	0.129
AR2 (p-value)	0.424	0.756	0.549	0.820
Hansen-J (p-value)	0.0550	0.0238	0.0557	0.0419

Note: 3DP stands for 3D printable. Standard errors in parentheses (* p<0.10; ** p<0.05; ***; p<0.010).
Source: SITC export data was extracted from COMTRADE. Own calculations.

Second, results are tested to instrument reduction by collapsing the instrument matrix and reducing the lags in the Holtz-Eakin, Newey, and Rosen (1988[66]) equation, and by doing both at the same time, as suggested by Roodman (2009[57]). The proxy variable for imports of 3D printers remains positive and significant across these different robustness checks (Table C.5). The estimation is also run with difference GMM with similar results, as reported in Table C.3.

Table C.5. Model results across Roodman (2009) recommended robustness checks

	System GMM estimation (2010-2018)				
	Instr. collapse	Laglimit=1	Laglimit=2	Instr. collapse & laglimit(1)	Instr. collapse & laglimit(2)
3DP exports (N-1)	0.548***	0.652***	0.659***	0.580***	0.590***
	-0.133	-0.0959	-0.0933	-0.168	-0.169
3DP exports (N-2)	0.0703	0.267**	0.285**	0.0716	0.0622
	-0.107	-0.124	-0.113	-0.185	-0.167
Proxy for 3D printer imports	**0.0351*** **	**0.0159***	**0.0142** **	**0.0363***	**0.0353***
	-0.0128	-0.00847	-0.00665	-0.0189	-0.0206
Total imports	0.398***	0.0753	0.0456	0.364	0.365
	-0.14	-0.086	-0.0553	-0.306	-0.32
GDP per capita	0.0732	-0.0142	-0.0136	0.0765	0.0749
	-0.047	-0.0288	-0.0229	-0.0843	-0.0901
R&D expenditure	0.172**	0.0464	0.0338	0.158	0.156
	-0.067	-0.0342	-0.024	-0.116	-0.122
Inward FDI	0.00207**	0.000821	0.000628	0.00191	0.00188
	-0.000918	-0.000623	-0.000556	-0.00128	-0.00136
Observations	765	765	765	765	765
No. of instruments	32	46	53	18	20
No. of groups	124	124	124	124	124
AR1 (p-value)	0.013	0.0301	0.0351	0.00626	0.00229
AR2 (p-value)	0.932	0.282	0.235	0.94	0.888
Hansen-J (p-value)	0.743	0.443	0.638	0.34	0.724

Note: Standard errors in parentheses (* p<0.10; ** p<0.05; ***; p<0.010).
Source: Own calculations.

A further sensitivity check consisted in replacing the variable of above-average unit value imports in 8477.80 with a variable of above average unit-value imports of 8479.89, an alternative code that could capture 3D printers (especially those working with metal materials) according to existing guidance (Hodes and Mohseni, 2014[58]). The coefficient from this model is not significant – and the same is true when using an 'unfiltered' import measure of 8479.89.

Lastly, the sensitivity of the model results are tested through a series of placebo GMM regressions including imports of diverse items like apples, explosives and locomotives to verify whether the model is not capturing a spurious link with imports that are not specifically linked to the code 8477.80. These regressions do not yield statistically significant results. The import variable is also substituted by a variable of total imports of capital goods (as identified using the BTDIx correspondence, excluding HS 847780), as well as a variable of injection moulding machines (HS code 847710) whose imports are however not significant in explaining the growth of exports in 3D printable products. For each of these regressions, care is taken to remove the placebo regressor from the total sum of imports used as control variable in the model.

Results across country groups for high technology products

Table C.6. Results across country groups for high-tech goods

	High-income countries		Developing countries	
	1-lagged instr.	2-lagged instr.	1-lagged instr.	2-lagged instr.
High-tech 3D printable exports(N-1)	0.916***	0.896***	0.369***	0.439***
	(0.111)	(0.130)	(0.0862)	(0.0987)
High-tech 3D printable exports(N-2)	0.0105	-0.171	0.264	0.160
	(0.177)	(0.140)	(0.270)	(0.249)
Proxy for 3D printer imports	**0.00820**	**0.0151**	**0.0431****	**0.0349***
	(0.00871)	**(0.0140)**	**(0.0170)**	**(0.0192)**
Total imports	0.0740	0.263***	0.274	0.326
	(0.137)	(0.0735)	(0.310)	(0.302)
GDP in current prices	-0.0106	-0.0456	0.0192	0.0431
	(0.0350)	(0.0797)	(0.0991)	(0.130)
R&D expenditure	0.0358	0.167**	0.587**	0.583**
	(0.0808)	(0.0679)	(0.289)	(0.270)
Inward FDI	0.000728	0.00206**	-0.00839	-0.00317
	(0.00100)	(0.000927)	(0.0107)	(0.0165)
Observations	406	406	322	322
No. of instruments	18	20	18	20
No. of groups	53	53	58	58
AR1 (p-value)	0.0125	0.0159	0.0293	0.0437
AR2 (p-value)	0.287	0.154	0.461	0.743
Hansen-J (p-value)	0.775	0.342	0.583	0.317

Note: Instruments are collapsed and lag limits restricted to keep the count of the number of instruments below the number of groups. Standard errors in parentheses (* p<0.10; ** p<0.05; ***; p<0.010).
Source: Own calculations.

