Innovation diffusion in London

Report to the Greater London Authority

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Belmana
ANALYSIS FOR POLICY

Contents

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Executive Summary

Innovation diffusion is the spread of new products, values, policies or processes beyond the locus of their original success (Rogers, 2003). This study looks at innovation diffusion in London, providing evidence – from existing literature, empirical analysis and stakeholder interviews – about the importance of diffusion in supporting productivity improvements, barriers to the effective diffusion of innovations and policy levers that could be used by the GLA to overcome these barriers. Analysis shows London is responsible for substantial amounts of knowledge spillovers for the city itself, the rest of the UK and globally. Translating these innovation strengths into productivity improvements in London depends on the diffusion of ideas and best practice across businesses in the capital.

There is substantial scope to raise the productivity of businesses in London, and enhanced innovation diffusion can support this.

- While London has many businesses at or near the productivity frontier, there is also a tail of lower productivity businesses. Analysis suggests that about 20% of London's employees are in businesses where productivity is lower than the median business calculated sector-by-sector.
- Analysis then indicates how, if these businesses could raise themselves from being in the productivity tail, the level of productivity in the city would be 2-5% higher.
- This highlights the potential in London for productivity improvements through sharing best practice.

London produces innovations in a range of high-tech and knowledge-intensive fields.

- The analysis of patent data provides an insight into the fields where London is strongest in the production of new ideas.
- Compared to the OECD average, London has a comparative advantage[1] in many technologies, with the greatest being in 3D printing, pharmaceuticals and IT methods for management.
- Evidence indicates that London produces the most patents in the categories of computer technology, telecommunications and artificial intelligence (AI).
- The category 'IT methods for management' ranks fifth in London (compared to 26th in the UK) in terms of the number of patents, much higher than in the rest of the UK.
- London specialises in sectors of the economy, such as business services, that tend to use the patent system less.

[1] Comparative advantage is in London's favour where London patent share exceeds the wider average for a particular technology.

Looking at patent citations provides an indication of which of these innovations diffuse most successfully, and to where.

- Patent citations allow the diffusion of ideas originating in London to be tracked and – combining with estimates of the market value of patents – enable the value of the take-up of these ideas to be estimated.
- The total value of spillovers from London patents is $47bn, about 0.5% of the US total and about 10% of the rest of the UK. Biotech and pharma are particularly important contributors to this total.
- The average value of spillovers from London innovation is high: more than $3mil. This is comparable to the average for the US which tops this indicator, and higher than the rest of the UK which comes in at just under $2.5m.
- The value of innovation spillover flows into London from the rest of the UK is lower than from London into the rest of the UK: for the patents during the period 2000-14, London gave $4.1 bn and only received $3.7 bn.
- This becomes starker when comparing the per capita figures: $460 for every Londoner vs $64 for every non-Londoner.
- It is also instructive to see which technology areas generate the highest benefits within London; i.e. where spillovers arise between inventors based in London either directly or indirectly. The dominant areas here include pharmaceuticals, biotechnology and organic fine chemistry.
- After these two technology areas, the highest spillover value from London patents is from computer, technology, telecoms and AI, three technologies where the capital has a comparative advantage.
- Innovations produced in different fields spill over to businesses at different geographies – in London, the rest of the UK and internationally. In life sciences, instruments and fundamental research on macromolecular chemistry, the spillovers are significantly to other London businesses.
- London telecom patents have high spillovers which accrue outside of London as many businesses in this sector are located outside the M25. Artificial intelligence and computer technology are sectors where spillovers accrue in both London and the rest of the UK, but they are relatively higher outside London.

However, the literature and stakeholder interviews identify a number of barriers to effective innovation diffusion.

- The literature identifies a range of barriers to innovation diffusion centring around market failures, as well as so-called system failure and emergence failure. System failures slow knowledge transfer, perhaps due to disconnects between businesses and researchers. Emergence failure is where key ingredients in the innovation ecosystem (from skills to product standards) are missing.
- Interviews conducted with London stakeholders highlighted that businesses' capacity to absorb new ideas has an important bearing on innovation diffusion. This capacity is affected by skills gaps or competitive pressures preventing investment in

change. A lack of demand or understanding of innovation also acts as a barrier in some instances.
- Sector-specific barriers to diffusion were also highlighted, for example regulatory processes slowing innovation adoption in areas such as life sciences.

There are policy actions that the GLA can consider helping to overcome these barriers to diffusion and facilitate the spread of ideas. As a local body with strong capabilities, the actions can be designed with a local dimension building on the innovation strengths of the city identified in the study.

- There is potential to speed the diffusion of ideas from research using city-level testbeds. There are sectors in which the GLA leads public service delivery – such as waste and re-use – where a greater emphasis on diffusion could be valuable given that rapid innovation is occurring. There may be some benefit from the GLA identifying and addressing gaps in how technologies and associated skills might be spread in London.
- Collaboration between the prime business and supply chains in innovation have been supported in advanced manufacturing and GLA may consider whether this approach is suitable in London sectors where the supply chain's adoption of best practice is a concern, such as construction.
- Lessons can be learnt from recent diffusion focused place-based interventions. GLA is the spatial planning lead for London, and so area-based interventions are being promoted and delivered. These could incorporate lessons from what has worked in London's recent Knowledge Quarter investments to promote diffusion such as the importance of the close proximity to facilitate open innovations as well as the importance of place-based networks in facilitating relationships across peers.
- Diffusion may be encouraged by utilising adult skills and training provision in London. Given the importance of skills deficiencies to innovation adoption, improved skills provision is a central response. This could target specific sectors (low-pay, low productivity sectors) or the specific skills needed to support innovation adoption, such as digital skills or SME adoption-related management skills.
- The support of discipline-based peer networks that promote the sharing of ideas across researches, policymakers and industry is another positive avenue in promoting innovation diffusion. These can also support policy making, providing a forum as implementing the industrial strategy considers sector specific diffusion.
- Innovation vouchers have been found to be reasonably successful where they introduce businesses to creative services supporting product and process design. However, the evaluation of previous innovation voucher schemes such as the Growth Vouchers Programme and Creative Credits scheme points to some lessons around their successful implementation, such as around improving sustained innovativeness beyond the voucher-supported activities.

London's universities also play an important role in promoting diffusion, and there may be scope for policymakers to work more closely with them to achieve diffusion objectives.

- London universities have a strong record of income from consultancy. Intellectual property (IP) revenues are also strong, suggesting the city's universities can successfully commercialise the IP outputs of R&D.
- Spin-offs (with university involvement) exhibit a positive correlation with research quality and London's best performers are Imperial and UCL.
- London's best performers for student start-ups – Royal College of Art (RCA) and Kingston University – are amongst the universities that have programmes that support their students towards setting up business. On staff start-ups, London's best performers are Queen Mary and UCL.
- The GLA can use its convening power to promote information sharing between London universities and London industry, highlighting examples of successful collaboration and opportunities from both sides – perhaps via an online platform.

1. Introduction

London is required by Government to produce a Local Industrial Strategy (LIS) that sets out a clear approach to raising productivity in the city and is supported by a robust and granular evidence base.

A key issue for all areas developing LISs is around how to address the long tail of low productivity businesses seen in the UK, including in the capital. The productivity gap between frontier and laggard firms has widened over the last decade and this is a source of concern for policymakers; Haldane (2017) at the Bank of England and the Department for Business, Energy and Industrial Strategy (BEIS) have both identified businesses shifting up the distribution of firm-level productivity as an important strategic objective for the UK.

