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BIG INNOVATION CENTRE

Three Dimensional Policy

Why Britain needs a policy framework for 3D printing

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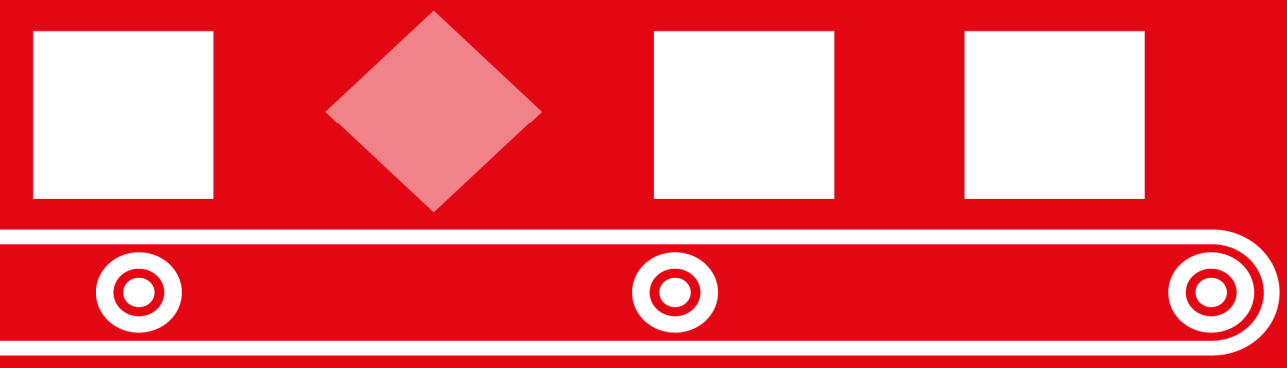

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Executive Summary

3D printing is an emerging technology with the potential to transform the global manufacturing industry and the UK economy. By enabling people and companies to download designs from the internet and turn them into physical objects, it could challenge the mass production model of manufacturing, and redistribute jobs around the world.

The opportunities presented by 3D printing are huge. It could become a major source of economic growth, and one which plays to the UK's strengths in design and online retail. It could bring significant environmental benefits, by removing the need to transport bulky goods around the world, and enabling new, sustainably sourced materials. It could vastly reduce the capital costs involved in manufacturing, and make it far easier for entrepreneurs to launch new ideas. And it could give customers an unprecedented degree of choice, allowing products from household items to transplanted organs to be custom-built around the needs of the user and their environment.

But the market for 3D printers and the goods they produce will not emerge instantaneously. There are a series of challenges that must be overcome before 3D printing reaches a mass market, and both businesses and government must play a role in solving them. The disruption caused by 3D printing will put significant strains on government policy. By removing barriers between the internet and the physical world, 3D printing will throw up significant questions for intellectual property laws, for regulators and for competition authorities. On top of that, 3D printing will need new infrastructure, new standards, and a host of other measures to help it mature and develop.

If the UK can get its policy response right, it stands to benefit enormously from 3D printing. And time is of the essence; there may be big first mover advantages for countries that adopt 3D printing early, and the UK has an opportunity to lead the world in this area. Given the rapid rate of progress in 3D printing technology, we believe that the debate around 3D printing policy must begin now, and seek to resolve the key issues as soon as possible. The key policy questions that this debate must address are:

- **Intellectual property** – the 3D printing movement has been built on an open-source ethos, and openness and flexibility will remain central to the technology's success. However, if 3D printing is to move into complex, investment-intensive parts of the manufacturing industry, it will also need to provide significant incentives for businesses to invest in designs and patentable ideas, without fear of copying. Resolving this tension between openness and returns on investment will be key to the success of 3D printing and will require bold thinking from legislators and lawyers alike;
- **Regulation** – 3D printers may make it possible for people to produce dangerous items, such as guns, in their homes. Regulators will need to find suitable ways of controlling such activities, without stifling the operation of 3D printing markets;

- **Legal responsibility** – determining liability when 3D printed products cause accidents may not be straightforward, and a clear legal framework for this will help build consumer confidence;
- **Standards** – developing effective standards for parts, processes and safety will be needed to help firms involved in 3D printing work together, and build consumer confidence;
- **Materials** – 3D printers need suitable materials to unlock their full potential; prize competitions may be a useful way to encourage the development of innovative new materials; and
- **Infrastructure** – 3D printing will put new requirements on the UK's infrastructure, both digital and physical, and government has a role to play in tackling these.

Solving these policy challenges will require a wide range of public bodies to work together, and take leads from business. The government must be proactive in addressing these questions and leading the debate, and ensure that it can respond promptly to developments in 3D printing. There is no place for government to pre-empt or attempt to force through the creation of 3D printing markets, but they must not allow any aspect of policy to hold back innovative businesses in this area.

First steps towards a coherent 3D printing policy

As a first steps towards seizing the 3D printing agenda, the government should:

- Create a **3D printing task force**, led by the Department for Business, Innovation and Skills (BIS), able to bring together ideas from business and academia, while co-ordinating the various levers of government policy;
- Scope a **review of the intellectual property implications** of 3D printing, building on the work of the Hargreaves Review;
- Fund the establishment of more **pilot 3D printing workshops**, to enable members of the public to experiment with the technology;
- Develop models for and explore the feasibility of a **digital design exchange**, analogous to the mooted digital copyright exchange;
- Provide funding for **competitions to develop new materials** for 3D printing; and
- Commission research and feasibility studies into possible methods for **regulating 3D printing** markets, particularly with regard to the production of dangerous items.

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Chapter 1 Introduction

3D printing – the ability to translate a digital file into a physical object – has already generated a huge amount of excitement and hype, much of it justified. Its implications for the future of manufacturing, for jobs and for economic geography are immense, so much so that some observers are heralding it as a "Third Industrial Revolution"[1]. 3D printing has the potential to completely disrupt every aspect of the global manufacturing industry; it raises the possibility of replacing two centuries of mass production with a new localised, personalised approach to making things. This could fundamentally alter global supply chains, relocate millions of jobs, and change the way businesses interact with customers. It also presents significant opportunities for the UK to reinvent itself as a world leader in manufacturing, and as a global hub for design, revitalising its economy in the process.

3D printing is close to becoming a reality; the technology behind it is advancing at an extraordinary rate. Enthusiasts can now produce a range of basic personalised objects in their bedrooms, using designs available on the internet, while some specialised manufacturers have begun using them in their assembly lines. With the costs of 3D printers falling, and their capabilities inexorably growing, the technology is fast approaching the point where it is ready for a mass market.

But a large-scale market for 3D printing will not just form instantaneously. There are a range of challenges besides technology that will need to be overcome before 3D printing takes off in a big way. The disruptive forces that 3D printing could unleash will put strains on the intellectual property system, on our infrastructure networks (both physical and digital) and on legal and regulatory regimes. These are challenges that policy makers must engage with, in a flexible and responsive manner, and in collaboration with businesses and entrepreneurs. Get the policy response wrong, and the UK could easily stifle much of the potential of 3D printing before it takes hold.

To date, there has been a considerable amount written about the technical capabilities of 3D printing, and about the effects it might have on society, but very little on the policies needed to make 3D printing work. We believe that a policy debate on 3D printing is badly needed. This paper is an attempt to start that debate, by setting out a range of policy considerations and ideas for enabling 3D printing to reach a mass market. The stakes are high; if the UK, or any other country, is able to create the right framework for a mass 3D printing first, it has a strong chance of being a leader in this area.

[1] "The Third Industrial Revolution: The digitisation of manufacturing will transform the way goods are made – and change the politics of jobs too", *The Economist*, 21 April 2012

3D printing and market making

This paper is intended to be viewed in the context of the government's role in facilitating the growth of new, innovative markets. The UK desperately needs new to seize new opportunities for growth, and the best of these opportunities tend to come from new, disruptive technologies. 3D printing looks likely to be one of the most disruptive technologies of the coming decade or two, hence our interest in it. But the process of turning new technologies into new markets, growth and jobs is complex, and often under-estimated. There are often a series of potential barriers that these new ideas have to overcome, from building consumer trust to establishing effective standards. Businesses and entrepreneurs work to solve many of these problems, but often cannot do so without support from the government. There is a role for government to play in helping businesses to create new markets, without trying to foresee what consumers will want in the future or taking the lead itself.

