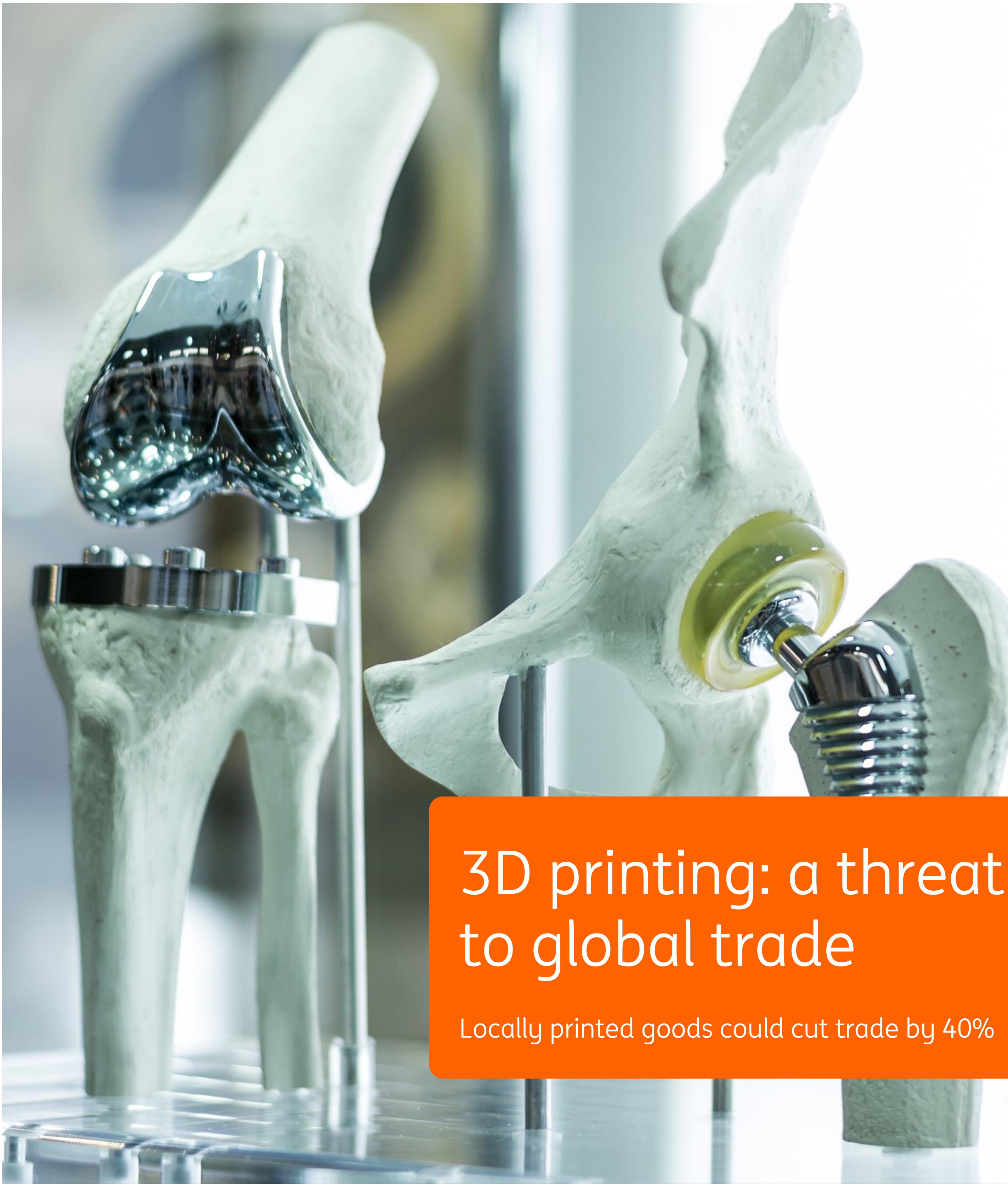

3D printing: a threat to global trade

Locally printed goods could cut trade by 40%

Economic and Financial Analysis
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Special thanks to research assistant Jin Huang

Source cover photograph: 123rf.com

Publication date 28 September 2017

Executive summary

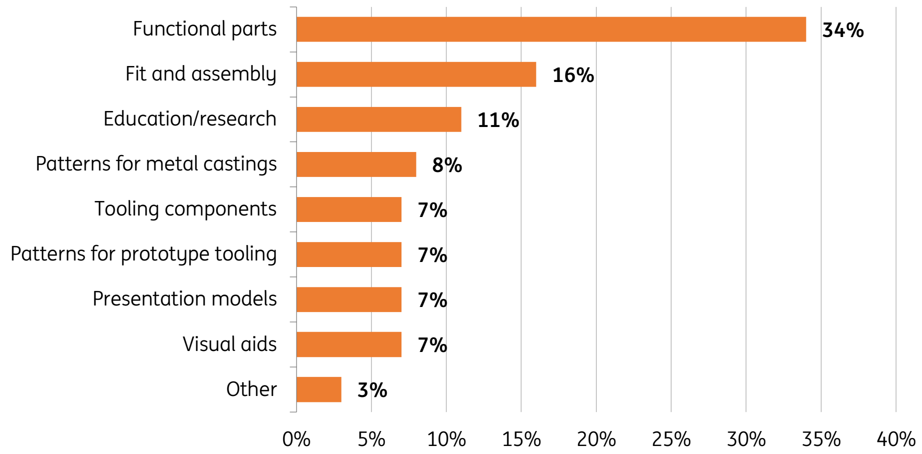
- 3D printing is still in its infancy. For now it has very little effect on cross-border trade.
- This will change once high speed 3D printing makes mass production with 3D printers economically viable. The first technical steps have already been taken.
- 3D printing will lead to less trade growth because 3D printers use far less labour, reducing the need to import intermediate and final goods from low wage countries.
- It is tricky to define the exact potential of 3D printing, but some experts expect a share of 50% in manufacturing over the next two decades. Tentative calculations show that, if the current growth of investment in 3D printers continues, 50% of manufactured goods will be printed in 2060 in scenario I, with this figure possibly being achieved as early as 2040 in scenario II in which investment doubles every five years.
- This is estimated to wipe out almost one quarter of world trade by 2060 under scenario I (or two-fifths by 2040 under scenario II).
- Automotive, industrial machinery and consumer products are the industries that, as a result of 3D printing, will take the lead in suppressing cross border trade These industries are top investors in 3D printers and are large players in world trade.
- In automotive, the dominant bilateral trade flows are exports from Mexico, Japan, Germany and Canada to the US. So these flows will be most affected by 3D printing.
- Locally printed car parts will increase jobs at US-based automotive factories.
- In industrial machinery and consumer products, the largest bilateral export flows also have the US as their main destination. China is the main origin country.
- The direction of flows in the most important 3D printing industries will lower US trade deficits with Mexico and Germany (automotive) and China (machines, consumer products), all large contributors to the US trade deficit.
- Less trade means that countries with trade deficits in manufacturing will see deficits decline. This will be more pronounced for countries that import relatively many products from leading industries in 3D printing. Countries with a surplus in manufacturing trade will see their surpluses shrink, especially if they currently export many products that will be 3D printed in the near future.