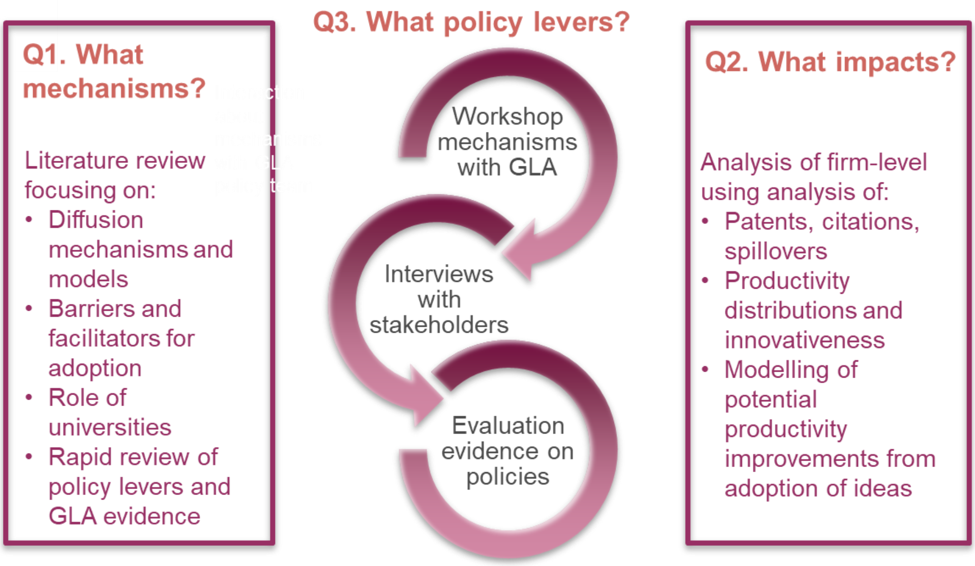
One explanation for this widening productivity distribution is the slow diffusion of technologies and innovations across firms and countries, both between and within sectors (Andrews et al. 2016). While innovation is 'an idea, practice, or project that is perceived as new' (Rogers 2003), diffusion focuses on the spread of these new ideas and practices. Policy makers are increasingly aware that, despite many policies to encourage research and development (leading to innovation), the translation of innovation into productivity improvements across whole sectors and regions has been limited (OECD, 2017).

This report focuses on building the evidence base for the diffusion of innovation from, to and within London. It also makes recommendations for actions the Greater London Authority (GLA) can take to promote the spread and uptake of innovations among the capital's businesses. The intention is that such an approach can support productivity improvements among London's lower-productivity firms and sectors, with subsequent benefits for those employed by them.

Study approach

The study seeks to answer three questions:

- What are the mechanisms by which innovation diffuses into, out of and within the London economy and are there barriers or facilitators of diffusion?
- What is known about impacts on productivity and spillovers of innovation?
- What are the policy levers available to the GLA to enhance innovation diffusion in London?



The diagram above presents our approach to addressing the three research questions. Broadly, three methods have been employed; quantitative data analysis, qualitative research and literature review:

- Quantitative empirical analysis of The Office of National Statistics (ONS) business data, patent data and university survey data was undertaken to benchmark London's performance relative to other parts of the country and provides insights about the diffusion in London.
- Qualitative data gathering, including via interviews and workshops, was conducted to ground the findings in policy making for London. This research involved four in-depth interviews with stakeholders involved at various stages of the innovation diffusion process in London, including university knowledge transfer experts, representatives of sector bodies and advisory service providers that are focusing on improving best practice. These stakeholders represented the life sciences, retail and construction sectors. This element of the study also involved two presentations/meetings, one with GLA and a second involving bodies supporting businesses in adopting ideas.
- An extensive literature review was conducted to synthesise the existing evidence on diffusion mechanisms and policies. It also provided an opportunity to look at the approaches to innovation diffusion adopted by comparable cities around the world, to identify best practice or novel ideas for the GLA to consider applying in London.

An Evidence Base for Innovation Diffusion in London

This report analyses the sectoral, locational and firmographic perspectives of innovation diffusion. It then provides an analysis of London's highly productive and globalised knowledge intensive sectors including business and financial services and the sectors identified as facing diffusion/productivity challenges. The approach produces analysis grounded in innovation diffusion pathways, starting with innovation itself and then tackling collaboration and wider diffusion, such as patent citations indicating how London's ideas diffuse abroad.

The rest of the report is structured as follows:

- **Chapter 2: Defining diffusion and its mechanisms and barriers to the spread of ideas.** The chapter considers some drivers to diffusion policies specific to sectors and tailored to city-level interventions.
- **Chapter 3: Considering the context for innovation diffusion in London**. The chapter considers evidence on how the aim to increase UK productivity may be met by targeting low productivity businesses and encouraging these to adopt new technologies and best practice. It also looks at which innovation areas London has an advantage in.
- **Chapter 4: Compiling evidence on diffusion**. Important actors in the early stages include R&D active bodies – companies, startups, spinouts – where spillovers from universities are important. The analysis also uses a new dataset that tracks the spread of ideas in patent citations.
- **Chapter 5: Policy levers available at city level.** GLA is – in OECD (2010) terms – a "mission-oriented" local body and Deleidu and Mazzucato (2019) highlight levers of mission-oriented organisations, such as regulation and procurement to provide a standard-setting, signalling or demonstration effect (OECD, 2018); aiding diffusion. Chapter 5 maps to the barriers the policies that GLA might consider as it encourages innovation diffusion.

2. Diffusion Mechanisms: What is Known about how Ideas Spread

Innovation diffusion is the spread of new products, values, policies or processes beyond the locus of their original success (Rogers, 2003). This chapter describes diffusion in terms of the mechanisms by which ideas are transmitted and looks at the barriers to diffusion. Adoption is modelled as progression through steps, such as finding out about a new approach or testing its usefulness. This breakdown of the diffusion process helps to understand what drives the speed of adoption and identify where barriers may arise.

The discussion is based on insights from the literature combining this with views of key stakeholders interviewed for the study. The findings are:

- Diffusion mechanisms have increasingly been defined in terms of innovation systems moving beyond models centring on how firms adopt new technologies.
- Barriers to diffusion stem from market failures, system failures and emergence failures. Barriers differ across sectors and, while cities are generally better at facilitating diffusion than other areas, barriers do exist at the city level which city authorities may be able to help address

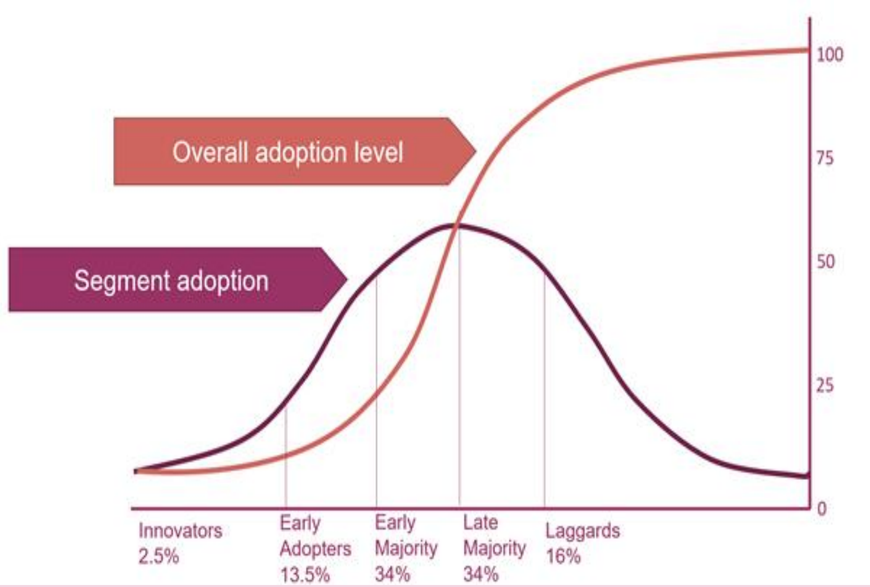
Modelling Diffusion

Studies into diffusion have identified an S-shaped curve of adoption of innovations over time (Dearing, 2009). Figure 2.1 indicates such an adoption curve, with the market divided into five segments according to businesses' response to the introduction of a disruptive technology. The first segment is the innovators – characterised by high R&D capabilities and greater tolerance for uncertainty. They are 'venturesome' (Fichman, 1999) and risk-takers and so the first to adopt an innovation. The second segment are the early adopters – a set of businesses more integrated with the innovation system, with the greatest degree of opinion leadership (Rogers, 1995).