This paper is not a comprehensive assessment of the state of 3D printing technology, nor is it an attempt to predict definitively how 3D printing might evolve in the future. Rather, the paper takes a look at what 3D printing markets might look like in the future, and identifies some of the difficult policy questions that governments are likely to face. The response to these questions cannot be prescribed now, but must be developed as 3D printing technology evolves over time.

The innovation ecosystem for 3D printing

Like all radical new technologies, 3D printing will need to develop its own ecosystem of institutions, which support innovation and enable developments to be brought to market. This ecosystem will include the financial institutions that fund investments in 3D printing by businesses and start-up entrepreneurs, the universities and research bodies that develop and diffuse new ideas, and the skills needed to make 3D printing work. In addition, the 3D printing ecosystem will depend on a range of market institutions and levers of the state, which are discussed in detail in this paper. For the UK to make the most of 3D printing, all of these elements of the innovation ecosystem will need to be in place and work together effectively. It is impossible to predict exactly what the right institutional mix will look like for 3D printing, but businesses and government alike must think about the development of the technology in these ecosystem terms.

Chapter 2 What is 3D printing?

3D printing is a fundamentally new approach to making things. Additive manufacturing, the technique on which 3D printing is based, involves building products up layer by layer using a range of different materials. That is in contrast to predominant "subtractive" techniques, which involve taking blocks of material, cutting them down into the right shape, and assembling them into more complex products. In technical terms, additive manufacturing offers a number of potential advantages over traditional manufacturing techniques: it makes the manufacture of some complex objects possible, and has the potential to reduce waste. At present, 3D printing techniques are used for some specialised tasks, such as creating customised artificial legs and hearing aids.

What is truly transformative about additive manufacturing, though, is the potential to manufacture individual products anywhere in the world, and to customise each of them. Rather than make manufactured goods in one place and ship them around the world, 3D printing makes it possible to send design blueprints instantaneously via the internet, and manufacture them where they are needed. Manufacturing has always been done at scale, and required significant investment in fixed factories and machinery; 3D printing may vastly reduce these, as well as saving on transport and logistics costs. 3D printing could enable "just-in-time logistics" to be replaced by "just-in-time manufacturing", which ought to make business processes cheaper and more agile.

3D printers are growing in sophistication, and can create increasingly complex objects, including those with different component parts. Breakthroughs in techniques such as metal sintering mean that 3D printers are no longer restricted to generic plastics. The use of nanoparticles in 3D printing is progressing rapidly, and could vastly increase the range of products that can be manufactured in this way[2], potentially including chemicals. 3D printing also has the potential to manufacture some products that feature multiple working components in one go, such that objects work immediately without the need for assembly. These and other capabilities will continue to advance over the coming years, increasing the power of 3D printing, although this technological trajectory will be unpredictable.

Assuming that the development of 3D printing technology continues apace, its benefits could include:

- **Customisation and personalisation** – 3D printers offer far greater scope for customising products according to the needs of the customer. The shape, appearance and function of a product can be tweaked according to customer taste,

[2] Campbell, Williams, Ivanova and Garrett (2011) Could 3D Printing Change the World? Atlantic Council, Strategic Foresight Report

or the needs of the environment it operates in. Products can also be bespoke designed from scratch where appropriate;

- **Reduced inventories** – Instead of having to stockpile large numbers of products and trying to predict sales, 3D printing could allow manufacturers and retailers to operate with less stock, producing only what they need on demand. However, 3D printers would still require stockpiles of materials with which to operate;
- **Reduced capital costs** – 3D printers should, in theory, reduce fixed capital costs for manufacturers, by reducing the need for large scale investment in factories and machinery. Of course, the costs of 3D printers themselves would still need to be factored in by manufacturers, but assembly lines and supply chains are likely to be vastly reduced;
- **Reduced transport costs** – 3D printing should reduce transport costs, by removing the need for intermediate and finished goods to be shipped from one factory to another. While there will still be transport costs associated with materials, it is likely that these will be easier to source; and
- **Environmental benefits** – 3D printing should enable companies to reduce their carbon footprint – through reduced transport and supply chain activity – while using alternatives to scarce materials.

Against these potential benefits, there are also a number of limitations and challenges associated with 3D printing technology. These include:

- **A slow process** – 3D printing takes considerably longer than other manufacturing processes, and the overall speed of the process is ultimately limited by the laws of physics[3]. This may make it harder for 3D printers to produce large quantities of goods quickly, and will have implications for the distribution and size of 3D printing operations
- **Legal responsibility** – the rapid transmission of designs around the world, which are combined and manufactured using different machines and processes, could raise difficult legal questions about who is liable when things go wrong. Where 3D printed products go wrong and cause harm, it may be very difficult to tell whether the fault is with one of the component designs or with the manufacturing process. Without a clear framework for dealing with such issues, this may undermine consumer confidence in 3D printed goods, and create complex and stifling legal disputes
- **Real world proofing** – In theory, 3D printers may be able to replicate designs anywhere in the world, but there are a range of practical problems that may make the process difficult, especially for high precision operations. Changes in temperature and atmospheric conditions could conceivably affect the operation of 3D printers in different places, while there may also be a host of issues around lining up

[3] Campbell, Williams, Ivanova and Garrett (2011) Could 3D Printing Change the World? Atlantic Council, Strategic Foresight Report

and configuring different processes correctly. While this problem should not be insurmountable, it may require specialised staff to operate 3D printers, and increase the complexity of the process

- **Assembly issues** – while 3D printers are able to produce many products with components already built into them, they may not *always* be able to manufacture things that are fully assembled. This means that 3D printers may not always eliminate assembly lines, and therefore may often require larger, more capital- and labour-intensive assembly facilities.

None of these challenges are likely to be insurmountable, but they have implications for how 3D printing markets will develop, and the policies needed to make them work.

Will 3D printing become a general purpose technology?

Freeman and Perez (1988) set out three criteria which mark a transformative technology that forms a new "techno-economic paradigm":

- Rapidly falling relative costs;
- Almost unlimited supply over long periods; and
- Clear potential to be used as a factor of production in many different industries.

Whether 3D printing will meet these criteria in full is still uncertain, but there is a strong chance that it will. Its relative costs are falling rapidly, although they will have to continue to do so to cause rapid uptake. The supply of 3D printers is likely to be plentiful, provided that the intellectual property behind 3D printers is readily available. Whether 3D printing will affect most parts of the economy is harder to predict, although it looks increasingly likely that the technology will eventually be used (albeit in different ways) in many parts of the manufacturing industry, and could also affect parts of the service sector (such as retail and healthcare).

What is the opportunity for Britain?

3D printing, and the accompanying revolutions in supply chains, logistics and retail that it could trigger, present a major opportunity for the UK economy. 3D printing has the potential to boost economic growth around the world, and especially in the UK, where it plays to several of the country's economic strengths.

3D printing has the potential to create a number of new, wealth-creating markets, besides disrupting others. Some of these new markets are obvious – the market for 3D printers themselves, both for the home and for industrial uses, could be extremely valuable and generate a large amount of economic activity. But just as important, 3D printing could significantly increase the market for design services, by placing increased emphasis on the value of design. Equally, there may be opportunities for retailers, digital firms and a range of

technical service companies to benefit from the growth of 3D printing, as it spawns demand for a range of other services.

The UK has enormous potential in many of these areas. The UK appears to have a strong, internationally competitive design industry, especially in design services[4]; 3D printing could provide huge opportunities to project UK designers onto an international stage. Britain also appears to be a world leader in online retail, ranking among the leading countries in the world according to internet engagement and value of online transactions[5]. On top of that, the UK has also played a role in developing 3D printing technology, through academic research projects and initiatives such as RepRap, which came out of the University of Bath[6].

Besides these direct opportunities, 3D printing may have wider implications for economic geography and the distribution of jobs around the world. At present, manufacturing activities tend to be clustered in particular areas, with goods being mass produced in a relatively small number of factories and locations. Over the past few decades, the supply chains underpinning manufacturing have tended to become more globalised, with many assembly activities being "offshored" to emerging countries, including China. 3D printing is likely to create a much more localised distribution of activity and jobs, with production taking place close to sources of demand. It is possible that this may lead to some "reshoring" of manufacturing jobs, with Britain, which currently consumes far more goods than it produces, standing to benefit from any such trend.