1. Introduction: what is 3D printing and who does it?

3D printing changes production processes because it reduces the need for assembly

When the internet was invented, few people imagined its huge impact on how we live and work today. It has changed the way we do business. 3D printing could see history repeat itself. On a small scale, it has already changed the way production processes in some sectors are organised and has the potential for much wider application. In this study we look at the effect that 3D printing potentially has on trade flows. 3D printing requires fewer or even no intermediate products, which are now often imported from other countries.

Fig 1 How are 3D printers utilised?**



Responses from 61 producers of 3D printers asked what their customers use the printers for. Respondents from North American, European and East Asian industrialised countries and China, India, Thailand and South Africa.
**11% of 3D printers sold are used in courses to train engineers how to work with them or for research purposes
Source: Wohlers report 2017, 3D printing and additive manufacturing, state of the industry, annual report

Identifying the trade flows of goods that are potentially most affected by 3D printing is important for current exporters of those goods and their local competitors. It is also of interest to businesses linked to trade, such as transportation and trade finance.

To manufacture an intermediate product or a final product the traditional way, for example a computer mouse, various components are produced separately and then assembled. A 3D printer works in a completely different way. A mouse can be printed as a whole, layer-by-layer. This makes the assembly process almost entirely obsolete. Customised features, like a special shape for the mouse, can be added. Products that are customised are already popular in some industries (trainers for example), but with 3D printers much more can be done. This comes at little additional cost, unlike with the resetting of traditional machines.

Will consumers print products themselves or will production companies continue to be the main suppliers? The relatively low costs of producing one or only a few units of a product and needing only raw materials (the 'ink' for the 3D printer) makes 3D printing well suited for consumers that wish to produce products for their own needs. It is likely that these so called 'prosumers' will have a significant impact on growth potential of production companies.

In the short to medium term the skills needed to work with a 3D desktop printer, the high price of 3D printers and the relatively expensive raw materials are impediments preventing many consumers from turning themselves into prosumers. In time, these hurdles can be overcome – 3D printers will become cheaper (as was the case with PCs) and high prices for raw materials should lead to more suppliers and hence lower prices.

3D printing will give rise to so-called ‘prosumers’: consumers that produce (print) their own goods for consumption

While many consumers might, in time, acquire the skills to work with 3D printers, not all will turn into ‘prosumers’. Although innovations in artificial intelligence might help (you tell your computer what product you want and it transforms this information into the printing file that the 3D printer needs), not everybody will want to do this. So production companies will continue to exist.

Technological progress in professional printers will enhance high speed and mass production unsuitable for the prosumer’s desktop printer at the kitchen table. In any case, not all products are candidates for customisation and hence 3D printing. While it is not hard to imagine that quite a few people would like to print their own clothes, furniture or food, it is harder to expect that many people also want customised versions of garbage bags or plugs. So, in general terms, we can assume that consumers that prefer customised products, and are willing to pay for these, will print at home. Others will prefer standardised products. These will be made by traditional machines or by professional 3D printers once they can compete with the economies of scale of traditional mass production methods.

Professional use

Production companies currently use 3D printing in all production phases, from product development to aftersales service. According to the 2017 annual report on the 3D industry by Wohlers Associates, a consultancy firm specialising in analysis of the 3D printing market, a third of 3D printing time is used is to produce “functional parts”. A sixth of the time is used for “fit and assembly” of physically big products and almost another sixth is used for making “patterns for prototype tooling or tooling of metal castings” (Figure 1, page 4).

Industries making most use of 3D printing include aerospace, automotive, medical/dental devices, industrial machinery and consumer products

The 3D printing technique could potentially be applied to many more products. Far from all manufacturing industries have experience with this production technique. Industrial machinery, automotive, aerospace, medical/dental devices and consumer products (electronics, etc) are the five industries that have been using 3D printing for quite some time now and are the largest buyers of printers and related services (Figure 2).

Fig 2 Fields of application and consequences of 3D printing, 2016*

Fields of application	Share in sales of 3D printers	Examples of what is made	Effects on production
Industrial machinery	19%	Production of tools like jigs and fixtures	Less time consuming/cheaper to produce (shorter lead time)
Aerospace	18%	Geometrically complex and lightweight parts	Fewer stocks and sometimes faster (so cheaper) to produce
Automotive	15%	Functional prototypes, small and complex parts for luxury and antique cars. Mainly non-mass production of specific tools and parts and for prototyping.	Reduce or even eliminate tooling, welding and entire assembling lines. Design and manufacturing tools become dispensable
Consumer products (a.o electronics)	13%	Micro-electromechanical systems, microwave circuits fabricated on paper substrates, radio-frequency identification devices inside solid metallic objects (RFID), polymer based, three dimensional, grippers	Easier adaption to domain specific development processes, acceleration of design process, functional integration of a number of different electronic devices in just one product, functional prototypes, spare parts produced on demand
Medical and dental devices	11%	Hips, knees, dental aligners, hearing devices, digital prostheses, etc.	Reduced processing times, digitalisation of manufacturing process, easy reproducing of production properties.
Other	24%		

Responses from 61 producers of 3D printers asked what their customers use the printers for. Respondents from North American, European and East Asian industrialised countries and China, India, Thailand and South Africa.

Source: Directorate-general for internal policies, European Parliament, Open innovation in Industry, including 3D printing; 2015; Wohlers report 2017, 3D printing and additive manufacturing, state of the industry, annual progress report.

Mass production is not possible yet with most 3D printers but aerospace companies have experience of printing parts in series of (tens) of thousands...

These five industries have been the largest investors in 3D printers for most of the past decade. Although medical and dental devices and aerospace are the industries that use 3D printers and print services most, they are smaller industries than industrial machinery, automotive and consumer products. These last three industries are responsible for the lion's share of worldwide investments in 3D printers.

Appendix 1 describes more in detail how 3D printing is applied in the five main industries – the main conclusion is that printers are not yet suitable for mass production, with some exceptions. Automotive, for example, has been investing in 3D printers for more than three decades, but the printers are mainly used for prototyping and making specific tools and parts. That said, Honda and Local Motors have produced cars that consist almost entirely of 3D printed elements. For the time being though 3D printing concerns production of a few units or parts rather than mass production.

Aerospace companies have some experience of printing certain parts in series of (tens) of thousands and Ikea launched a 3D printed chair in its 2017 collection. Medical devices is an industry in which 3D printing has advanced quickly and is replacing production using traditional machines. A global CEO survey from PWC (2016) reports, for example, that now all medical hearing devices in the market are made with 3D printers, with 3D printing technology outperforming traditional manufacturing, both in terms of cost and quality. The customised character of these products explains why 3D printing has taken over.