Figure 2.1: Adoption of innovation over time in different market segments

- Plot of when adoption occurs by five categories of businesses and their overall adoption rate
- Segments are innovators (2.5%), early adopters (13.5%), early majority (34%), late majority (34%) and laggards (16%).
- Each segment behaves differently over time as adoption increases

Source: Wood (2017)



The segmentation then splits the majority of businesses into an early and a late segment, differentiated by their risk aversion to technological advances. The late majority segment has a longer knowledge-to-decision process: these businesses seek assurances that a whole product or process change derived from an innovation is proven to offer significant value. The early majority segment is important as it determines the success in diffusion to the mass market. The fifth segment covers the laggards – those that view all innovation as high risk and require certainty before adoption; these businesses may also exhibit aversion to change.

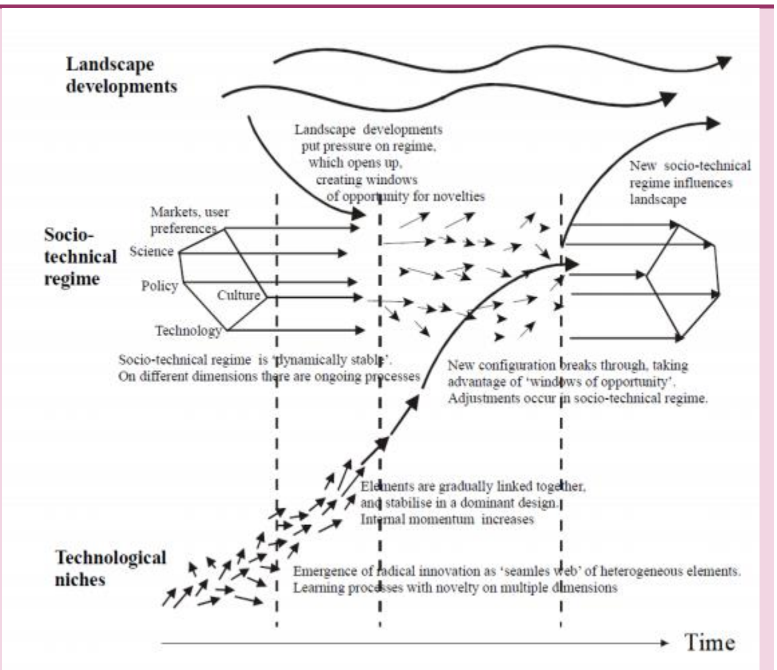
Figure 2.1 focuses on diffusion from the perspective of businesses. More recent studies consider diffusion within an innovation system covering businesses, research and innovation bodies, and a wider set of institutions (covering laws, regulations and policy). Diffusion processes are then modelled in this ecosystem, with a particular insight being recasting “knowledge” as distributed across actors (Nelson and Winter, 1982). The ecosystem approach emphasises a need for collaboration across and within organisations. Frenken (2017) describes this as a complexity-theoretic perspective and Nesta (2019), as technology emergence modelling. The key departure is it considers the co-evolving of institutions and markets alongside the adoption of technologies in businesses.

Key within this wider ecosystem is the ‘triple helix’ of university-industry-government relations (Etzkowitz and Leydesdorff, 2000), stressing the benefits of collaboration and coordination. Many innovation processes involve a multitude of actors who each contribute to the shaping and success of new technologies and services. Areas characterised by a high share of innovative industries and entrepreneurship, such as Silicon Valley in the US or the Cambridge cluster in the UK, surround universities and appear to benefit from agglomeration economies and associated knowledge (see Carlino and Kerr (2015) and Henderson (2007) for reviews of the literature). Mazzucato (2013) highlights the role of the state from a systems perspective, where innovation and diffusion are processes which feed into government policy-making, in turn driving diffusion.

Accordingly, this is an area of focus in the UK’s national industrial strategy, where the 2017 White Paper sets out a vision for a knowledge-led economy, in which “innovation clusters will form and grow around our universities and research organisations, bringing together world-class research, business expertise and entrepreneurial drive” (HMG,2017).

Figure 2.2: Diffusion Mechanisms in a System

- **Landscape developments.** The “macro” social, political and economic setting. The rate of change at this level is slow. However, events and trends at this level are of significance.
- **Socio-technical regime.** The collection of actors that comprise the immediate functional system. The rate of change at this level can be stable for long periods of time, until the needs of a transition imply a rapid reconfiguration of actors and their relationships.
- **Technological niches.** Characterised by high rates of change, most individual niche innovations are of small overall impact ultimately depending on the scope of the niche itself.



Source: OECD (2015)

Figure 2.2 presents a stylised pattern of a system innovation process (from OECD, 2015). Each transition is unique, but the general pattern is that technological niches accumulate, interconnect, gather momentum and a dominant design emerges; the emergent dominant design interacts with the prevalent socio-technical regime, eventually breaking through and having widespread impact.

Barriers to and Facilitators of Diffusion

There are potential barriers to and facilitators of innovation diffusion. This section considers those related to market competition and the market, system and emergence failures that prevent innovations from diffusing, such as legal and regulatory conditions; or a lack of access to information about the innovation. There has also been considerable analysis about firm-level issues, such as the business absorptive capacity, firm size and their ability to collaborate through open, networked, partnered innovation.

Findings from the Literature

Where businesses face competitive pressures and there is a strong business case for the adoption of a technology, diffusion should occur. Businesses not adopting a productivity enhancing technology would see their market position weaken as competitors adopt. However, the literature on diffusion mechanisms does highlight several reasons why adoption may proceed slowly or stall. Broadly, Nesta (2017 & 2019) highlights three frameworks halting the diffusion of innovation.

- Market failure. Business absorptive capacity might be low due to skills gaps, poor access to finance or an inability to mitigate risks; competitive pressures may facilitate or deter adoption.
- System failure. Disconnections between researchers and industry due to differences in culture, goals and values.
- Emergence failure. Complexity of adoption due to legal or regulatory issues may deter adoption.

Competition

The case for policy action to encourage R&D and the generation of new ideas has often been grounded in market failure arguments. Knowledge has some visibility, whether the adoption of new work practices or the development of new products, and so it will leak, and an investor will then not be able to retain all the returns of an innovation. This leads to under-investment. Equally, the innovation may have externalities, such as spillovers, such that an innovator will be unable to capture these.

Market failures can also affect the diffusion of ideas. Characterising the failure in terms of the degree of competition, this can either incentivise innovation via a process of creative destruction or alternatively, by reducing the potential for rents, dampen the incentive to invest in new technologies or way of doing things. Aghion (2016) reviews the theoretical and empirical studies about this Schumpeterian paradigm finding that there is an inverted U-shaped relationship between competition and productivity growth, and adoption mechanisms may explain this.

The next chapter describes more about this literature, but the key points are that a modest amount of competition dampens adoption as dominant firms face insufficient external pressure to motivate them to incur the costs and risks of adoption. At high levels of competition, the up-front costs associated with adoption may not be met with sufficient returns before competitors adopt. Competition may also have the negative impact of driving firms to chase the latest technology, even when the firm has not yet learnt how to effectively assimilate existing technologies.

These important findings about productivity, competition and adoption have been complemented by studies from a diffusion mechanism perspective. Pro-business market reforms have been found to enhance the ability of entrepreneurs to adopt technologies

(Allard, et al, 2012), while cultural and linguistic barriers across countries have reduced adoption (Caiazza, 2016). The business environment is also negatively influenced by uncertainty and scepticism around potentially 'risky' new and innovative technologies. It is necessary to reduce the risk and uncertainty surrounding such technologies before

Business to business diffusion: Sectoral and area-based mechanisms

Relevant for policy making has been the mechanisms by which diffusion occurs between businesses and research organisations, which system failure may inhibit. Collaborative research is supported to address supply chain barriers to innovation and adoption. BEIS (2015) support for manufacturing recognises how – since the 1980s – prime manufacturers have raised their productivity by specialising in assembly of finished products with a supply chain of component makers. Transactional and co-ordination frictions – such as a risk that the prime or supplier might free-ride – may dampen the business-to-business diffusion, justifying policy action, such as the supply chain collaborative research initiatives.