On the question of UK manufacturing jobs, a far more significant question is whether 3D printing will be a net creator or destroyer of jobs. UK manufacturing has shed around 4.5 million jobs over the last 30 years, and only around 30% of this fall can be attributed to offshoring of jobs[7]; the majority of the job losses are down to productivity gains and outsourcing of activities to the service sector. Given the high degree of automation involved, and the reduction of assembly lines, 3D printing may increase manufacturing productivity significantly, which in turn could reduce the number of manufacturing jobs in the world economy. However, this effect should be offset by an increase in overall manufacturing activity (through the opening up of new markets), and by an increase in associated service jobs. It is difficult to predict which of these effects will dominate, and exactly what effect 3D printing might have on the number of manufacturing jobs.

What is likely, though, is that 3D printing will change the composition of jobs in manufacturing[8]. By reducing the labour input into production processes, 3D printing is likely to further reduce the number of production jobs, which have already been in decline for

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[4] Big Innovation Centre (2012) *UK Design as a Global Industry: International Trade and Intellectual Property*. A report for the Intellectual Property Office.
[5] Boston Consulting Group (2012) The Internet Economic in the G-20
[6] RepRap is a community project that focuses on 3D printers replicating themselves. See http://reprap.org/wiki/RepRap for details
[7] See Brinkley (2009) Manufacturing and the knowledge economy, *The Work Foundation*
[8] See Back to Making Stuff: Manufacturing still matters, but the jobs are changing, *The Economist, Special Report on Manufacturing and Innovation*, April 21st 2012

decades[9]. Production jobs currently account for just over 40% of manufacturing employment, with most of the remainder in professional occupations[10]. 3D printing is likely to create opportunities for designers, engineers, technicians, software programmers and other such occupations, but likely to reduce production jobs, which will have implications for the UK's skill mix, and may exacerbate labour market polarisation[11].

[9] Production jobs in the manufacturing industry (SOC 2000 codes 5 and 8) fell from 2.5 million in 1998 to 1.2 million at the start of 2012. Source: Labour Force Survey.
[10] See Sissons, A (2011) More Than Making Things: A new future for manufacturing in a service economy, *The Work Foundation*
[11] See Sissons, P (2011) The Hourglass and the Escalator, *The Work Foundation*

Chapter 3 What might a mass market for 3D printing look like?

While 3D printing is beginning to be used for a range of different manufacturing functions, it is a long way off reaching a mass market. At present, only serious enthusiasts or highly specialised manufacturers use 3D printers; in the future, everyone may find themselves consuming the products of 3D printers. It is impossible to predict exactly how long it will take for 3D printing to reach a mass market, or exactly what these markets might look like, but there are certain features that are worth discussing. In practice, 3D printing will not create a single, homogenous market; it will most likely be used in different ways, give rise to different types of business and different approaches to manufacturing. The most significant likely markets involved in 3D printing include:

- **Design** – 3D printing will likely create a global market for digital designs, both for generic blueprints and bespoke design services;
- **Bespoke manufacturing services** – 3D printing may well place increased emphasis on the service aspect of manufacturing, with retail and production being fused into a bespoke service;
- **Home 3D printing** – Some 3D printing is likely to take place within the home, while some will take place within shops or factories; these domestic and commercial markets will look very different;
- **Manufacture of 3D printers** – Producing and servicing 3D printers themselves should be a big money industry; and
- **Materials** – Creating and sourcing materials for use in 3D printers will also be a significant market.

Each of these markets may have quite different dynamics, and different implications for business. This section considers what these markets might look like. Trying to predict how the market for an emerging technology might develop is an uncertain business, and our view is not intended to be prescriptive, but to shed light on the types of policy that might be needed to hasten the spread of 3D printing.

A global market for designs

The growth of 3D printing is likely to create a global market for digital designs. If the customer is able to choose a product design from the internet, with the manufacturing process and materials relatively standardised, design is likely to be the key selling point for many products. Vendors of 3D printers have already created online catalogues of printable designs, which can be used by anyone with a printer. These digital catalogues are likely to grow in time, and may adopt different standards, file formats and software conventions.

The increased emphasis on design is significant for a number of reasons. First, it means that much of the value of 3D printed objects is likely to be embodied in the design (an intangible asset) rather than in the materials or the manufacturing process. That will create major opportunities for designers – an industry in which the UK appears to be very strong[12] – but it will also put considerable strains on the intellectual property system (see section 4).

Secondly, a digital market for designs could play to the UK's strengths in online retail. The UK has one of the highest rates of online retail usage in the world, and should be well placed to have a strong digital design market; this market could even become a significant source of exports. Just as iTunes has come to dominate the market for digital music, there are significant opportunities for companies to become major online retailers of digital designs.

Thirdly, a market for digital designs would offer significant scope for personalisation and customisation. There are likely to be many generic designs, some of them very profitable, but the use of design software would enable these designs to be customised according to an individual customer's tastes where appropriate. This increases choice for customers, and it also offers different ways for designers and businesses to make money. Some businesses will invest significantly in trying to create "blockbuster" designs, which would then used by large numbers of customers. Other design firms may offer bespoke design services, sometimes licensing generic designs and customising them, sometimes designing products from scratch.

The interaction between different types of design within a single product could become complex, especially where products have multiple components. A complex product, such as a mobile phone[13], might use components licensed from many different companies (such as batteries and processor chips), while still having certain features customised by a designer (such as the size of the screen). The issues of combining these virtual components into a single printed product, and of paying royalties on each of these designs, could make the market for 3D printed products extremely complex.

Materials for 3D printing

3D printing may allow designs and technologies to be transmitted anywhere in the world, and remove many of the challenges of logistics, but it still requires suitable materials to be available locally. At present, the range of materials that can be used by 3D printers is limited, but it is growing quickly, boosted by the development of metal-based techniques. Delivering standardised materials to every 3D printer in the world may be difficult, especially if these materials are complex composites. However, it may be possible to use a range of alternative materials in different places, to develop new synthetic materials, and to source materials locally in some cases. As a result, there is an opportunity to use 3D printing to increase the

[12] Big Innovation Centre (2012) UK design as a global industry: International trade and intellectual property. A report for the Intellectual Property Office.
[13] See Print me a phone: New techniques to embed electronics into products, *The Economist*, 28th July 2012.

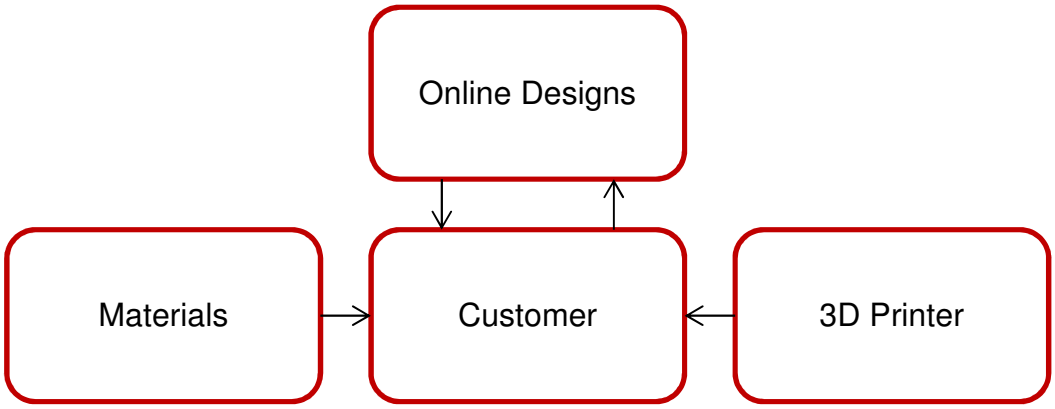
sustainability of manufacturing, both by reducing carbon footprints and substituting for scarce materials. The development of new materials for 3D printing will be an important aspect of the technology's development.

Shops, factories or in the home: where will 3D printers be used?

One of the most interesting questions surrounding 3D printers is whether they will predominantly be used in the home, or in shops and factories. The likely answer is that they will be used in all three, although the model for using them will look different in each case.

The development of desktop 3D printers, combined with archives of open-source designs, makes it possible for people to produce simple objects within their own homes at relatively low cost. This market is likely to be slightly less sophisticated than that for more complex items, but it will provide a great deal of flexibility for consumers. Users will be able to browse digital design catalogues, many of which will be open source and free to use, and print them in the home. This domestic market should provide opportunities for the vendors of 3D printers, both through selling printers and offering access to digital catalogues. It is possible that these in-the-home printers may be supplemented with service packages, such as a supply of materials and maintenance of the 3D printer. Figure 1 presents an outline of what the domestic 3D printing market might look like.