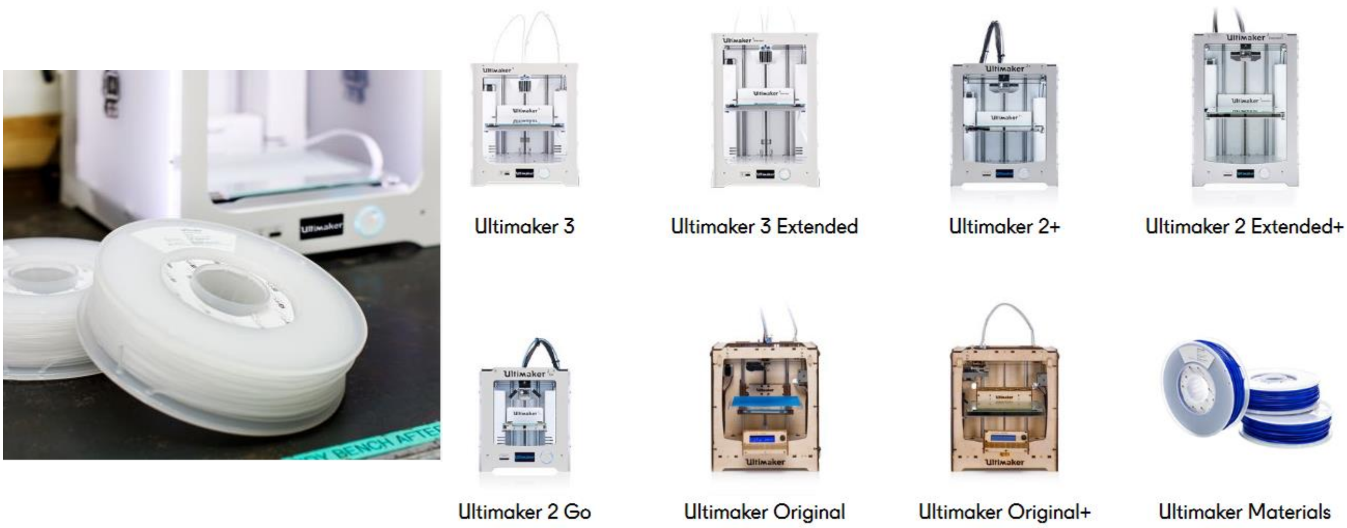
It should be stressed that, besides the technical prerequisites for wider application of 3D printing, economic viability for mass production is needed as well. Figure 3 illustrates how this can vary, often within the same industry.

Fig 3 Car components: technical and economic viability

Component	Technically possible to apply 3D printing	Economically beneficial to use 3D printing instead of traditional production methods
Distributor caps	Yes	Yes
Radiators	Yes	No
Brake callipers	Yes	No
Tyres	No	n/a
Brake pads	No	n/a

Source: DesRosiers Automotive Consultants, 2015

Fig 4 Ultimaker 3D printers



Source: Utimaker

2. The potential of 3D printing

It is difficult to forecast the future share of 3D printed goods and services in manufacturing globally. No data is available on the value of goods currently produced with 3D printers and on related services (maintenance, training for operators, etc).

On top of this, it is uncertain if this technology will facilitate mass production on a large scale. However, recent technological advances indicate that high-speed and thus mass production with 3D printers is becoming a reality. An advanced 3D printing technique, called high speed sintering, is capable of mass-producing up to 100,000 (smaller) components a day. This method is, according to the scientists of Loughborough University who developed this technique, up to 100 times faster than existing techniques. It is recognised for elevating the capabilities of 3D printing to major industrial quotas of complex components.

...and the latest technological innovations hold the promise of a future with 3D printers that can apply mass production in most sectors

Aside from technological advances, the adoption of 3D printing will also depend on awareness of it in company boardrooms. It takes time to incorporate new techniques in a production process. After all, the high speed sintering technique was launched in 2009 but, as noted, the share of 3D printed products in total manufacturing output is still marginal.

Expert opinions: interviews

To get a sense of the potential of 3D printing we held interviews with users of 3D printers, producers of printers and an expert who provides 3D printing training services. The conclusion we draw is that these experts see considerable potential for 3D printing, but vary in their expectations for the growth of this production technique over coming decades.

"The effect of 3D printing on the economy are hugely underestimated. I expect that in the next one or two decades about half of all manufacturing products will be produced with 3D printers", says Lodewijk van der Borg, CEO of the Dutch Kaak Group. Kaak Group started to use a 3D printer last year to make moulds for baking bread.

Adwin Kannekens, Sales director of Wilting, a company that does machining of metal, forecasts that in the long run 40-50% of its revenues will come from work done with a 3D printer. For the next ten years a market share of 5-10% in manufacturing industries is the limit in his view, reflecting various thresholds for the growth of 3D printing (see next section).

"3D printing will increasingly dominate markets of labour intensive, complex shaped and of customised products"

Eric Sas, CFO of Ultimaker, a Dutch 3D printer producer, is cautious regarding the long run. He agrees that a market share of 5-10% in manufacturing industries is possible in the next decade. For the longer run he expects further growth, but is uncertain about how large this share will be. He sees many hurdles and doesn't want to commit himself to forecast an exact market share.

Differences of opinion about the speed with which 3D printing will conquer manufacturing are logical, according to Lauren Slowik, Design Evangelist for Education at Shapeways, a large online 3D printing service company. 'It is very hard to estimate how fast this technology will grow' says Slowik. According to her, 3D printing will not be adopted in all industries in the near future because the entry cost of producing 3D printed goods are still too high for some lines of business. For Kaak group, for example, the price of a 3D printer was a hurdle that could only be crossed by buying the printer with two partners.

Besides the high investment costs of 3D printing, Slowik argues that for some time to come, regular (non-complex) shaped products will still be fabricated in a traditional way because that will remain much cheaper. "Producing with 3D printing technology will increasingly dominate markets of highly complex shaped industrial products and of products that have to be customized", says Slowik.

The experiences of machining company Wilting are in line with this view. According to Kannekens, 3D printing is most competitive when the traditional production method involves many steps, for example combining machining, laser welding and wire eroding.

Scenarios

The share of products and services produced with 3D printers is estimated to be currently less than 0.7% of worldwide manufacturing (0.1% of world GDP)...

Although there is no data on the value of 3D printed products and related services worldwide, the revenue growth of producers of 3D printers illustrates the size and growth of investment in 3D printers. Given the positive relationship between the amount of investment in capital goods (in this case 3D printers) and scale of production, investment in 3D printers will inevitably lead to more production with 3D printers. It should be noted though that currently 3D printing is largely used for prototyping which means that higher 3D investment does not translate into correspondingly higher production. On the other hand, technological improvements of 3D printers in combination with increasing competition in this market should lead to more productive printers for the same price. This means that going forward fewer extra 3D printers will be needed to generate a given increase in production.

According to the annual report on 3D printing by Wohlers (2017), companies worldwide spent US$6.6bn on 3D printers and related services in 2016. For comparison, in 2016 worldwide private investments in traditional machinery added up to US$6,700bn, 1,000x as much as private expenditure on 3D printers.

This indicates that the amount of goods produced with 3D printers and the value of related services is currently only a fraction of total worldwide production of goods and services. This is even more apparent when we note that the difference between investment in 3D printers and investment in traditional machines was larger in the past than currently - implying that the difference in the stock of traditional machines and the stock of 3D printers is even larger than 1,000x.

If we assume that the productivity of a 3D printer is equal to the productivity of a traditional machine of the same value, 3D's share of world GDP is less than 0.1%, or less than 0.7% of total world manufacturing production.