Smallness may also function as a barrier to innovation diffusion. Large firms not only already have certain infrastructure and skilled employees in place, but the size of the firm also means that they can afford the risk of experimenting with innovation, as the risk can be 'spread' across the firm (Kerr et al., 2014). Fons-Rosen et al (2016) address a channel by which local firms can benefit from the entry of large, typically multinational "Million Dollar Plants" (MDPs) in the manufacturing sector into their local areas: the diffusion of knowledge to local inventors. They find that patents of these entering firms are 68% more likely to be cited in the winning counties relative to the losing counties after entry. They also find that the increase in citations is larger from patents belonging to the same technology class of the cited patent. Bloom et al (2016) use a similar methodology to find evidence for the diffusion of organisational practices from MDPs to incumbent firms.

diffusion occurs. When a technology is 'fully developed' the barrier to diffusion ceases to exist and the innovation becomes mainstream (Wood, 2017).

Supply-side factors

Anderson and Stejskal (2019) discuss some recent developments from Rogers' work. Many (e.g. Tidd, 2010) have overlaid a supply-demand context for the steps. Supply-side factors focus on the absorptive capacity in businesses to adopt innovations, with demand-side focusing on market drivers or the "pull" on businesses to adopt. Moore (1991) considers supply-side issues, suggesting that innovations fail to diffuse because of a large 'chasm' between the early adopters and early majority segments, i.e. very soon after innovation. The participation of entrepreneurs in research enhances the chances of adoption (Hall, Matos and Sheehan, 2010). High levels of collaboration by firms in a locality can also help improve knowledge diffusion and ensure that firms maximise the potential of any innovative opportunities (Roper and Bonner 2019).

However, there has also been research on the barriers to adoption due to businesses inability to absorb new technologies or improved management practices. Low absorptive capacity could be due to skills gaps, information constraints, financing constraints and risk aversion. Forth et al. (2019) looked at the diffusion of human resource management, comparing different parts of the UK. While identifying how adoption diminishes in the UK away from London, this can be explained by indicators such as well-qualified managers and non-managers in a location.

Demand-Side Factors

Demand mechanisms focus on the market-pull for businesses to adopt and so diffuse innovation. A focus is on the speed and willingness of consumers in a market to absorb technologies. This is often then complemented by the existence of lead users, with individuals or organisations that experience and express a need for innovation earlier (Edler, 2011, such as Gregersen & Johnson, 1996, Rothwell, 1992, Von Hippel, 1998).

Since Mazzucato (2011), the role of public bodies in driving innovation demand has been emphasised. Most directly, this can be achieved through procurement to meet the organisation's own needs. This could be for the delivery of public services or to more strategic public investment, sometimes termed moon shots. The demand for an innovation may also be increased by standard setting, with regulatory agencies or industry bodies contributing to diffusion by quickly setting new standards that are achievable by adopting an innovation (Blind and Jungmittag 2005). Conversely, retaining out-of-date standards can impede diffusion, "emergence failure".

Insights from Stakeholder Interviews

For this study, a series of discussions were held with stakeholders engaged in innovation and its diffusion. These interviews generally confirmed findings from the literature around the barriers to diffusion. Barriers identified by stakeholders include the lack of demand for innovative technologies from businesses because of a lack of finance constraining investments or risk aversion combined with an over-estimation of risk. Interviewees highlighted that demand was also affected by whether business leaders knew about and understood innovations, suggesting that barriers to innovation adoption may exist at senior levels in firms.

Knowledge stickiness is cited as a barrier to tacit knowledge transfer and therefore halts the diffusion of innovation (Nonaka 1991,1995, Von Hippel 1996). Instead, when tacit knowledge is properly leveraged, it offers a strong comparative advantage due to its uniqueness and difficulty in replication by competitors and hence is valuable for improving innovation capabilities (Sikombe et al. 2019). R&D may have occurred outside the business so that such knowledge built up during R&D requires a business to first invest in knowledge exchange through partnering with a research body. As familiarity with a new process or idea increases, focus will turn to designing the innovation into business processes, including training staff (from interview discussions). Innovative businesses can often be SMEs, where the managers are time poor so that this can only be progressed outside of work hours.

Interviewees highlighted that the strength of the relationship between a business and any research collaborators has an important bearing on adoption. This includes trust and a track record of effective collaboration. Adopting businesses where key employees have been working at the organisation for a long time will be perceived as advantageous for clients and collaborators, facilitating the testing of new technologies and ways of working. Trust between the innovation team within the business and those leading the overall direction of the business is important, with the latter needing to show commitment to see the project through.

The contradictory effects of competitive pressures found in the literature was also highlighted by interviewees. Firstly, the adoption process could be associated with a dip in efficiency and can mean losing competitive advantage, albeit in the short-term. Further, any rapid growth, sometimes necessary to take advantage of a new technology, was accompanied by the risk of financial problems.

City and Sectoral Specific Barriers and Facilitators

This section explores where the mechanisms for innovation diffusion and associated barriers differ across different sectors in the economy and how those issues might apply to large global cities like London.

Sector-specific Barriers and Facilitators

There are some barriers to innovation diffusion that, rather than affecting the entire economy, are selective in influencing only some sectors or firms within a sector. Recent studies have considered the level of digital adoption, for example, which differs widely across sectors (Calvino et al., 2018). Some sectors, such as automotive and financial services, are currently leading in adoption, such as implementing solutions using Artificial Intelligence (AI). Other sectors such as tourism and construction are falling behind (McKinsey Global Institute, 2017).

This section focuses on three specific sectors: retail, life sciences and construction, and is supported by findings from interviews with stakeholders. Findings from this section include:

- In the construction and retail sectors, the barriers faced for diffusion are predominantly at the market and system failure level, such as the lack of skills, demand and existing infrastructure.
- For the life sciences, the innovation system is more complex, consistent with emergence issues. Any GLA role in diffusion may be modest, as barriers may involve other actors (and in fact there are bodies that have statutory roles).

The construction sector

The potential for innovation adoption in the construction sector is significant, but structural barriers exist. Large infrastructure projects operate within tight risk management and timescales that may not allow experimentation. In general, experimentation must occur outside the delivery of a project, in testing centres. The way projects are structured also matters, an issue raised in the interviews for this study. A relatively large construction prime tends to lead, with a wider supply chain of smaller firms. These operating models tend to be inflexible to new innovations, and only exist for the life of the project, resulting in the transient nature in the sector. Sometimes, however, this prime/supply-chain model can facilitate diffusion, with large projects (such as highways), forcing firms to bid as a consortium, thus enhancing collaboration between firms.

The culture of the industry was cited as a further barrier. Concern over reputational damage, for example, may not permit discussions about project failure, which are necessary to share learnings and identify opportunities for improvement.

The retail sector

Interviews also covered the retail sector. McKinsey (2016) has found that retailers often lack the skills to exploit and integrate data effectively, and may store data poorly, raising concerns regarding data privacy. Interviewees also highlighted difficulties in maximising the value of data across complex supply chains. Lack of knowledge and appropriate skills were perceived by interviewees as additional barriers to innovation diffusion, impeding the uptake of, for example, new technologies using purchasing data. Here, competition pressures were identified as being effective in a Schumpeterian sense, with technological innovation causing the closure of low productivity organisations.

Table 2.1 reports a generalised version of the framework for adoption barriers in a recent GLA-LSE project, which seeks to encourage retail and hospitality SMEs to adopt AI. The project is on-going and the response to trial interventions as well as survey responses should help shed light on which barriers are more important in the context of AI technologies.

Table 2.1: Barriers for AI adoption amongst SMEs (GLA-LSE Project)

	Categories	Barriers
1	Internal capacity	Lack of information on technology and potential benefits/costs
2	Internal capacity	Lack of information on technology providers
3	Internal capacity	Lack of required management/workforce skill
4	Internal capacity	Business specific doubts over applicability
5	Internal capacity	Resistance to change from management
6	Internal capacity	Resistance to change from employees
7	Finance and costs	Financing constraints (regarding investment - e.g. software costs)
8	Finance and costs	Costs of reorganisation (training, reallocating tasks)
9	External risk - tech market	Uncertainty in technology market - rapid change, potential for lock-in
10	External risk - market	Uncertainty over impacts on customers and hence revenues
11	External risk - competitors	Uncertainty over relevance and demand amongst SMEs in sector
12	External risk - macro	Uncertainty about macroeconomic outlook (e.g. Brexit)

The life sciences sector

The life sciences sector is characterised by relatively sophisticated R&D processes, and innovations occur within a structured approach that integrates steps for diffusion. At the early stages, the technical complexity of a project can act as a barrier or disincentive to innovation. Interviewees raising this issue highlighted that research is likely to involve specific research facilities that are located across London and beyond, and the ability to gain access to these facilities determines whether a project can go ahead.