Figure 1: Indicative structure of the domestic 3D printing market

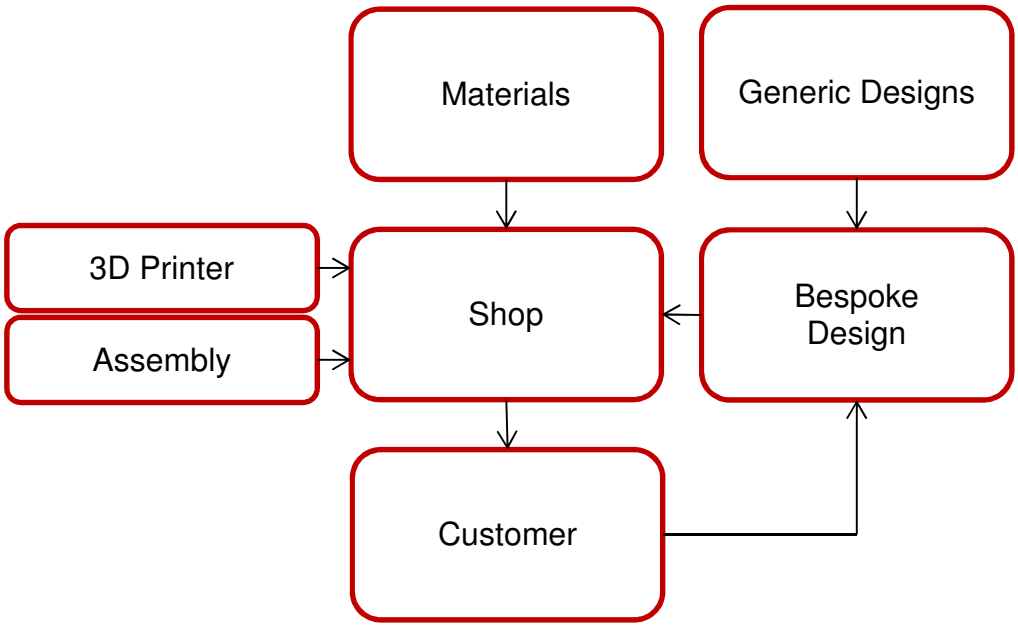


For more complex products, such as electronics or furniture, 3D printing is more likely to be offered as a bespoke retail service. Users should be able to access 3D printing workshops and request bespoke products, customised to their needs and produced on-demand. For businesses, this will involve combining component designs, adding bespoke design services and a retail offer as part of a single package. This will mean moving to a true "manu-services" business model, and present significant challenges for businesses in this field[14]. These localised 3D printing workshops are likely to employ a number of staff, covering

[14] See Sissons, A (2011) *More than making things: The future of manufacturing in a service economy*

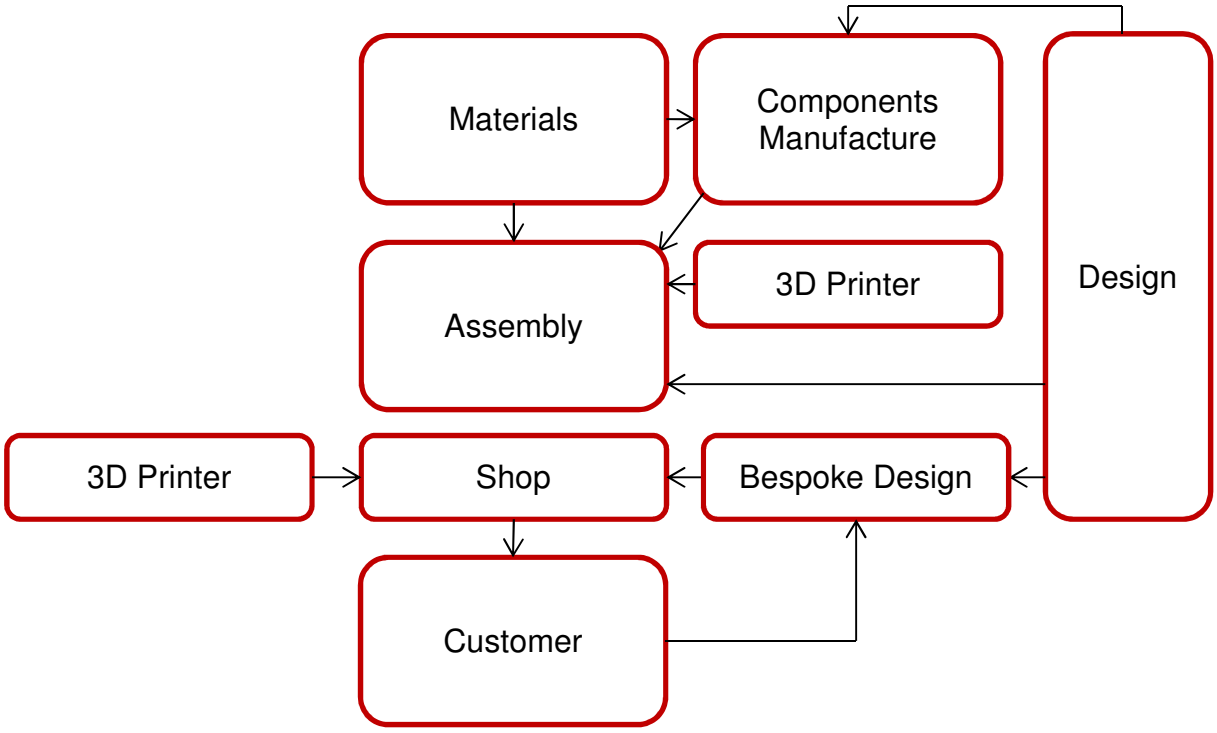
design, operation of the machinery and customer service. They would be able to assemble a range of products and source a range of materials, while featuring supplementary machinery, such as laser cutters. At the same time, these workshops are likely to be able to provide bespoke services, being able to tailor designs at the request of the customer, as well as providing on-demand products and perhaps delivery. Significantly, these workshops may also provide after-sales care, and provide guarantees against defects in designs or products. Figure 2 presents an outline of what a shop-based 3D printing market might look like.

Figure 2: Indicative structure of a shop-based 3D printing market



On top of this, 3D printers are also likely to be used in factories, to build specific components as part of existing assembly lines. This use is likely to be less disruptive, but still significant for many manufacturing businesses. Figure 3 presents an outline of how 3D printers might be incorporated into manufacturing assembly lines.

Figure 3: Indicative structure of a manufacturing supply chain including 3D printers



Will 3D printing replace current manufacturing processes?

Another major unknown in the development of 3D printing is whether it will supplement mass production or replace it as the dominant form of manufacturing. Technologically, additive manufacturing has a number of benefits over current subtractive or moulding techniques, while the prospect of localising manufacturing, using new materials and reducing logistics costs are also attractive. However, the global manufacturing industry continues to become ever more productive, with globalisation, automation and lean manufacturing processes continually driving down costs. For example, the price of consumer electronics to UK consumers fell by 81% between 1997 and 2009, while the price of clothing halved during that period[15].

At root, 3D printing will only begin to replace mass production if it becomes cheaper, of higher quality, or can offer customers and businesses something significantly different to traditional manufacturing processes. Given the potential for reduced transport costs, savings on inventories and capital spending and greater flexibility in global supply chains, there are plenty of reasons to believe 3D printing may eventually become the more attractive option. However, there are likely to be drawbacks and challenges to 3D printing that keep mass production the dominant approach. Mass production allows a high degree of specialisation,

[15] See Thompson and Sissons (2012) *Consumer Habits and Innovation: How do our spending decisions shape the economy?* The Big Innovation Centre

more rapid production, and a greater degree of certainty, which may give it a permanent advantage over 3D printing.

Realistically, the amount of disruption caused by 3D printing is likely to vary from one industry to another. In lower value manufacturing sectors, such as clothing, crafts and consumer goods, 3D printing may be able to compete with mass production approaches within a few years. Equally, some parts of the high-tech manufacturing industry, such as pharmaceuticals, may be ripe for disruption by 3D printing. By contrast, more complex manufacturing sectors may be slower to abandon the assembly line approach; for example, it is hard to see whole aeroplanes or cars being 3D printed in the foreseeable future, even if some components are produced using 3D printers. Equally, food and drink manufacturing appears far less likely to move towards 3D printing, without a major shift in attitudes towards synthetic foodstuffs. In general, industries with more complex supply chains, and whose products have a high value relative to their shipping costs, are less likely to be affected by 3D printing. Table 1 offers speculation on the potential disruption caused by 3D printing for every manufacturing subsector.