Results across types of goods and countries in the import model

Table C.7. Results across types of 3D printable items and country groups (imports)

	All countries		High-income countries		Developing countries	
	High-tech 3DP imports	Low-tech 3DP imports	High-tech 3DP imports	Low-tech 3DP imports	High-tech 3DP imports	Low-tech 3DP imports
Imports of high-tech 3DP items (N-1)	0.539***		0.641***		0.706***	
	(0.0825)		(0.100)		(0.143)	
Imports of high-tech 3DP items (N-2)	0.131***		0.231***		0.0605	
	(0.0342)		(0.0456)		(0.0526)	
Imports of low-tech 3DP items (N-1)		0.661***		0.701***		0.757***
		(0.0846)		(0.155)		(0.101)
Imports of low-tech 3DP items (N-2)		-0.00186		-0.0599		-0.0535
		(0.0471)		(0.0962)		(0.0508)
Proxy for 3D printer imports	**0.00642****	**0.00397**	**0.0103*****	**0.00903****	**0.00859****	**0.000743**
	(0.00306)	(0.00312)	(0.00321)	(0.00427)	(0.00391)	(0.00420)
Total imports	0.322***	0.333***	0.117	0.355***	0.212*	0.287**
	(0.0749)	(0.104)	(0.0994)	(0.129)	(0.116)	(0.121)
GDP per capita	0.0255*	-0.0235	0.0339	-0.0803**	0.0157	0.0196
	(0.0139)	(0.0158)	(0.0311)	(0.0349)	(0.0257)	(0.0481)
Human capital indicator	-0.00527	0.0739**	-0.0371	0.0575	0.0239	0.0194
	(0.0207)	(0.0368)	(0.0235)	(0.0700)	(0.0241)	(0.0432)
Inward FDI	-0.000922***	-0.00100*	-0.000401**	-0.000539	-0.000111	0.00316***
	(0.000301)	(0.000601)	(0.000197)	(0.000544)	(0.00258)	(0.00111)
Observations	1220	1220	459	459	590	590
No. of instruments	69	69	32	32	32	32
No. of groups	136	136	51	51	66	66
AR1 (p-value)	0.0000256	0.0000756	0.00780	0.0264	0.000955	0.000343
AR2 (p-value)	0.446	0.194	0.0767	0.613	0.293	0.403
Hansen-J (p-value)	0.371	0.0262	0.281	0.0730	0.347	0.416

Note: 3DP refers to 3D printable. Standard errors in parentheses (* p<0.10; ** p<0.05; ***; p<0.010).
Source: Own calculations.

Results with Thingi10k goods

Table C.8. Internet searches for 3D printing filament are not strongly correlated with changes in imports of household 3D printable goods

	Imports of household 3DP items		
	Instr. collapse	Instr. collapse & laglimits(1)	Iinstr. collapse and laglimits(2)
Imports of household 3DP goods (N-1)	0.256	-0.00870	0.152
	(0.223)	(0.179)	(0.218)
Imports of household 3DP goods (N-2)	-0.158	-0.0895	-0.143
	(0.0984)	(0.0754)	(0.103)
Internet searches for 3DP filament	-0.00870	0.0188	0.00908
	(0.0410)	(0.0352)	(0.0373)
Total imports	0.930***	1.125***	1.006***
	(0.139)	(0.180)	(0.183)
Human capital indicator	0.327**	0.361**	0.334**
	(0.137)	(0.140)	(0.159)
GDP per capita	-0.0685	-0.0337	-0.0271
	(0.0543)	(0.0615)	(0.0643)
Inward FDI	0.00403	0.00574	0.00315
	(0.00323)	(0.00432)	(0.00384)
Observations	450	450	450
No. of instruments	41	20	23
No. of groups	50	50	50
AR1 (p-value)	0.269	0.553	0.376
AR2 (p-value)	0.945	0.486	0.810
Hansen-J (p-value)	0.537	0.196	0.144

Note: Total imports excludes Thingi10k products. Standard errors in parentheses (* p<0.10; ** p<0.05; ***; p<0.010).
Source: Own calculations.

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