Turning to diffusion, interviewees highlighted the role of universities, observing that adoption may be slowed, partly because innovation within universities is curiosity driven rather than commercially driven. Therefore, there may be a slowing of ideas transferring between the two sectors. The often-prolonged negotiations over the terms of engagement before a business can begin work with a university also acts as a barrier to commercially focused innovation. The interviews highlighted that universities' increasingly focus on producing spin-out companies (based on research-derived IP) can be effective if the team is large enough and has business experience. However, lack of business skills represents an important obstacle to the success of this approach as a pathway for diffusion, and in these circumstances a licencing agreement might prove more successful.

The most significant diffusion concern raised by interviewees was around the processes to take life science innovations to market, where the phases of readying a technology for use in the health services can be a barrier to diffusion. This was discussed in terms of processes in other countries, where innovations were tested in the market earlier. Japan was considered the best example of an effective system for the adoption of next generation technologies into health systems.

The focus on health highlights issues for diffusion where the ecosystem is complex with multiple actors and large players. Innovation diffusion is central to many public bodies, such as NHS Improvement. Horton et al (2018) reviewed almost a decade of projects designed to spread innovations and found that successful innovation adoption requires context specific adaptation as well as perhaps the development of new skills and techniques and alterations to the existing culture and relationships; the central argument is that successfully spreading complex health care interventions will require packaging them up in more sophisticated ways and designing programmes to spread them in more sophisticated ways. Interviewees highlighted that – given this wide set of bodies – the role for GLA needs to be carefully tailored. Where diffusion barriers are very much due to system failures or emergence issues (or – as in health care – where the organisation level barriers are handled by bodies with that mission), GLA assistance on the diffusion of technologies may be more focused on city-specific barriers such as training and skills and, at a more strategic level, actions to support co-ordination at city-level.

Diffusion and Adoption Drivers and Barriers at City Level

Cities are sometimes viewed as accelerators, with their growth depending on "their ability to speed up the velocity of circulation of ideas, people and money" (Nesta, 2019). Existing evidence emphasises the characteristics of cities that support innovation and the transfer of ideas, such as important universities and wider research base. Cities tend to house large companies and their headquarters, having access to capital and often with an existing competitive advantage. Cities also tend to have more highly skilled workforces; and other infrastructure assets – everything from public transport to broadband connectivity.

In terms of diffusion mechanisms, the innovation district (or the city itself) exemplifies the triple helix models cited above. Innovation districts cluster start-ups, small firms, incubators and accelerators with anchor institutions such as research organisations or innovative large businesses. Such districts facilitate diffusion through the availability of research infrastructure, transport accessibility, skills, talent and networks.

The facilitative role of the anchor university has been explored in the economics literature, with evidence of economic and innovation spillovers from research universities to surrounding economies. A number of papers based on US data link university research spending to industrial performance, see for example Aghion et al. (2009) and Kantor and Whalley (2014), who use exogenous instruments for research spending to identify its impacts on growth and patenting, and labour income respectively. Woodford et al. (2006) and Bania et al. (1993) relate university research spending to start-up activity in manufacturing.

Other papers exploit natural experiments due to policy changes and find that policies focussed on increasing the incentive to patent result in an increase in innovation diffusion. Hausman (2012) exploits variation induced by the Bayh-Dole Act in 1980 which gave US universities property rights to innovations and therefore raised incentives to patent. She finds that employment and pay increased in sectors closely tied with university innovative specialisms, and that the effects are larger in larger cities. Anderson et al (2009) exploit the natural experiment of decentralisation of HE in Sweden and find that output per worker and patenting has been greater in Swedish municipalities where more university researchers are employed, and that the effects are strongly localised. There is also an established literature on the innovation spillovers from universities, often measured in terms of patenting, stemming from Jaffe (1989) (see Chapter 4 for more discussion).

However, Pique (2019) noted in recent work on 22@ Barcelona, a government led innovation district, that government involvement in innovation districts such as this, has supported co-evolving policy making, regulations, alongside innovation diffusion. Evidence in the interviews supported the need for:

- Facilitating a dialogue between policy and delivery, such as London's drive for circular economy approaches translating into specific engineering elements for how to minimise waste and design it into products.
- Marrying up "the science savvy and the business savvy" and enhance collaboration between business and science schools.
- Collaboration to drive innovation diffusion in the transport and delivery sectors, as a dialogue between delivery businesses and city transport may facilitate solutions that are far more innovative and efficient.

City bodies might facilitate this, recognising that markets do not commission work in such a way that allows for joint city planning. One of the most marked findings from academic research however is the variable picture across cities in their success. Nesta note that efforts to create districts in areas without any pre-existing infrastructure usually fail, citing many examples in biotechnology and the dozens of failed attempts to mimic Silicon Valley.

Nesta emphasise the role of venture capital providing finance and access to specialist expertise and mentoring. They argue that seed funding is an example of a policy that increases innovation diffusion. Interviewees observed that the Mayor's Fund, providing seed funding for project ideas in London and currently paying for feasibility studies such as the Peckham Coal being turned into a linear park, helps organisations pay for innovations that they would otherwise not be able to afford.

Conclusions

This chapter synthesises evidence on how innovations diffuse and the factors that can impede or support this. The prevailing models for the diffusion of technology both take a business perspective and consider wider, complex innovation systems involving a range of actors, which are a better representation of the London context.

- Broadly, the barriers identified have been due to market failures such as skills shortages; there are also system barriers such as difficulties collaborating with research organisations.
- Research also highlights emergence failures, where the adoption of an innovation can be held back by the needs for complex changes in numerous areas, such as regulation and infrastructure.
- The sectoral picture is helpful in delineating more specific barriers and identifying where a city-level body may consider intervention. The construction, life sciences and retail sectors mentioned here have particular diffusion barriers at market level, system level and around emergence. Crucially, there may be a mature set of actors in place to tackle these barriers, such as in life sciences, where GLA's role will require defining in terms of supporting a complex city-level ecosystem.
- One area where city powers are important – and where successful diffusion is highlighted as city-level barriers are tackled – is the innovation district. The barriers and facilitators, such as the need for policy and regulations to evolve alongside technology adoption, are complex and inter-related at this sectoral/area level. The role for and powers of the GLA in addressing barriers and facilitating diffusion will need to be considered and will vary across sectors.

3. Productivity, Efficiency and Innovativeness of London Businesses

This chapter presents evidence about the productivity and efficiency of businesses in London in comparison to other areas of the UK. There is a focus on productivity because, since Solow (1956), economists have viewed technical innovation to be a key driver of productivity increases in the long run. Growth in the economy will slow down eventually if the innovation frontier is not constantly pushed out. However, growth can also slow down if innovations are not adopted fast enough.

Firm-level data is used to analyse the distribution of the value-added per employee and remuneration per employee. Evidence is provided on the potential to improve productivity through innovation diffusion. The chapter then describes the context for innovation diffusion in London:

- The distribution of firm-level productivity in the city, contrasting with other parts of the UK.
- The potential productivity improvements when firms are encouraged to emulate the most productive firms.
- The London innovation landscape, exploring patenting activity in the capital and evidence about the technologies London has a comparative advantage in.

Frontier productivity firms and the role of innovation diffusion

Cross-country differences in aggregate productivity are increasingly being linked to differences in firm performance within sectors (Bartelsman et al., 2013; Hsieh and Klenow, 2009). There is a spread in business productivity, even when focusing on businesses in tightly defined industries, with high productivity (frontier) firms alongside far less productive (laggard) businesses. This section highlights that:

- Frontier technologies do not diffuse to all firms. They are first adopted by frontier firms and diffuse to laggards at a slower pace, once the technology has been tested and adapted.
- Competition interacts with innovation diffusion. Businesses need rents to justify new technology investments; but little competition can reduce competitive pressures to adopt.
- Collaboration by firms can also help improve knowledge diffusion and ensure that firms maximise the potential of innovative opportunities.