The role of 3D printing in the economy will, however, increase fast. The annual growth rate for investment in 3D printing has been 29% over the past five years, compared to an average of 9.7% for global investment growth in traditional machines.

...but if current growth of investment in 3D continues, half of world manufactured products will be printed in 2060...

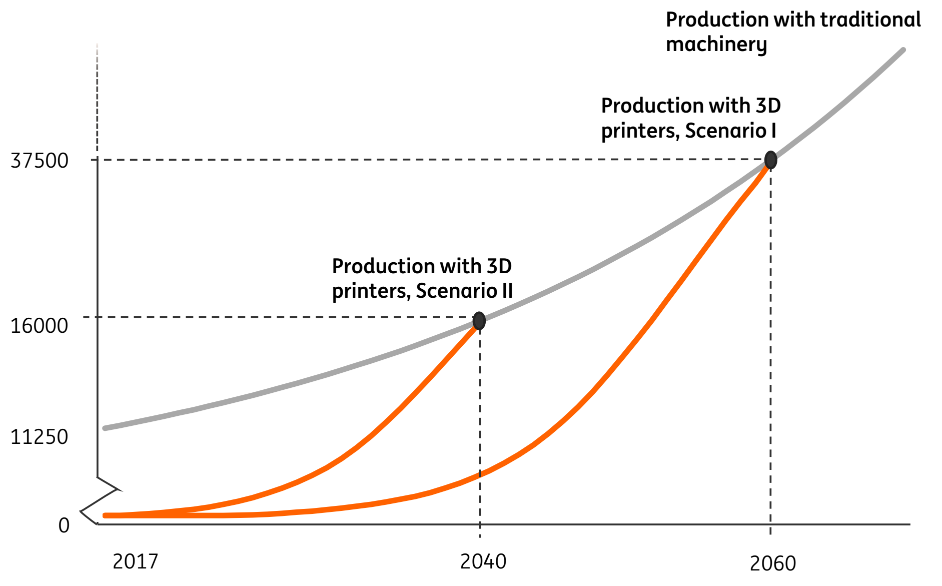
To see how the share of 3D production might develop, we take the nominal investments in 2016 as a starting point (US$6,700bn and US$6.6bn) and consider them as the respective capital stocks for traditional machines and 3D printers. If we assume that the annual difference in investment growth continues to be c.19% on average for coming decades, the stock of 3D printers will equal the capital stock and hence output of traditional machines in 2060 (see *Appendix 2* for calculations). This represents scenario I (Figure 5).

...but if growth of investment in 3D printers doubles every five years, half of the world's manufactured products will be printed in 2040

We are dealing with a disruptive technology that most companies still have to get used to and we should be aware of the possibility that technological progress could enhance revenues from producing with 3D printers (due to productivity increases, as seen with personal computers). This could cause the rate of investment in 3D printing to accelerate, bringing forward the point when 3D printing matches traditional manufacturing output. So as an alternative scenario we assume that the rate of investment in 3D printers will double after five years and the rate of investment in traditional machines will fall by a third after ten years. In this scenario the size of the capital stock of 3D printers will equal that of the capital stock of traditional machinery, and hence production size, in 2040 (Figure 5, scenario II).

It should be noted that we assume that mass production with printers becomes possible during these four decades, in both scenario I and scenario II.

Fig 5 3D printing's impact on world manufacturing production, ING scenarios I and II* (US$bn)



Note: Due to the break in the vertical axis the lines in the graph are somewhat distorted up to 2040.
*Scenario I assumes the current 19ppt difference in growth of investment in 3D printers and traditional machines continues, so that the capital stock and manufacturing production of 3D printers will equal that of traditional machines in 2060. Scenario II assumes the rate of investment in 3D printers will double after five years and the rate of investment in traditional machines to fall back by 33% after 10 years.
Sources: Oxford Economics; Wohlers report 2017, 3D printing and additive manufacturing, state of the industry, annual progress report, calculations by ING

3. What pushes 3D printing and what holds it back?

3D printing leads to all sorts of cost savings, but a cost disadvantage is that high speed production is not yet possible for most products

Based on the literature and interviews that we held, we identify the factors that we believe will drive the speed of expansion for 3D printing and the factors that will hold back that expansion.

What drives 3D printing?

3D printing is revenue enhancing for various reasons. First of all it facilitates customization. The extra value of customisation for consumers means that they will be prepared to pay a higher price. 3D printing leads to greater production flexibility and will lower delivery times, with production closer to the consumer. This gives companies that switch to 3D printers a competitive edge. 3D printing also reduces a range of costs:

3D printing is attractive for non-mass products that require much assembling or involve high costs for labour, transportation and inventory or create much waste

1. Lower labour costs

3D printing requires less manpower than producing in traditional ways. Assembly of the final product is sometimes still needed, but with fewer steps. This reduces the labour needed for assembly, coordinating processes, and transport of intermediates.

2. Lower other costs

1) **Reduced consumption of raw materials** because there will be no wastage; round metal products for example no longer have to be cut out of square steel pieces.

2) **Lower costs due to human error** because fewer humans are involved when producing with 3D printers.

3) **Inventory costs will fall**. 3D printing involves fewer economies of scale than traditional production methods. There is less incentive to produce large quantities which leads to less need for storage of products.

4) **Transport costs decrease** because there is less transport of intermediates and because 3D printing brings production closer to the consumer.

5) **Prototyping cost are lower** using 3D printers. Making prototypes from clay is a very labour intensive and time consuming process, which makes it expensive.

6) **Fewer traditional capital goods are needed**, because 3D printers reduces the need for production of many intermediates.

What is holding 3D printing back?

Quality of 3D printed products falls short sometimes which makes traditional manufacturing in some cases still more reliable

1) **High speed production cannot be done with most common 3D printers**. Traditional mass production is in many cases still cheaper. High speed sintering (heating up to little less than melting point) brings high speed production within reach for certain products. How rapidly high speed printing will be applied for other products depends on technological advances and the speed of adaption by companies.

2) **Recapturing cost of investments in traditional capital goods.** New plants involve high fixed costs and companies want to make this investment worthwhile before replacing with a 3D printer (Abeliansky et al (2015)). The older the current capital stock of (traditional) machines, the more economically viable is switching to 3D printing.

3) **High prices of raw materials used for 3D printing push up variable costs.** The raw materials market is characterised by a few suppliers with monopoly pricing power.

4) **Lower wages** and lower prices of traditional capital goods will result from substituting traditional capital goods with 3D printers. This will slow the substitution of traditional production methods by 3D printing.

5) **Slow adoption** of 3D printers by business. Kannekens notes that “technical shortcomings of 3D printers are not the main hurdle for wider use of 3D printing in metal products. Lack of knowledge about 3D printing and cold feet are the most important hurdles.”

6) **Quality of 3D printed products falls short** in some cases (Reeves and Mendis, 2015). For example, printed metal products sometimes contain holes and some products require an accuracy that 3D printers cannot deliver yet. According to Kannekens it will take quite some time to close this accuracy gap. “It took 3D printers ten years to raise the accuracy by a factor five, so you can imagine that increasing the accuracy by a factor ten, as needed to serve companies like ASML, will also take many years.”