Table 1: Potential for 3D printing disruption in each manufacturing subsector

Subsector	SIC code	Total Gross Value Added, £billions (2010)	Potential for disruption from 3D printing
Food, drink and tobacco	10 - 12	25	Unlikely to move wholly to 3D printing, although some components (including packaging) may be 3D printed within supply chains.
Textiles, clothing and leather	13 – 15	4.5	Likely to be heavily disrupted by 3D printing, with design, logistics and retail processes potentially transformed.
Wood and paper	16 – 17	4.8	3D printing penetration will depend on ability to process different materials.
Printing and recording	18	7.1	Printing and recording have already been hugely disrupted by shift to digital content; this is likely to be far more significant than 3D printing, as digital media dominate physical media.
Refined fuels	19	2.2	Unlikely to be significantly affected by 3D printing.
Chemicals	20	11.7	Some parts of the industry may be affected by shift to 3D printing, but complexity of chemical technologies likely to make 3D printing slow to disrupt.
Pharmaceuticals	21	11.9	Significant potential for on-demand manufacture of drugs in hospitals, although much will depend on technology.

Rubber and plastics	22	5	High likelihood of disruption, especially for bespoke shaped plastics. Plastics are also likely to be the key material for 3D printing, which may prompt innovation in development of plastics.
Metals and building materials	23 – 25	22.9	Potential for significant disruption from 3D printing. However, 3D printing may not provide the scale of production required for some industrial and construction processes.
Computers, electronics and electrical equipment	26 – 27	13.8	Some potential for disruption from 3D printing, although issues of assembly and precision may limit uptake.
Machinery	28	10.4	3D printing is likely to play a major role in providing bespoke and on-demand machinery.
Cars and other vehicles	29	5.6	3D printing is unlikely to remove assembly lines or end mass production, but may play a role in manufacture of components.
Ships and aerospace	30.1 and 30.3	5.6	Large scale building projects make 3D printing unlikely, although may be involved in the supply chain.
Furniture	31	3.5	3D printing should play a major role in re-shaping furniture markets, with designs and logistics heavily disrupted.
Other manufacturing	32 and rest of 30	4.2	Other manufacturing includes a range of low-tech, bespoke manufactures such as toys; these are likely to be one of the earliest markets for 3D printing.

Source: GVA data from ONS Supply and Use Tables, 2010. Commentary based on authors' assessment.

The most significant aspect of the potential disruption from 3D printing is about changes in the supply chain and the way goods are sold. Many manufacturing sectors may use 3D printers for certain jobs, but keep their assembly lines, inventories and shipping of goods in tact. The most disrupted sectors will be those in which large factories cease to exist, with manufacturing becoming localised and on-demand. It is likely that, in industries which become disrupted, there will be a period of competition between incumbent mass producers, and disruptive localised manufacturers. In many cases, markets will be split between these two modes of production.

It is clear that 3D printing could cause significant disruption to global manufacturing, and create some major new markets and opportunities for the UK. However, these new markets will not be homogenous, and will likely evolve over time. This makes it vital that government policy remains sufficiently flexible to adapt to changes and support the growth of different 3D printing markets.

Chapter 4 What are the policy challenges that need to be addressed?

3D printing is an enormously disruptive technology, and could place significant strains on government policy, particularly around intellectual property. The digitisation of the content and copyright industries (such as music, publishing and the press) has been causing enormous disruption and innovation for well over a decade, and yet policy in these areas is still sometimes inconsistent and ill-conceived, with the tension between open access and copyrights still partly unresolved. 3D printing will have a similarly disruptive effect on the manufacturing industry, and thus an even bigger effect on the UK economy; manufacturing is bigger, more global and far more economically important than the copyright industries. Given this, it is critically important that debates about policy and legal frameworks begin as soon as possible, to maximise the opportunities presented by 3D printing.

3D printing's implications for the intellectual property system are huge. At present, manufacturers are often protected from copying by the large fixed costs involved in creating assembly lines, and the difficulty of replicating physical products. On top of this, manufacturers are able to use intellectual property rights, such as patents, trademarks and design rights, knowing that any potential breaches of these rights are likely to be carried out by other, legally responsible manufacturers whom they can pursue in the courts. 3D printing will upend this status quo, because it will allow manufacturing designs to be transmitted over the internet via digital files, making copying easier and tracking it more difficult. But 3D printing by its nature will also depend on openness and on the ability to share and combine designs easily. In response, the intellectual property system will be need to reconcile these two needs, offering incentives and rewards to those who invest significantly in new ideas, without stifling innovation and openness in the use of these online designs. That is a daunting legal challenge, and one that will require new thinking from government, from lawyers and from businesses.

Aside from these intellectual property issues, there are a range of other policy questions that 3D printing will throw up. Questions of safety, regulation and liability will come to the fore. Who will be responsible if a defective 3D printed product causes an accident? How do you prevent users creating weapons and other banned items? Creating new, effective standards and building consumer confidence in 3D printing will be important, and rely in part on government support. 3D printing will also require new infrastructure, and potentially present issues for the planning system.

To help answer these policy questions, it is useful to think about them in the context of government support for new industries and markets. Breakthrough technologies always need to overcome a complex series of challenges before they become mature markets, and governments almost always play some kind of role in supporting this process of commercialisation. Many such policies, including changes to intellectual property policy and standardisation, represent a low-cost way for governments to boost economic growth.

Alongside this paper, the Big Innovation Centre is also publishing a working paper on "Market Making"[16], which provides an intellectual framework for many of the issues addressed in this paper. The paper considers how governments can best work with the private sector to turn disruptive technologies into wealth-producing markets, and drive economic growth in the process. 3D printing is poised to be one of the most disruptive technologies of recent decades, and its transition to a mass market must be carefully and proactively considered by businesses and government alike.

Where does policy on 3D printing currently stand?

3D printing policy remains very much in a scoping phase, with most attention focused on the technology behind 3D printing, rather than on the policy issues it may raise. The government's Foresight Horizon Scanning Centre identified "manufacturing on demand" as one of three key transformative technologies for the 2020s in 2010[17]; subsequent work by both the Technology Strategy Board (TSB) and the Foresight Future of Manufacturing projects has also picked up on the topic.

More recently, the TSB has formed a Special Interest Group for additive manufacturing, which has identified significant opportunities and challenges for the UK in 3D printing technology. The TSB reports that the global market for additive manufacturing currently stands at $1.9 billion, and could potentially grow to around $100 billion by 2020 given the right technological breakthroughs[18]. In its report, the TSB group recommended developing new machine platforms for additive manufacturing, consolidating UK research into demonstration projects, and stimulating experiments with new 3D printing business models. The UK has not been as proactive in funding 3D printing as some other countries to date, however. The USA recently announced the creation of a National Additive Manufacturing Innovation Institute, with $30 million of government money leveraging $40 million of private investment[19]; by comparison, the UK's total investment in 3D printing is just £90 million ($140 million)[20].

In terms of wider policy considerations, the debate remains at an early stage. The influential Hargreaves Review of Intellectual Property used the development of 3D printing to highlight tensions in the treatment of designs in the intellectual property system[21]. It is likely that efforts to develop a more comprehensive evidence base on the intellectual property implications of 3D printing will follow over the coming years.

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[16] Sissons and Thompson (2012) Market Making: Turning disruptive technologies into high-growth industries
[17] Foresight Horizon Scanning Centre, Government Office for Science (2010) *Technology and Innovation Futures: UK Growth Opportunities for the 2020s*
[18] Technology Strategy Board (2012) *Shaping our National Competency in Additive Manufacturing*
[19] White House Press Release (August 16th 2012) *We Can't Wait: Obama Administration Announces New Public-Private Partnership to Support*
[20] Technology Strategy Board (2012) *Shaping our National Competency in Additive Manufacturing*
[21] Hargreaves (2011) *Digital Opportunity: A Review of Intellectual Property and Growth*

Intellectual property

Widespread adoption of 3D printing technology poses several challenges to the intellectual property (IP) system, the patents, trademarks and design rights that businesses register in order to protect the intellectual value of their goods. The ability to copy physical products much more cheaply than is currently possible has the potential to reduce the incentives for businesses to engage in research, development and design. This means that IP protection may need to be strengthened. At the same time it is vital that open methods of physical product development and collaboration are fostered. 3D printing has so far developed with a strong open-source ethos, and an intellectual property regime that is too restrictive and too proprietorial could restrict innovation within the field. Resolving this tension between the need for openness on the one hand, and for incentives for investors in intellectual property on the other, is vital to the development of 3D printing markets.