Analysing the distribution of productivity provides an important starting point for developing industrial strategies. There are high productivity firms operating at the “frontier”, which are not only more productive than laggard firms, but are also more capital and patent-intensive, have larger sales and are more profitable. These firms are more likely to be part of a multinational group, in line with new models of trade (Melitz, 2003) and the international business literature on multinationals (Dunning, 1981). Perhaps surprisingly, firms at the multi-factor productivity frontier are younger and not significantly larger in terms of employment, consistent with the idea that young firms possess a comparative advantage in commercialising radical innovations (Henderson, 1993; Baumol, 2002; Benner and Tushman, 2002).

Productivity growth at the global frontier has remained relatively robust in the 21st century despite the slowdown in average productivity growth. This has led to an increasing gap between high productivity firms and the rest that suggests a diffusion issue. Andrews et al (2015) consider how new technologies developed at the global frontier are spreading. They find the spread is at an increasingly fast pace across countries so that technologies are adopted by the globalised, high productivity, multinationals across their entities in different countries. However, the spread from the frontier multinational within an economy to other businesses is slower. Many technologies may remain unexploited by all but the frontier globalised business. The productivity growth of laggard firms within a country is more strongly related to productivity developments of the most advanced domestic firms as opposed to those (foreign firms) at the global frontier.

This is in line with findings from other studies (Bartelsman et al., 2008; Van der Wiel et al., 2008; Iacovone and Crespi, 2010) leading to a conclusion that frontier technologies do not immediately diffuse to all firms. Competition across firms is understood as monopolistic and spillovers derive from knowledge diffusion and drive long-run productivity growth. It is only recently in the literature, however, that scholars have begun to explain the entry, exit and the process of innovation diffusion to provide a framework for policy analysis.

Aghion (2017) characterises the dilemma about how competition interacts with innovation diffusion, noted in the last chapter. Businesses need some monopoly rents to justify the investments into a new technology, which can easily be eroded if new ideas diffuse too quickly. This may be through IP protection or through market behaviours that lessen competition. However, too little competition can negate the pressures on businesses to operate at the frontier, such as fewer businesses using new technologies or fewer businesses forced to exit due to a failure to adopt or innovate.

Diffusion is often in the context of complex market conditions, where research behaviours and the settings in which firms conduct R&D may arguably attenuate competitive pressures. Notions of open, partnering or networked innovation have received considerable recent attention in the literature. High levels of collaboration by firms can also help improve knowledge diffusion and ensure that firms maximise the potential of innovative opportunities[2].

Productivity distributions

By looking at the distribution of productivity across firms and over time, a sense of how the diffusion process operates can be gained. For instance, if there are diffusion barriers and competition is low, a wider spread of the productivity distribution is expected as tail firms who are relatively far from the frontier are able to survive while slow diffusion makes gaps entrenched. However, a wide spread could also be consistent with a highly competitive economy with high entry (and exit) rates and fast rates of diffusion due to the low incentive for laggards to adopt new technologies without the prospect of attractive rents.

Nevertheless, a careful examination of the productivity distribution is a good starting point. The firm-level analysis conducted for this study focuses on businesses located in London as well as the rest of the UK and uses public datasets to explore analysis conducted by the Office for National Statistics (ONS), using a tailored micro-dataset constructed from the Annual Business Survey (ABS).

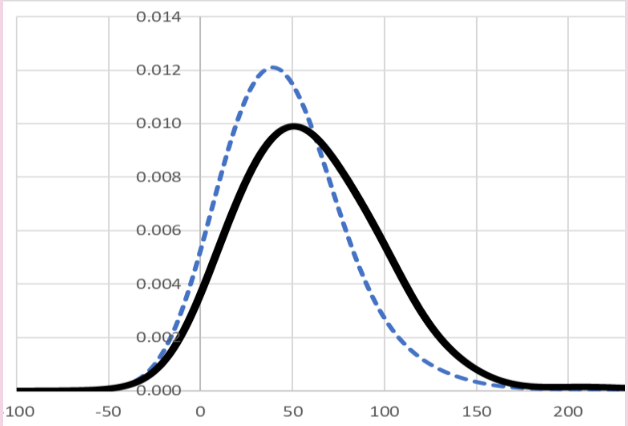
The top panel of Figure 3.1 presents the ONS results, plotting out the approximate gross value added (aGVA) per employee over a period of 12 months for the local units of the firms and their plants registered in the Inter-Departmental Business Register (IDBR). A firm or enterprise may have more than one plant in different locations. These are referred to as local units. Local units of an enterprise may be engaged in different parts of the business such as production, accounting or head office. Therefore, each local unit is assigned its own Standard Industrial Classification (SIC) 2007 code, which corresponds to the local unit’s principal activity. Note that this dataset apportions aGVA across the LU (Local Unit) universe, rather than the ABS LU sample. The local unit version of the dataset provides better geographical accuracy for analysis.

[2] Roper and Bonner (2019) report a metric based on the percentage of firms in any local economic area which were collaborating for innovation during the period 2014 to 2016.

Figure 3.1: Analysis of firm-level productivity distributions

Panel 1: ONS Study on Spatial Productivity for London

- ONS study indicates the gross value added per employee in London (black line) to the right of the GB average (blue dashed)
- This study allocates value added to the local units of establishments, estimating the value added locally by multi-site businesses
- The distributions include individual businesses whether micro, small, medium or large multinational businesses
- Focus on larger businesses and on the remuneration part of value added (so excluding operating surplus)

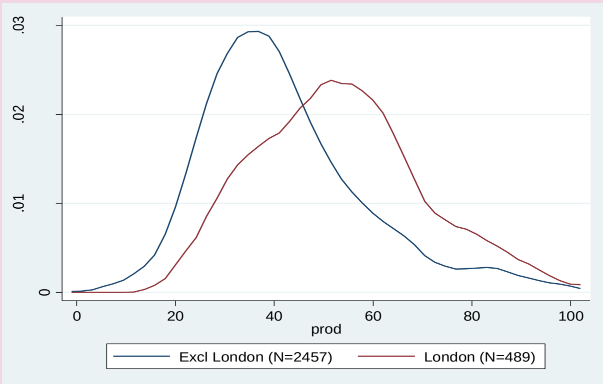


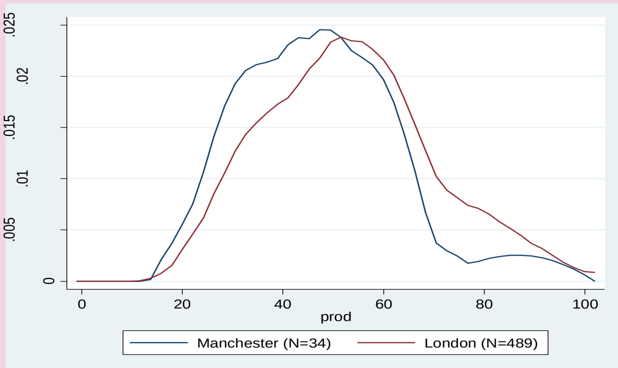
GVA/per employee (£000)

Source: ONS study on Understanding spatial labour productivity in the UK

Panel 2: Employee Remuneration for Innovate UK Supported Firms

- Density plots for remuneration per employee as reported in FAME for selected businesses, £'000, trimmed at £100k
- Graph of 2,946 business-university KTPs, with 2,531 businesses having a single university they partner with and 17 businesses having 4, 5 or 6 universities they partner with
- Plot separates London businesses from rest of UK, indicating the London wage premium (top) and Manchester vs London (bottom)
- NB: Per employee remuneration is adjusted for the London pay premium





Source: Belmana analysis using Bureau van Dijk FAME[3]

[3] Employment is used as the measure of labour input in calculating labour productivity. Employment includes employees and working proprietors and was obtained from the IDBR at the time of sample selection of the ABS. It should be noted that employment from the IDBR is derived from several different sources (such as the Business Register Employment Survey (BRES), HM Revenue and Customs (HMRC) records or imputed), and some of the employment information, especially for small businesses, may be several years old.