7) **Availability of skilled designers** to write the printing files that the 3D printer needs to operate is a problem as well. ‘Most of the more experienced engineers are not properly trained for 3D printing’, says Kannekens. ‘New, young engineers who have the schooling are often not in a position within the company to make changes in the production process. So application of 3D printing currently depends on a few early adapters among the settled engineers’, says Kannekens.

4. Which companies are best suited to benefit from 3D printing?

Section 3 suggests that, with the current state of technology, switching to 3D printing will be attractive for non mass-production companies that make products with complex shapes that require assembly of many different parts, create a lot of waste material and incur high labour, transportation and inventory costs.

For some industries or companies 3D printing is simply not an option yet for technical reasons. Only when the quality of the printed products can compete with that of traditional machines, including in terms of accuracy and mechanical properties, 3D printing will become an option if it is also economically viable. The sooner mass production becomes possible with 3D printers, the faster it will become economically viable.

5. Does 3D printing signal the end of cross-border trade?

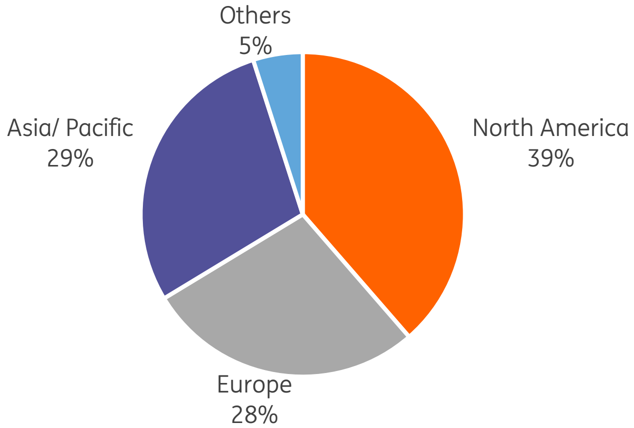
An important characteristic of producing with 3D printers is reduced labour input. With the adoption of 3D printing geographical differences in labour costs therefore become less important when deciding on the location of production of various product parts. Labour costs have been the main driver for companies to unbundle their production process and set up global value chains.

Re-bundling of different production phases, due to 3D printing, would reduce cross border trade in intermediates and final goods

A re-bundling of production phases closer to the customer would reduce cross-border trade in intermediates and final goods significantly. 3D printing will not only lead to re-shoring of production to developed countries and, hence, diminish imports, it will also reduce imports to emerging countries. Asia is already making considerable investment in 3D printing (Figure 6).

The cross-border flows of raw materials will also diminish. The major categories of inputs used by 3D printers are polymers and metals (Wolhers 2017). Oil, gas, cokes and a variety of metals, such as nickel, copper, gold and silver, are the ingredients for the materials that serve as 'ink' for the printers. Because 3D printing leads to less wastage than when producing the traditional way, the quantity of raw materials needed will fall.

Fig 6 Regional shares in private investments in 3D printers (2016)



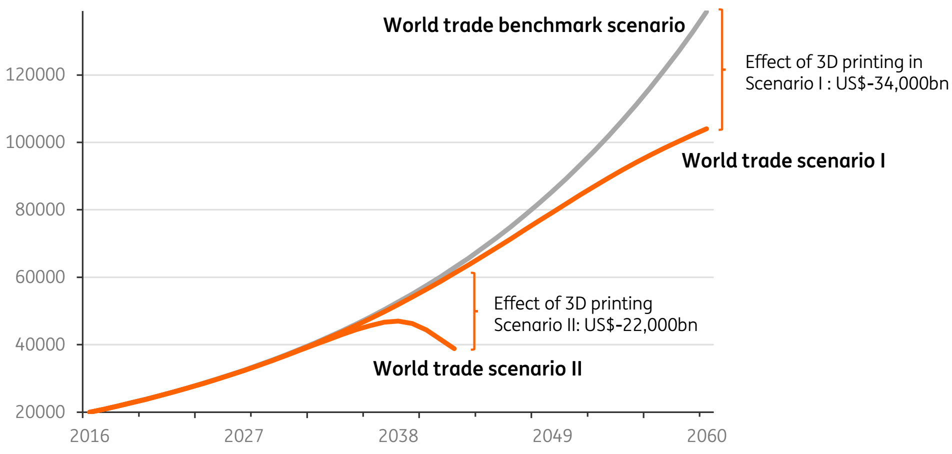
Source: Allied Market Research, New Vision, 22 April 2015

Effect of 3D printing on trade in goods

World trade in goods and services will be 22% lower in 2060 if 3D printing grows at current pace (2040 if growth accelerates). But mass 3D printing has to become viable

In section 2, we concluded that half of manufacturing products will be made with 3D printers by 2060 in scenario I (assuming continuation of current growth rate of 3D printing) or by 2040 in scenario II (accelerating growth). If we take into account that world trade also consists of commodities and services and assume that the downward trend in manufacturing's share in the world economy continues, manufactured goods will make up a little less than half of world trade in 2060. Due to 3D printing, half of goods that are currently imported will be made locally. This would imply that world trade in goods in scenario I will be almost a fifth (18%) lower in 2060 than in our benchmark scenario without 3D printing (see *Appendix 2* for calculations). In scenario II world trade would be almost two fifths lower (38%) in 2040 (Figure 7). For this to happen mass production with 3D printers has to become economically viable in multiple industries.

Fig 7 Scenarios for effect of 3D printing on world trade (goods and services) (US$bn)*



*See note below Figure 5 for explanation of scenarios and *Appendix 2* for calculations

Source: Oxford Economics; Wohlers report 2017, 3D printing and additive manufacturing, state of the industry, annual progress report; Unctad, calculations by ING

Effect of 3D printing on trade in services

The effect on trade doesn't stop with its influence on manufacturing. Services are affected as well. They currently make up 22% of world trade. Some services, such as harbour services, trade finance services and transport, depend heavily on trade in manufacturing products. If we follow an empirical finding of Wixted et al (2006) and assume that 20% of exported services are related to manufacturing, this results in a loss of exported services in 2060 of US$8,260bn (6% of world trade, see *Appendix 2*).

On the other hand, 3D printer related services, like installation, repair, education, will increase with the rise of 3D printing. These services are partly imported and it is estimated that this would lead to an upward effect of 2.5% on world trade (see *Appendix 2*). So total damage to services is calculated to be 3.5%.

Overall effect on trade in goods and services

If local mass production with 3D printers becomes reality, growth of world trade will be unable to outpace the growth of world GDP in the coming decades

Together with the 18% decrease in world goods trade, due to less trade by manufacturers, adding in the effect on services leads to the conclusion that in scenario I world trade in 2060 would be 22% lower than in the benchmark scenario (in scenario II this effect will be almost twice as high and obtained by 2040). This implies that world trade in goods and services will be US$108,000bn in 2060 instead of US$139,000bn in the benchmark case (currently world trade is US$21,000bn). This implies that world trade by value would grow 3.9% per year in scenario I, instead of 4.5% in the benchmark scenario. If we assume that 3D printing will not affect the development of world trade prices (1% price increase per year), world trade in volume would grow 2.9% per year, just as fast as real world GDP. In other words, if 3D printing develops according to scenario I, world trade growth will fall back from the forecast benchmark scenario of 1.2 times the growth rate of world GDP to no more than world GDP growth. In scenario II trade growth falls further to only 0.7 times GDP growth.