What are the intellectual property implications of 3D printing?

The key change brought about by 3D printing is on the cost and ease of reproducing a physical object. Currently businesses have to spend large amounts to buy the machinery and skills needed to 'copy' a mass-produced good. They need to purchase machines to perform the tasks of a production line, and employ individuals with the specialised skills to adapt and implement the product's design, run and maintain the machines, and perform those production tasks that rely on the dexterity of human inputs. Because of these large costs, manufacturers need to produce a large number of each good to be profitable.

3D printing technology has the potential to vastly reduce these costs. Instead of the need for complex and specific machinery and skills, a single 3D printer, run by a non-specialist operator using generic materials, will be able to copy many different products from existing designs that are easily and quickly shared over the internet.

This means that IP may become the dominant method through which businesses in some areas of manufacturing can fund the research, development and design of new physical products. As it stands, manufacturers can often rely on the large costs they are able to pay, or on getting a product to market quickly and before competitors, to ensure it is difficult for their products to be copied. But the advent of high-quality mass 3D printing reduces the ability of manufacturers to rely on these methods. Therefore, the ability of businesses to extract value from their IP will become increasingly significant as a value generator and incentive for new product development.

At the same time, however, the open architecture nature of the internet means it is difficult to control and limit the sharing of IP. This is analogous to the difficulties in the last decade or so of controlling peer to peer sharing of copyrighted creative works like music and other media. In terms of 3D printing, it will be easy for individuals and businesses to access and share the designs and technical information of physical products for free and over the internet. This ability to share and modify designs quickly offers enormous opportunities for innovation and development of new ideas, because far more people and companies can get involved in this

creative process, but it may limit incentives to invest heavily in designs. This may challenge the ability of businesses engaged in research, development and design to extract value from their IP, at the same time as IP becomes the central generator of value for those businesses. Without an appropriate legal consideration of these issues, there is the potential to greatly reduce the economic incentives for businesses to develop new physical products, especially in markets where 3D printing is likely to be highly disruptive. At the same time, new businesses will emerge to make the most of this new manufacturing landscape. 3D printing policy must not fall into the trap of favouring incumbent businesses or encouraging models that are too proprietorial, but it must also not overlook this issue of incentives.

Where does the law currently stand on 3D printing?

A recent paper on the IP implications of 3D printing showed that the printing of most physical objects for non-commercial and personal use is legal[22]. That has significant implications for 3D printing in the home. For products with low complexity, and where quality and precision is less important, consumers will be able to print designs of a sufficient standard for personal use in the home. But for more complex products, such as consumer electronics, it is unlikely that home-use printing will pose a serious threat to the ability of businesses to generate value from their intellectual property, at least in the foreseeable future. The important point here is that the IP system will need to remain alert to the evolution in quality amongst home-use 3D printers. It should be prepared to act if the situation changes, whilst at the same time protecting the rights of users to make simple parts and products for their own use.

However, we see the early market for 3D printing technology and use as being driven by local 3D printer shops and labs. In this environment the IP situation is different. Taking an existing design and turning it into a product for sale would currently be illegal unless the 3D printer shop does not license the design from the rights holder. This is likely to be fairly easy to enforce, since shops need a license to trade and can be more easily regulated and legally challenged. There are a number of exceptions to this restriction, such as producing non-trademarked and generic spare parts, or distinctive parts where they are being used for cosmetic repair. There is also a legal ambiguity around whether a 3D printing lab is selling a product or merely the services of a 3D printer. In the latter case it could be argued designs are being turned into products for personal and non-commercial use, which in the current legal framework has fewer restrictions on what can be copied. This distinction will need to be clarified.

What does the intellectual property system need to do to support 3D printing?

In general, we would expect 3D printer shops and labs to have to license a large number of designs from rights-holders. The co-ordination costs associated with doing this on a case-by-

[22] See Bradshaw, S, Bowyer, A & Haufe, P (2010) The intellectual property implications of 3D printing *SCRIPTed Vol. 7-1*

case basis, with individual contracts drawn up every time, will be prohibitively high. This will be likely to encourage the development of businesses that act as online brokers and marketplaces between rights holders and shops. The IP system needs to act to facilitate this transition, helping 3D printing become an effective online mass-market. It must be as easy to trade in online designs and assign prices to them as it is to buy products on Amazon or Ebay.

The IP system has to be flexible enough to suit the bespoke tastes of consumers and fully realise the potential of personalised manufacturing. It should allow designers in 3D printing shops to be able to combine different components in new and creative ways to make composite products, something that may be difficult given current IP restrictions. The IP system already forces some patented technologies to be open for license by others, through 'fair, reasonable and non-discriminatory' (FRAND) provision. There may be a case for using the FRAND provision for a greater range of key technologies and components, to ensure the benefits of 3D printing are realised.

There may also be a requirement for the state to help in developing an online IP exchange, analogous to its plans for digital copyright[23]. This, when developed, could act as an online marketplace where 3D printing shops and online design catalogues can access registered IP quickly, as well as offering a service where patents and designs can be registered and uploaded cheaply and efficiently.

It should also allow for the easy registration of generic and 'open source' designs, which would be free to use and modify in the same way as open source software. This will require the development of open alternatives to traditional intellectual property mechanisms. This process is already far-advanced for copyrighted works. The 'creative commons' system of licensing gives creators an opt-out from copyright restrictions. A similar range of open IPRs for patents and designs needs to be developed.

Standards, Legal Responsibility and Regulation

Many early experiences of 3D printing have led to heated debate around the issue of regulation. What should the appropriate government response be when individuals or organisations have the ability to print dangerous and illegal objects such as firearms and other weapons? How do we ensure products printed locally are of sufficient quality to meet safety requirements? And how can standards agencies seek to improve the quality of 3D printing services and encourage greater usage amongst consumers?

These questions centre around three aspects of government policy: regulation, the legal framework, and standards. All are related and need to be co-ordinated by the state in order

[23] See Hooper, R & Lynch, R (2012) Copyright works: streamlining copyright licensing for the digital age *Intellectual Property Office*

to meet the needs of an emerging 3D printing industry, as well as increase business and consumer confidence in 3D printing technology.

Regulation

Much debate around 3D printing has illustrated the tension between mass-adoption of personalised manufacturing and regulation. The ability to print objects on demand, it has been argued, may lead to mass-production of illegal or restricted goods such as handguns, other weapons and banned substances. Clearly there needs to be a consideration of these issues by policymakers.

Currently many products face specific restrictions on their sale. It is illegal to purchase a handgun in the UK, or sell certain products to children, for instance. If the initial mass-application of 3D printing takes place via labs and shops selling to consumers, as we believe, it is clear that these restrictions on sales should apply in a similar way. Where a license is required for the purchase of certain goods, there may be a case for either restricting these to traditional retail outlets (e.g., gunsmiths), or making it easier for staff at 3D printing labs to check licenses via an online service or similar.

There is a potential regulatory issue around home-use 3D printers. Many observers and commentators have expressed concern that the advent of mass-use 3D printing will lead to individuals printing weapons in their home. Whilst this may become a significant issue in the future when advanced 3D printers that can print complex products become cheaper and widely accessible, it is unlikely that this will occur in the medium-term. Policymakers and regulatory institutions should monitor developments in home-use 3D printing markets and be ready to act accordingly.

Legal responsibility

Defining who has legal responsibility for the quality and safety of printed products will be a key step in developing a mass-market for 3D printing. If a consumer were to buy a 3D printed cycling helmet, for instance, and the helmet later proved to be faulty, who would be legally responsible? It could be a fault with the original design, or an error by the shop that printed the product. It could also be an issue with materials, or with the printer itself.

Currently mass-produced goods undergo considerable safety testing. If a significant number of products fail or cause health concerns, the product is removed from sale. The challenge posed by mass-adoption of 3D printing is that this kind of testing will be difficult to carry out when products are made on a one-off, bespoke basis, and formed of a variety of different components and materials.

Until there is clarification around who has responsibility over product quality and safety, businesses will be less likely to enter the market for 3D printing, as they face a potential financial risk of an undefined size should something go wrong. At the same time, consumers

will be less likely to purchase 3D printed goods, as they will be unsure of what legal recourse they have in the event that a product is faulty.

It is difficult to gauge what the specific legal response should be at this stage. It is perhaps too early to define whether the designer or the 3D printer manufacturers have ultimate responsibility. The business models and shape of supply chains in the 3D printing market are still nascent and under development. But in some respects it may not matter, as by assigning responsibility to one point in the supply chain for 3D printed goods, the businesses' up- and down-stream will adjust accordingly.