Notwithstanding these caveats, Panel 1 of Figure 3.1 provides an illustration of the productivity premium of London businesses, measured as GVA per employee.

Panel 2 of Figure 3.1 then presents an analysis of public datasets covering remuneration per employee where businesses have partnerships with universities. The analysis correlates distributions of productivity to a dimension associated with diffusion.

The distributions of remuneration per employee is as reported by businesses in their accounts (using the FAME database). So, it covers only the largest businesses, as most SMEs are exempted from providing Companies House with detailed accounts. An additional problem for this analysis is that the accounts are only reported for the entire business, aggregating across the different establishments in a business. These are likely to be in different areas.

However, the accounting data allows the distribution of the remuneration per employee analysis to be linked to other public firm-level data. The figure plots the distribution of 489 businesses that report full accounts and have benefitted from an Innovate UK-funded knowledge transfer partnership. The remunerations per employee are generally higher for London-based businesses but the distribution is more similar when comparisons are made to Manchester-based businesses, a sample of 34 businesses, with a flatter density to this measure of business productivity.

Productivity distribution discussions have underpinned a focus on diffusion. Where analysis looks at large businesses focusing on cities, the tail appears flatter, suggesting a denser distribution at productivity levels near but below the highest levels. This differs somewhat from studies such as ONS, covering all businesses including micro firms. Some diffusion literature focuses on the leader-laggard split; some on a more staged nature to adoption with early and late adopters. Large cities may support the greater delineation, because there are more and diverse businesses.

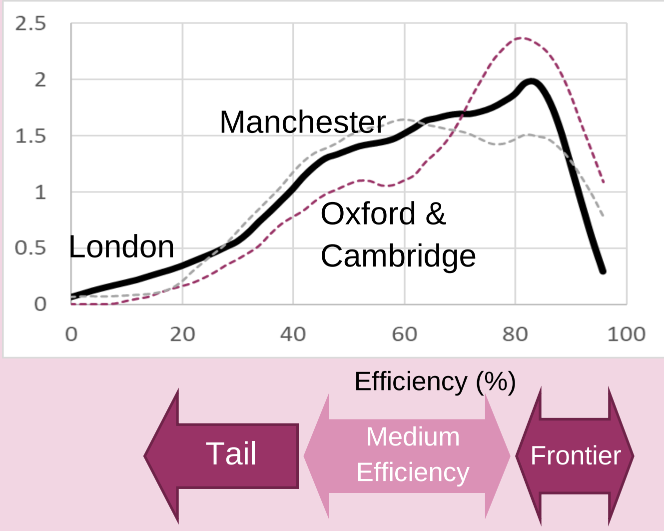
Efficiency Metrics

Economic efficiency refers to the extent to which objectives are achieved in relation to the economic resources used (Jacobs, et al., 2006). It consists of technical efficiency and allocative efficiency components, with technical efficiency focusing on the use of productive resources in the most technologically efficient manner and allocative efficiency the ability of a production unit to use inputs in optimal proportions or choosing the optimal bundle of outputs to produce, given their respective prices. These measurements differ from productivity measured on a per-hour or per-employee basis.

Figure 3.2: Analysis of firm-level efficiency

Panel 1: Firms and the Frontier in London, Oxford and Manchester

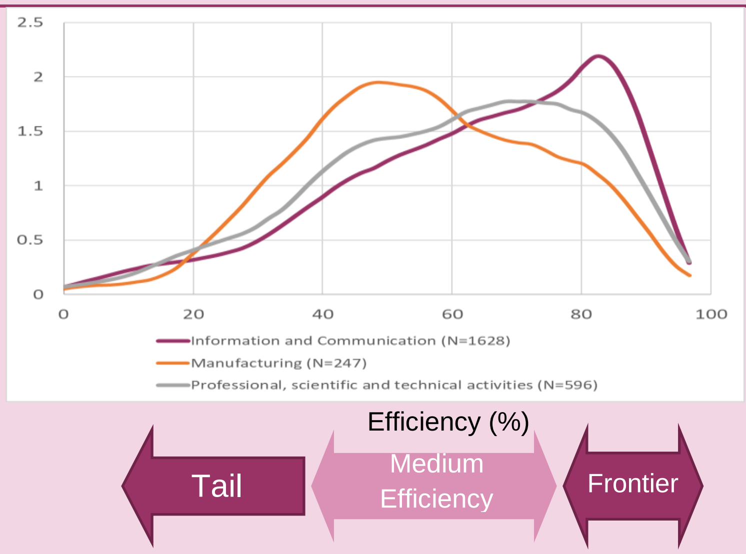
- Graph plots distribution of businesses in terms of efficiency - the percentage towards the frontier - with 100% meaning at the frontier
- 2,471 KI businesses in London in black have a flat distribution from around 40% efficiency to the frontier; similar for Manchester's 271 businesses
- Contrasts with 45 businesses in Oxford and Cambridge which are closer to the frontier



Source: Belmana Analysis

Panel 2: Firms and the Frontier by Industry

- Graph plots distribution of businesses in terms of efficiency, the percentage towards the frontier with 100% meaning at the frontier
- 1,628 businesses are in information technology and efficiency peaks near the frontier; 596 professional and technical services businesses have more medium efficiency businesses
- Manufacturing (247 businesses) has fewer high efficiency businesses



Source: Belmana analysis

The idea of measuring the efficiency of a production unit involves a comparison of actual performance with optimal performance located on the production frontier - the boundary of the technological possibility set (or one of its value duals, such as cost, revenue and profit frontiers). The purpose of this is to understand the distance from the frontier and to provide evidence for inefficiencies (Carayannis and Goletsis, 2015). In practice, a production frontier is unknown with certainty but can be estimated. With this estimate, the distance of individual firms from the frontier can be a measure of the efficiency of the firm. This analysis has used stochastic production frontier models introduced by Aigner, Lovell, and

Schmidt (1977) and Meeusen and van den Broeck (1977) to measure the distance to the efficiency frontier by location and industry.

Figure 3.2 plots the frequency of firm-level data, but this time focusing on the efficiency of businesses. The distribution of firm-level efficiency is measured by how far the individual firm is from the modelled frontier. Productivity frontiers were constructed by looking at 6,953 businesses that are in knowledge intensive industries modelled on innovation and size indicators.

The first panel presents the distributions of efficiency of businesses in London, Oxford/Cambridge and Manchester. It shows London to have many businesses at or near the frontier, but a tail of businesses which are nearer to half the efficiency of the frontier. Oxford appears to have a larger proportion of its businesses near the frontier (though sample sizes necessarily are smaller) and the distribution for Manchester is flatter towards the frontier, suggesting, like London, a smaller proportion of businesses at or near the frontier.

The analysis highlights why innovation diffusion is of interest. Here the focus of analysis is large businesses, whose average productivity is higher than for SMEs in all UK regions (ONS 2019). Even here, there appears to be a potential to raise productivity by sharing best practice and so raising the efficiency of businesses without recourse to new technologies and innovation. Rather, particularly in large cities where there are likely to be frontier businesses, the focus may be encouraging the tail of businesses to adopt existing technologies. This may be less the case in knowledge intensive cities such as Oxford and Cambridge, where a greater share of large businesses operate at the frontier.

The sectoral picture is more complex. The information and communication technology sector may already have a good level of diffusion across large businesses, with evidence of many businesses operating at the frontier. Other sectors in the figure will have more diverse diffusion pathways with, for example, manufacturing covering very different industrial activities where technology levels as well as adoption of new technologies varying – for example – between knowledge intensive manufacturing and the rest of the sector.

Potential to raise productivity through diffusion

At the sectoral level, there will be a mix of firms, some operating at low productivity levels in the tail and some reaching a high productivity level at the frontier. It is possible to estimate a potential productivity improvement measure, quantifying overall productivity increases if the low productivity firms attained the level of productivity of the better performing businesses in their sector.

For this analysis, the UK Business Structure Database (BSD, ONS 2019) is used. This provides information at the enterprise and establishment level. It provides annual snapshots from the Inter-Departmental Business Register (IDBR) which also contains variables about firm demographics. For the present analysis, a panel was constructed at the enterprise level through the appending of the yearly cross-sectional data available in the BSD. The dataset contains key information about firms used in the analysis, such as level of employment, turnover and industry sector each year.