Which industries will drive the slowdown of world trade?

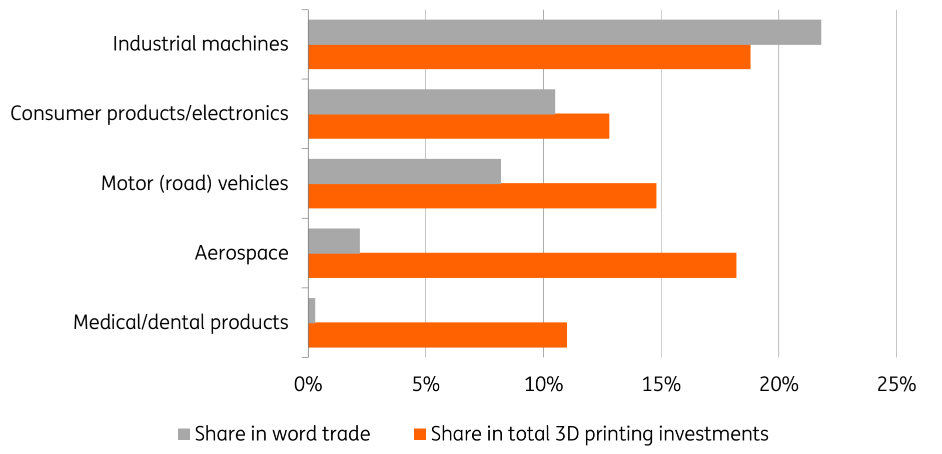
Figure 2 (page 5) shows us that industrial machines, aerospace, motor vehicles, consumer products and medical/dental products are, in this order, the five biggest buyers of 3D printers. They are responsible for 75% of all investment in 3D printing.

Figure 8 shows that these frontrunner industries make up only 43% of world trade. Of the top five, industrial machinery, consumer products and automotive are by far the most important for world trade, so their 3D activities will exert most influence on trade.

Industrial machinery, consumer products and automotive will exert most downward influence on trade

Once 3D printing techniques advance and become applicable for most products, other industries will catch up and also apply 3D printing. But we expect these five frontrunner industries to exert most pressure on cross-border trade in the near future.

Fig 8 Industry shares in world trade and shares in investments in 3D printers, 2016



Source: Unctad database; Wohlers report 2017, 3D printing and additive manufacturing, state of the industry

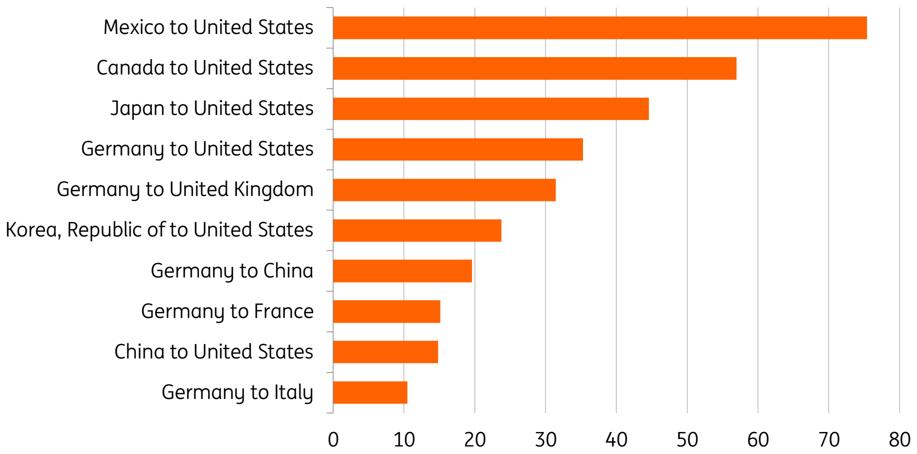
Which bilateral trade flows will be most affected?

Figure 9 shows that for automotive (road vehicles and road vehicle parts) the four largest bilateral export flows are all to the US. These exports to the US originate in Mexico (related to offshoring), Canada (supplier of parts), Japan (cars and parts) and Germany (cars and parts). Exports from Korea and China to the US are in the top ten bilateral automotive flows as well.

The most affected bilateral flows in automotive are exports to the US from Mexico (offshoring), Canada (car parts), Japan (cars and parts) and Germany (cars and parts)

The automotive exports of all these countries will be hurt if the manufacture of car parts is replaced by locally printed car parts and the local assembly of locally printed parts, however, German exports will suffer most. Germany is the originator of five of the ten largest bilateral automotive flows worldwide, with the UK, France, the US and China as its largest export destinations.

Fig 9 Top ten largest bilateral trade flows in automotive (US$bn, 2015)



Source: Unctad database

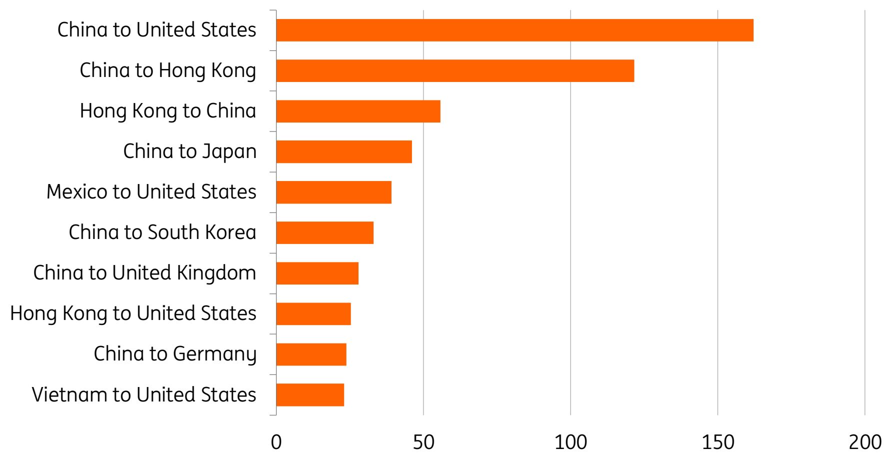
In the largest car importing countries (the UK, China, France and especially the US), locally based producers (domestic but also foreign automotive companies) will benefit because they are the prime candidate to supply printed parts of cars.

For consumer products, flows from Asian countries to the US will be affected most

For consumer products the US is also the most important export destination (Figure 10). The US imports a lot of labour intensive goods, such as clothes, footwear and toys. The main originating countries are China and Hong Kong. Other low wage Asian countries, such as Vietnam and Sri Lanka, also export consumer products to the US, and Korea sends electronics.

Just as for automotive, the US will benefit disproportionately from reduced cross-border trade in consumer products since the share of imported consumer products in total American imports is five times as large as the share of consumer products in American exports. Domestic American competitors of imports have much to gain from 3D printing while there are relatively little exports to lose. Note that foreign producers that produce in the US can benefit just as well if they switch to 3D printing.