Giving legal responsibility to 3D printing shops, for instance, will lead them to use designs exclusively from online catalogues with some form of safety check on designs, and to require guarantees and regular safety assessments from the manufacturers of the 3D printers they use. Most importantly, it should ensure the safety of 3D printed products is high enough that consumers are willing to buy them.

Whilst it is probably inappropriate for policy makers to make a judgement around legal responsibility now, when 3D printing is still in its infancy, this issue should be closely monitored by regulators.

Standards

Growth in the mass-market for 3D printing may be facilitated by the development and adoption of standards. Standards development involves codifying and making available aspects of the manufacture and use of technology or business practices. This can often lead to significant economic benefits. Having a common set of agreed standards reduces the costs to businesses of accessing information for the development of core or complementary technologies and services, and can increase user confidence in the products of a market. Having multiple competing standards can be economically inefficient, with incompatibilities developing between technologies that should be complementary. The main role played by standards is to support innovation and reduce inefficiencies, although they can also help regulate markets and build consumer confidence.

Standards are often developed by businesses themselves. The Windows operating system provided a standardised technology for which many other applications were developed, for instance. But policy-makers can also act to develop and select standards, by co-ordinating with the relevant market actors, or using their weight as a procurer to choose between competing standards.

Standards will play an important role in the development of 3D printing markets, and could apply to 3D printers themselves, to the materials they use, and to the digital software and systems that translate designs into 3D printable objects. Developing trusted standards for each of these will be crucial; they will ensure that 3D printer operators know what materials they can use, that designers know which technologies they are working with, and so that different types of design can be combined easily. It will be easier to develop an online design

catalogue if all design files are of a uniform type, all 3D printing software can use those files, and all 3D printers are compatible with that software. Similarly, competition in the market for 3D printers will be aided if there are clear and transparent standard guidelines for the technical specifications of printers.

Standardisation can also increase user confidence. Consumers will be more likely to purchase 3D printed products if there is a sufficiently high standard of quality in materials and printing services. Therefore there may be a need for consumer-facing quality standards, which could take the form of professional accreditation of those providing 3D printing services, or of regulated kite marks on 3D printed products.

However, the process of developing standards for an emerging technology like 3D printing will be complex and fraught with risks. As the technology develops and evolves, best practice is likely to change rapidly. Choosing the wrong standard, or creating restrictive standards too early in the development process, could seriously hold back innovation in 3D printing, or leave the market locked into an inferior technology[24]. Where a standard is proprietary and developed by a single business, it may lead to anti-competitive behaviour by that business.

The only way to avoid these risks in developing standards is to create them incrementally, in parallel with the development of the technology. At an early stage, standards should be as broad as possible, to give businesses the flexibility to experiment with a wide range of options. For instance, specifying a particular file format for 3D printing may be a bad idea at an early stage, but forming general rules for software conventions may help focus development efforts. To help develop these standards effectively, it will be important for the British Standards Institution to work collaboratively with investors in the technology (such as the Technology Strategy Board) and with leading entrepreneurs and inventors to ensure standards are useful and not overly restrictive. Once developed, any standards should also be open to constant review, to ensure that they are not left out of date.

Planning

One of the fundamental changes brought about by 3D printing will be widespread disruption to the geography of industrial production. Whereas current mass-production normally takes place in concentrated industrial areas both within countries and internationally, in the future 3D printing has the potential to move production towards a much more local scale, with labs and shops on high streets functioning as mini-factories to service local consumer needs.

This may have implications for planning policy. Considerable changes of use to buildings in the commercial centres of towns and cities may occur, turning standard shops into hybrid retail/industrial use. Most types of building use are classified into one specific category, such

[24] Arthur (1989) *Competing technologies, increasing returns and lock-in by historical events* shows that the early development of market standards can often lead to markets becoming locked in to inferior technologies.

as A1 (most shops) or B1 (offices and light industry). We would expect that 3D printing would fall into the B1 category under the current planning system, which would often preclude such facilities being located on high streets. Such a block could act as a significant barrier to the growth of part of the 3D printing market, and ought to be addressed by government. The planning system has a habit of changing slowly, and must not be allowed to act as a block on the development of 3D printing.

Materials

One of the key considerations of increasing the size of the 3D printing market is its impact on sustainability. There will be significant environmental benefits from localising manufacturing, reducing the need for carbon-emitting freight transport of finished goods. But there are question marks around the sustainability of the materials used for 3D printing. Currently 3D printing materials are predominantly based on acrylic plastic. Whilst this is cheap and highly versatile, one of its central ingredients is oil, a non-renewable resource that contributes to man-made environmental concerns. The quality of materials also needs to be considered. Lead users of 3D printers have expressed their need for more varied and higher-quality materials than acrylic in surveys[25].

Therefore, it will be necessary to develop a range of more sustainable and high-quality materials. Whilst the high price of oil-based materials like acrylic and the user demand for better quality materials is likely to incentivise private sector research in this area, there may be a case for a series of government-funded competitions or research grants to develop new materials. The Technology Strategy Board, the government body best-placed to lead in this area, could be offered a specific stream of funding for this purpose, while Nesta's Centre for Challenge Prizes may also wish to consider the theme.

The standardisation of materials will also be an important conduit to the development of 3D printing. Forming precise specifications for different materials will help to broaden the range of materials that can be used, and facilitate much easier collaboration between businesses. As an analogy, the semiconductor industry has undergone a high degree of standardisation in the silicon used within it, in terms of doping concentration, wafer diameter, wafer thickness and crystal orientation[26].

Infrastructure and locations

Most new technologies and markets rely heavily on supporting infrastructure. The uptake of passenger cars depended on the provision of a road network and petrol stations. Similarly,

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[25] Manufacturing in Motion: First survey on 3D printing community (2012) *Statistical Studies of Peer Production.* According to this online 3D printing survey platform, price of materials and metal materials were third and fourth most desired next development in 3D printing.

[26] The authors are grateful to Ben Sheridan of the British Standards Institution for providing this example.

mobile phones require access to wireless communication infrastructure to function. 3D printing is no different, but fortunately many of the infrastructure networks it requires to function already exist.

3D printing will require access to digital communication networks for the uploading of and access to designs. This reinforces the broader importance of ensuring that the UK has widespread access to quality broadband networks and other digital infrastructure.

The move from mass-production of goods to on-demand, localised manufacturing may disrupt the UK's logistics infrastructure, the network of business and transport links that currently deliver goods to wholesale and retail outlets. But ensuring 3D printing labs have access to materials for 3D printing will be likely to require similar infrastructure, so it is likely to be more of a shift in the business of logistics firms rather than a complete disruption to the sector.

At the same time, there may be a case for the government to fund the set up of 3D printing demonstration centres and labs. These could provide a useful forum for experimentation by 3D printer manufacturers and service firms, as well as helping to generate consumer engagement and feedback for the technology. These pilots could also function as centres of research into 3D printing and be set up in conjunction with universities.

Competition policy

3D printing has great potential to increase the efficient working of product markets. A global online marketplace for designs will encourage increased competition amongst the designers of goods, leading to lower prices. Similarly, the entry costs for those wanting to set up a manufacturing business will be lower. As noted above, starting a 3D printing lab will be much cheaper than opening a factory for mass-production, and should lead to the market for 3D printing services enjoying healthy competition and pricing.

But in some areas the disruptive changes brought about by the mass-adoption of 3D printing may lead to anti-competitive behaviour. As discussed earlier, where a technological standard is developed by a business and becomes a dominant design that underpins the functioning of a market, it can lead to a monopoly in that standard. This may occur in the 3D printing market, with a dominant design for 3D printers, 3D printing software, or 3D printing services emerging. If this occurs it may lead to monopolistic behaviour being exerted by the business that develops that dominant design.

This may manifest itself in a number of ways. There may be artificially lower pricing by a dominant standard provider, forcing competition out of a market and leading to higher prices in the long-term. Or there may be collusion between leading players at various stages in the 3D printing supply chain, with online catalogues or 3D printing service companies working together to charge artificially high prices.

As such, the UK competition commission should monitor developments in proprietary standards, aiming to gain the substantial benefits of standardisation whilst remaining alert to anti-competitive behaviour in the 3D printing market.

How should the government approach 3D printing policy?