Fig 10 Top ten largest bilateral trade flows in consumer products (US$bn, 2015)



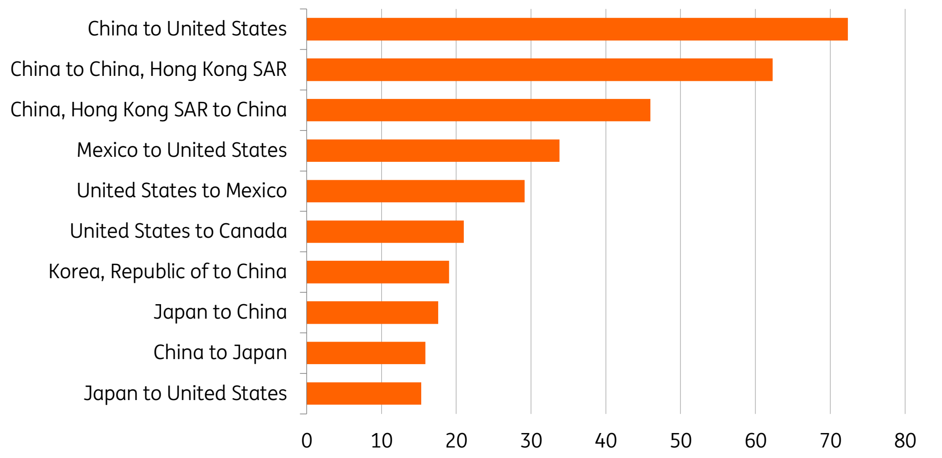
Source: Unctad database

For industrial machinery, the export flow from China to the US is currently most vulnerable to 3D printing, just as intra-Asian and intra-American exports

For industrial machinery the most important bilateral flows are exports from China to the US and exports up and down between Mexico and the US. Mutual flows between Japan and China belong to the most important bilateral flows as well (Figure 11).

Mutual flows between Hong Kong and China are also in the top three but differ in character because these flows exist mainly of re-exports. So, if 3D printing were to wipe out some of this trade, the producers that are hurt are mainly located outside Hong Kong. Hong Kong will suffer, but mainly the harbour and transport services.

Fig 11 Top ten largest bilateral trade flows in industrial machinery (US$bn, 2015)



Source: Unctad database

6. Consequences for US trade balances

Trade deficits have received a lot of negative attention lately from policymakers. Free trade has come under (verbal) attack, most notably from US President Trump. The rise of 3D printing will be welcome because less trade means lower deficits as GDP percentage.

US trade will be affected by the rise of 3D printing more than other countries, because the front running industries make up 58% of US imports compared to a share of 43% in worldwide imports

The US trade balance will benefit more than other countries from the rise of 3D printing, because the front running industries in 3D printing make up 58% of US imports compared to a share of 43% in worldwide imports. So the potential for substituting imports by domestically 3D printed goods, is relatively large for the US. Currently the US has deficits in most of these industries, especially with China, Germany and Mexico, countries that are among the four largest contributors to the US trade deficit.

For both consumer products and industrial machines, most imports come from China. By contrast, the US exports far less machinery and consumer goods to China. In other words, the emergence of locally 3D printed goods will reduce a significant part of the politically sensitive US trade deficit with China. This holds for automotive as well, although the bilateral deficit with China for automotive is much smaller.

The bilateral trade deficits of the US with Germany and Mexico will also shrink when the five frontrunner 3D industries start printing their goods in the US instead of importing.

Mexico runs a surplus with the US in automotive and consumer goods and Germany runs a large automotive trade surplus with the US. So, once 3D printing really takes off in these industries, the bilateral US trade deficits with these countries, criticised by the current US administration, will diminish as well.

Until all manufacturing product groups use 3D printing equally, the US will see its trade balance improve

So 3D printing could be a great help in reducing the trade deficits of the US with China, Mexico and Germany. China is responsible for 40% of the overall US trade deficit and

Mexico and Germany make up 8% each. So, through these three countries, 3D printing will have a significant downward influence on the overall US trade deficit.

However, for the total effect of 3D printing on the overall US trade deficit, trading with other countries also has to be taken into account. This makes a significant difference, mainly due to the fact that the US runs a large trade surplus with the rest of the world in industrial machines and aerospace.

We assume that, with time, other industries will catch up with the five frontrunner 3D industries, including other US industries that run a trade surplus with the world. In those industries the US has much more exports to lose. So the positive effect of 3D printing on the US trade deficit will fall as 2060 (2040) approaches.

Unfortunately, the industry 3D investment data is not available at a country level, so it is not possible to calculate the exact development over time of the trade balances of the US according to our two scenarios.

In any case, a 3D revolution is likely to cut the overall US trade deficit permanently. After all, 3D printing will cut both US imports and US exports of manufactured products. Even if the (nominal) reduction in exports were to keep pace with the (nominal) reduction in imports, the US trade deficit (as share of GDP) would come down because in nominal figures the deficit would be lower correspondingly.

Other countries' exports and imports of manufacturing products will also fall and their trade deficits or surpluses will often decline as well. As long as the five industries are in the lead with printing goods, the share that these industries have in the imports and exports of any country, will influence the size of the change in their trade balances. For countries with a large manufacturing surplus it takes a large over representation in imports of the five front running industries to avoid a decrease in their surplus.

In the long run however we suppose that all manufacturing industries are equally affected by 3D printing. So, this means that all manufacturing sectors have to be taken into account. Take as an example the large surplus country, the Netherlands. The trade balance for manufacturing products of this country is however more-or-less balanced. So the overall effect of 3D printing on the trade balance will be determined by sectors other than manufacturing. In the case of the Netherlands, that re-exports many imports, the transport, logistics and wholesale industries will turn the overall impact of 3D printing negative.

7. Concluding remarks

Currently, the consequences of 3D printing for cross-border trade are marginal. However, the growth of investment in 3D printing over the past five years has been three times as high as in traditional machinery.

Once 3D printing becomes widely applicable and economically viable for mass production it will boost 'local for local' production with 3D printers at the expense of imports. The first steps in the direction of high speed printing have been taken but it is uncertain when and to what extent high speed/mass production with 3D printers is possible in all industries. Having said that, it would not be the first time that (the speed of) technological advances surprises on the upside. Some experts involved with 3D printing expect 3D printing to account for half of world manufacturing eventually.

Assuming continuation of the current growth rate of investment in 3D printers, the capital stock of 3D printers will be as large as the stock of traditional machines by around 2060 and would produce half of world manufacturing output (assuming an equal productivity of 3D printers and traditional machines which is a conservative assumption because technological advances could lead to significant productivity increases of 3D printers, as we have seen with personal computers). If we assume a doubling of the growth rate five years from now, this breakeven point will be reached in 2040.

Due to the growth of 3D printing, world trade growth in scenario I will fall back from 1.2x the growth rate of world GDP (benchmark scenario) to no more than 1.0x world GDP growth over the next few decades. In scenario II it will be only two-thirds of GDP growth. World trade will be 23% lower in 2060 due to 3D printing in scenario I or 41% in 2040 in scenario II).

Lower cross-border trade in industrial machinery, automotive and consumer products may take the lead in supressing world trade given that these sectors are front runner industries in 3D printing and have a significant share in cross-border trade.

3D printing is good news for politicians that are concerned about their trade deficits. As the share of trade in GDP declines, so will their deficits. Especially if the share in total imports of products from the 3D frontrunner industries is above average. This is the case for the US. Besides bringing down the total deficit, 3D printing will especially diminish the politically sensitive US trade deficits with China, Mexico and Germany.

Appendix 1: Application of 3D printing in five industries

In medical appliances, 3D printing technology is well suited to many high-end medical devices with complex internal structures. It has become the dominant production technique for dental appliances. Medical devices are costly to produce by traditional manufacturing because they require a complex, time consuming production process. Many different parts have to be assembled while 3D printers print the product often in one step or very few steps, layer by layer.

Aerospace/aviation is an early adaptor of 3D printing particularly for geometrically complex and lightweight parts. In some areas, mass production is already in operation. For example, according to the annual Wohlers report 2017, General Electric Aviation produces tens of thousands of nozzles annually for its new LEAP machines and Airbus produces thousands plastic brackets, clips and holding devices with 3D printers.

Automotive is also an early adaptor of 3D printing. The industry has used 3D printers for almost three decades now, mostly in the pre-production stage, making prototypes/ show models but also small and complex parts for luxury and antique cars. Recently, automotive companies also applied 3D printing to the manufacture of car engines, the body of the car and panels. Local Motors has printed whole cars and most of Honda's car Commuter is 3D printed.

The consumer product industry has increasingly made use of 3D printing in recent years. Small specialised consumer electronic companies, for example, make individually customised products with 3D printers. Medium and large consumer electronics companies employ 3D printing in product design and producing prototypes.

Industrial machinery, an industry that consists of machines and office equipment, is not only a competitor of 3D printers (because 3D printers can substitute traditional machines) but also makes use of 3D printers, especially for prototyping and fabricating tools and specific machine parts and not so much for producing a whole machine layer by layer.

Although industrial machines, automotive and consumer products are the top 3 investors in 3D printing, the size of 3D investments is only a tiny fraction of investment by these industries in traditional machines. The share in total investment in 3D printers is larger in the smaller industries aerospace and medical appliances.

Appendix 2: The potential effect of 3D printing on world trade

Section 2 showed us that, on the conservative assumption that the productivity of 3D printers is the same as that of traditional machines and that there is a fixed relationship between capital applied and goods produced, 3D printers will print half of all manufacturing goods produced in 2060 in scenario I (continuation of the current growth rate of investments in 3D printers). Alternatively, this breakeven point would be reached in 2040 in scenario II (growth rate of 3D printed production doubles after five years).

To calculate the effect on world trade, we assume that the global annual real GDP will grow on average at the same rate as during the past 30 years (2.9%) and that world inflation will be half the rate of 5.1% that it has been. This holds both for scenario I and scenario II.

We calculate the benchmark trade growth (without 3D printing) by assuming that world trade in volumes will grow on average at 1.2 times the rate of world real GDP growth until 2060. So real world trade will grow 3.5%. This is much lower than the during the past three to four decades, but the period between 1990 and 2009 was a period of exceptionally high trade growth, pushed by a few one-off factors, such as the inclusion in world trade of an increasingly trade-oriented Chinese economy. In recent years, however, China has been moving towards a more domestic-oriented economy, which has rapidly pushed down their import ratio and thereby the growth of world trade. That is one of the reasons we forecast a much lower growth rate for world trade than over recent decades. Another reason is that the relatively rapid increase in wages in China and some other Asian emerging markets, has made offshoring less profitable, supressing the trade growth of intermediates.

Secondly, in line with the low overall inflation climate, we assume that world trade prices will grow at only half the rate of the past two decades: 1% per year. As a result, from these assumptions, nominal GDP can be calculated to be US$750,000bn and world trade in goods and services will value US$139,000bn in 2060.

Further, we assume that the share of manufacturing in world GDP will keep on declining so that it will make up 10% of world GDP in 2060 (12.5% in 2040), instead of the current 15%. Nominally, this results in a manufacturing production of US$75,000bn in 2060. But because half of manufacturing production will then be made with 3D printers, traditionally produced goods (that are subject to exporting) are 'only' worth US$37,500bn. If, as currently, half of this is exported, manufacturing exports will be US$18,750bn.

World trade is not measured in value added (while the global production figures do that to a much larger extent) but on the basis of national export turnover statistics. These turnover statistics are subject to double counting. According to the WIODD tables set up by the Rijksuniversiteit Groningen, export values are on average 1.4 times as high as the value added of exports. So to translate the production figures to export figures we have to multiply this production value by 1.4 times, which results in remaining worldwide exports of traditionally manufactured goods of US$26,250.

In other words, US$26,250 of the total world trade in manufactured products will be wiped out when made locally with 3D printers (2060). This is a reduction of 19% of world trade in 2060. Similarly, it can be calculated that two-fifths of world trade in goods will be lost in 2040 in scenario II.

Services

The consequences of 3D printing for world trade don't stop with manufacturing. Services currently make up 22% of world trade (US$17,000bn). Correcting for the double counting in export statistics, this is US$12,000bn in value added. We assume that total services will grow from 67% of world GDP to 72% in 2060 (US$540,000) because, as discussed, the share of manufacturing declines from 15% to 10%.

Currently, 5% of total services produced are traded across borders and we assume this to double to 10%. The question is, which of these services depend on manufacturing production. Wixted, et al, find in an OECD study (2006) that for some countries 20% of their services are used by manufacturing. We assume this, on average, to be the case for other countries as well, resulting in US$108,000bn services that are related to manufacturing in 2060. But because manufacturing exports only half of its production, services related to exports of manufacturing are equal to US$59,000bn. If we assume that manufactured products that are exported need twice as much services as manufactured products for domestic use (because of more transport services due to longer transport distances and trade finance/insurance sometimes getting involved), 20% of the manufacturing related services are exported services. This amounts to US$11,800bn. Because 'only' half of manufacturing exports is wiped out by 3D printing, the decrease in service exports (in value added) is US$5,900bn. But to translate the production figures to export figures we have to multiply this production value by 1.4 times resulting in a loss of exported services in 2060 of US$8,260bn (6% of world trade).

Increasing services related to 3D maintenance, training, writing the printing files and education offer a counterweight. Just as the current share of machine repair services is only 1.3% of world GDP, we assume that this will hold for all machines (traditional and 3D together) in 2060 as well. We also assume that half of machine repairs are related to manufacturing machines (0.65%) and because half of manufacturing products are exported, 0.325% of world GDP. Half of those exports will be replaced by printing the products locally, so the negative effect on manufacturing related services for exports will be 0.16% of world GDP. This equals 2% of world trade. We assume another 0.5% additional world trade exports due to other 3D services, such as installation and education services related to 3D printers. So the total impact on trade in services is 3.5% (6%-2.5%).

Summing up the effect on manufacturing trade itself and related trade in services, leads to the conclusion that 22.5% of world trade will be wiped out when 3D printing produces half of manufacturing in 2060 (or 41.5% in 2040 in scenario II).

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