The policy challenges involved in 3D printing cut across numerous different government departments, agencies and other public bodies. Some of the issues highlighted are legal ones that need to be debated amongst lawyers and associated bodies, while some may require parliamentary legislation. Table 2 sets out the different bodies that are likely to be involved in developing 3D printing policy, along with the relevant policy areas that each covers.

Table 2: Overview of the different public bodies likely to be involved in 3D printing policy

Department/Government Body	General function	Possible role in 3D printing policy
Department for Business, Innovation and Skills (BIS)	Oversight of business policy	Co-ordination and leadership of policy response
Intellectual Property Office (IPO)	Administering IP policy and overseeing changes to legislation.	Leading debate on IP questions, and providing research and evidence to support this.
British Standards Institution (BSI)	Standard setting, provision of guidance and certification	Helping to develop effective standards for 3D printing, to enable business cooperation and consumer confidence.
Health and Safety Executive (HSE)	Enforces safety standards in the workplace	Ensuring 3D printers are safe to use in shops and factories
Trading Standards	Enforcement of consumer legislation	Ensuring 3D printed products are safe, correctly regulated and have consumer confidence.
Office of Fair Trading (OFT)	Protecting consumer interests and regulating competition	Ensuring regulatory framework works and provides confidence to consumers. Also monitoring developments in market competition.
Competition Commission	Assesses competition issues where cases are referred to it by the OFT.	Ruling in any significant competition cases.
Department for Communities and Local Government (CLG)	Oversight of local authorities and the planning system	Ensuring planning policy does not act as a barrier to 3D printing

Technology Strategy Board (TSB)	Main funder and supporter of technology development and commercialisation	Funding research into 3D printing technology, running demonstrator projects, encouraging development of new materials, funding new 3D printing facilities.
Nesta (previously National Endowment for Science, Technology and the Arts)	Research and support for UK innovation	Potential to run prize competitions for new materials.

Given the range of different bodies involved, it is vital that the government is able to coordinate policy on this area. All of these institutions are relevant to a potential 3D printing mass-market, but occupy separate areas of policy. There is a need for one body, most likely the Department for Business, Innovation and Skills (BIS), to perform this coordinating role; many of the public institutions listed above sit broadly within the remit of BIS, and are already funded and coordinated by BIS in some capacity. BIS is well-placed to link these public bodies with relevant businesses and academics to ensure policy is appropriate and well informed.

There is a strong case for setting up a "3D printing task force", which would contain representatives from each of these institutions, as well as from businesses currently engaged with or affected by innovation in 3D printing. This would include 3D printer manufacturers, businesses that run 3D printing labs, design firms and others. This group would be able to monitor 3D printing technology and the 3D printing market, and develop and enact relevant policy.

Most of the policy discussed in this paper does not involve significant amounts of public funding. Many of the most pressing and vital policy issues around 3D printing will need changes to legislation and regulatory frameworks, which, whilst complex and in need of considered discussion, will not be expensive. Those that require funding, such as materials competitions and service design labs, are unlikely to be hugely costly.

The potential pitfalls of government intervention

There are several challenges to this policy approach, however. Firstly, we would expect the market for an emerging technology such as 3D printing to be driven by the success of small, high-growth businesses. These often prove challenging for policymakers to engage with, as by their very nature they have few employees and are extremely constrained in terms of their staffing and time. Successfully engaging with these businesses without burdening them excessively will be key to creating the right group of stakeholders to develop policy around 3D printing.

A related point is that there tends to be a bias towards large, incumbent businesses in policy development. These are of the size that allows them to devote resources to policy engagement. As 3D printing is likely to be extremely disruptive to many large manufacturers,

we might expect them to argue against many of the proposals that would see widespread uptake of 3D printing technology and services. Whilst their input on the transition to mass 3D printing are highly valuable and the impact upon their business extremely important, they should not be the exclusive source of private sector policy input in this area.

Government should also be wary of stifling competition through their collaboration with businesses. A 3D printing task force set up by government is likely to interact with only some of the businesses in the 3D printing market. It should therefore ensure that these businesses do not gain an undue advantage, or that market access is restricted, through their close working with government.

3D printing technology should not be rushed to mass market through government intervention. The complex interactions that take place between technologies and their lead users often take many years before they are ready for wider up-take. The government should look to remove barriers to growth in this market, and allow early adaption and innovation to occur naturally. The future evolution of 3D printing is still unpredictable. It may never become a mass market, or its economic applications may be very different to what is currently suggested. The government should therefore closely monitor how it develops, and be prepared to abandon interventions if the technology fails to take off, or adapt them if it evolves in a new and previously unforeseen way. They should not continue to push the technology if it is clear users do not wish to purchase 3D printing services, or businesses are unwilling to supply them.

Chapter 5 Conclusions and recommendations

It is clear that 3D printing could bring huge benefits to the UK economy, but its transition from exciting technology to everyday process will not be straightforward. The potential markets for 3D printers and their products are enormous, but these markets will require radically different frameworks and infrastructures to make them work. Businesses and entrepreneurs will lead the creation of those new frameworks, and persuade consumers of the merits of 3D printing, but they will require the right type of support for government. 3D printing is a truly disruptive technology that will place strains on many of our economic and legal conventions, and an unresponsive government must not be allowed to stifle its growth.

There should be a degree of urgency about responding to the policy questions that 3D printing raises. The UK's best chance to become a world leader in 3D printing is to develop working markets early, before they are perfected in other places. 3D printing has the potential to shake up the world's economic geography, and part of the opportunity for the UK lies in attracting international businesses who are seeking the best place to operate in this market. This will require government to act with foresight, and to remove regulatory barriers to innovation and market growth in this area. While there may be few pressing policy needs right now, the technology is likely to develop much faster than the policy response, so there is little room for delay.

While the government must take care not to second-guess or to stifle the 3D printing market, it must demonstrate that it can be proactive and listen to emerging businesses, not just incumbents. As first steps in moving 3D printing towards a mass market, we recommend that the government should:

- **Create a 3D Printing task force, led by the Department for Business, Innovation and Skills (BIS)** – this body would be able to bring together ideas from business and academia, and to co-ordinate the various levers of government policy that will affect 3D printing;

- **Scope out a review of the intellectual property implications of 3D printing** – following the recent Hargreaves Review of intellectual property, there may be a case for commissioning a review to look specifically at the IP implications of 3D printing;

- **Fund the set-up of more experimental pilot 3D printing workshops** – providing funding for more 3D printing labs, which could be open to the public and experiment with production techniques and service models, should help increase the exposure of 3D printing to the market;

- **Explore the feasibility of a digital design exchange** – given the current work on creating a digital copyright exchange for content (as recommended in the Hargreaves Review), the government should examine whether a similar exchange for digital designs could be created;

- **Provide funding for competitions to develop new materials for 3D printing** – funding prize competitions through Nesta or the Technology Strategy Board would provide an opportunity to speed up the applicability of 3D printing, and create UK-based strategic intellectual property. It may require additional funding from government; and

- **Commission research and feasibility studies into possible methods for regulating 3D printing markets** – this research should identify and test potential options for preventing the use of 3D printing for producing illegal and dangerous objects.

These recommendations mark initial steps on an agenda that is likely to progress rapidly. Government must ensure it responds with sufficient urgency to keep pace with all changes in the 3D printing landscape. Table 3 sets out which parts of government, under the coordination of the 3D printing task force, should begin to take forward key steps towards developing a coherent 3D printing policy agenda.

Table 3: Key actions and lead bodies in developing 3D printing policy agenda

Action	Lead body
Build consensus on the strategic direction of government action to support 3D printing	3D printing task force (BIS), drawing on advice from other policy agencies, the 3D printing community and academic experts
Identify emerging challenges and opportunities that must be tackled by government policy	3D printing task force, drawing on 3D printing community and technology foresight
Seek to raise the profile of 3D printing, both within and outside government	3D printing task force, in cooperation with media organisations
Scoping a review of the IP implications of 3D printing	Intellectual Property Office, with support from 3D printing task force
Fund the set up of more experimental 3D printing labs	3D printing task force, seeking to draw funding from private sector, universities and Technology Strategy Board
Explore the feasibility of a “digital design exchange”	Intellectual Property Office, supported by 3D printing task force and academia
Set up prize competitions for development of new materials for 3D printing	Co-ordinated by 3D printing task force, but with lead from Nesta and Technology Strategy Board
Commission research and feasibility studies into options for regulating 3D printing markets	Commissioned by 3D printing task force
Begin developing standards for 3D printing	Led by British Standards Institution, with input from across the 3D printing community

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