Measurement is conducted characterising a high performing “frontier” business as either the median of firm business-level productivity in each sector (i.e. the business that is in the middle of the distribution when firms in the sector are ordered by turnover per employee) or as the business at the 75th percentile. Firm-level productivity is calculated by dividing turnover by employment.

Figure 3.3 shows three measures to explore the productivity tail. A first is the share of employment trapped in the tail, that is the proportion of employment in firms with a productivity level below the median or below the 75th percentile. Shares far lower than 75 percent are found, suggesting that overall employment levels per firm in the upper portion of businesses are higher than in the lower portion. In 2010 and 2011, the employees trapped in low productivity firms peaked. It reached levels of 32 percent (when the cut-off is the median firm) and 46 percent (when comparing against 75th percentile firms). Annex A tabulates estimates.

London and Manchester have fewer employees in low productivity businesses than the rest of the UK. When calculated using the 75th percentile as the frontier, Manchester and London have between 30 and 33 percent of employees trapped while the rest of the country traps 46 percent on average. Manchester’s share of employees trapped in the tail declines over the period, crossing that of London’s during the recessionary period. However, London’s levels over the period have remained low.

Panel 2 and 3 consider the (counterfactual) productivity impact of moving lagging firms to a productivity frontier. This is called the Tail Potential Index (TPI). In Panel 2 the amount that aggregate productivity (GDP per capita) would increase if firms below the median in every sector could achieve the productivity of the median firm is examined. UK productivity would rise by approximately 10 index points. Note that the TPI has reduced in recent years suggesting that the “long tail” is less of a drag on productivity now. The decline accelerated after the Great Recession of 2008, suggesting that it could be the consequence of a “cleansing effect”.

Dispersion in productivity is not necessarily a bad thing. It could be the hallmark of a very dynamic economy with high entry rates of new businesses, a high rate of innovation and frequent trial and error to identify the most promising innovations (Hypothesis 1). But of course, it could also be the consequence of the exact opposite: a sclerotic economy where low productivity businesses can persist because of a lack of competition (Hypothesis 2).

Figure 3.3: Tail productivity potential in London, Manchester and UK

Panel 1: Employment trapped in the tail businesses 2002-17

Businesses have been ranked by their turnover per employee for 2002-17 for sectors and, for each sector, two cut-offs used to identify the tail. In the top, is the share of jobs that would be in businesses below median productivity; the lower figure has the cut-off at 75th percentile.

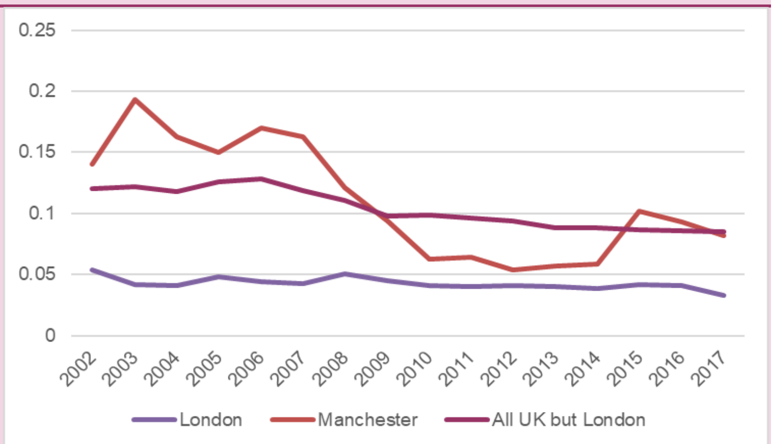
Employment shares in the higher, P75 tail are necessarily higher. However, in both measures London and Manchester are similar with UK outside London having a higher share of employment in productivity tail businesses.

Panel 2: Tail Potential Index, 2002-17 Median

The figure indicates the amount productivity will increase if below median firms are brought to median productivity.

Note that this is lowest for London (less than 5%) compared to the rest of the UK suggesting a long tail is less of a drag for London.

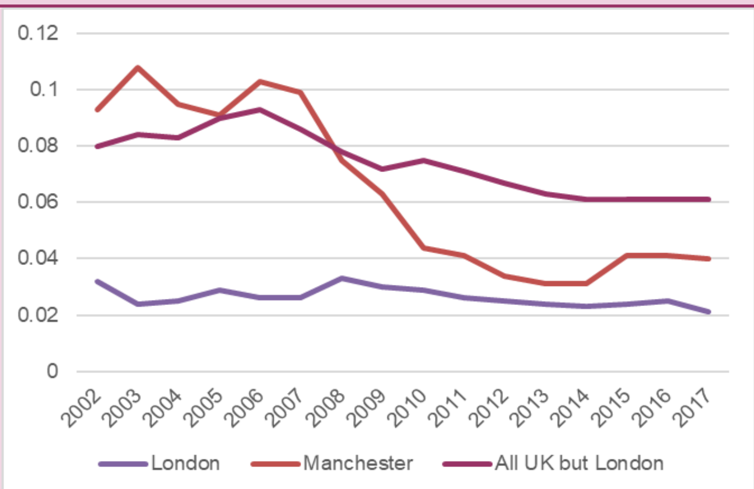
Also note that the "tail problem" seems to have reduced over time, particularly after the financial crisis.



Panel 3: Dynamic Tail Potential Index, 2002-17 Median

The figure indicates the increase in productivity that would occur if businesses below the median in the current year and five years prior would be raised to the median. Hence, this only includes persistent tail productivity firms in the calculation.

Note that this almost halves the potential suggesting a substantial part of firms in the tail are "dynamic".



To distinguish between the two, Panel 3 reports a dynamic version of the TPI (DTPI) that takes into account how persistently a low productivity business has been in this position. Hence, the analysis explores what would happen to aggregate productivity if the productivity of firms that have been in the tail in both the current year and 5 years prior is increased. By definition, this leads to lower improvement figures in Panel 3. Comparing Panel 2 and 3 it is evident that the majority of the dispersion in both London and the UK as a whole is of the sclerotic variety. However, the dynamic part is not negligible: it makes up between 30 and 40 percent of the simple TPI. The time profile as well as the relative ranking of the London versus the rest of UK is the same for TPI and DTPI.

Annex A explores the robustness of these conclusions of the productivity frontier by repeating the figures using the 75th (instead of median) percentile as the frontier. By definition, this leads to higher (D)TPI values (roughly twice as high) but the qualitative findings are the same. An interesting observation is that the difference between TPI and DTPI becomes somewhat bigger with the DTPI being only about half of the TPI. This suggests that the kind of dynamic dispersion associated with Hypothesis 1 outlined above is more relevant in the upper part (i.e. between the 50th and 75th percentile) of the productivity distribution.

The decline over time highlights that a larger fraction of lagging businesses did leave the market or moved up in the productivity distribution in a period of five years. Thus, the productivity improvement potential adjusting for the productivity for businesses below the frontier that have also been below the frontier five years ago was also declining; a cleansing process is also observed after the 2007-2009 crisis. The DTPI indicates that the UK had an employment-weighted productivity index gap of 9 percent a year before the crisis which decreased to 7 percent after the crisis.

In general, these figures suggest that the UK has struggled with low productivity growth since the 2008 economic downturn, but London has been one of the most important motors for productivity recovery in the country in the past ten years. In particular, the dynamic version of the analysis indicates that that could be the case. The low level and stability of the DTPI for London across the years in panel 3 (Figure 3.3.) might indicate that the cleansing process in the city has not been necessary, because there are not many low productivity firms to take out the market. Alternatively, the cleansing process has been successful with low productivity firms quickly exiting, keeping the gap low. Either case makes London perform better in this analysis than other cities and the rest of the UK.

Indicators of London’s Innovativeness

This section presents analysis of innovation activity in London and other parts of the UK. It focuses on the early stages of the diffusion process, highlighting the scale of innovation in London and in which sectors and technology areas it is concentrated. This is measured using IP indicators, also examining how the university sector links with businesses.

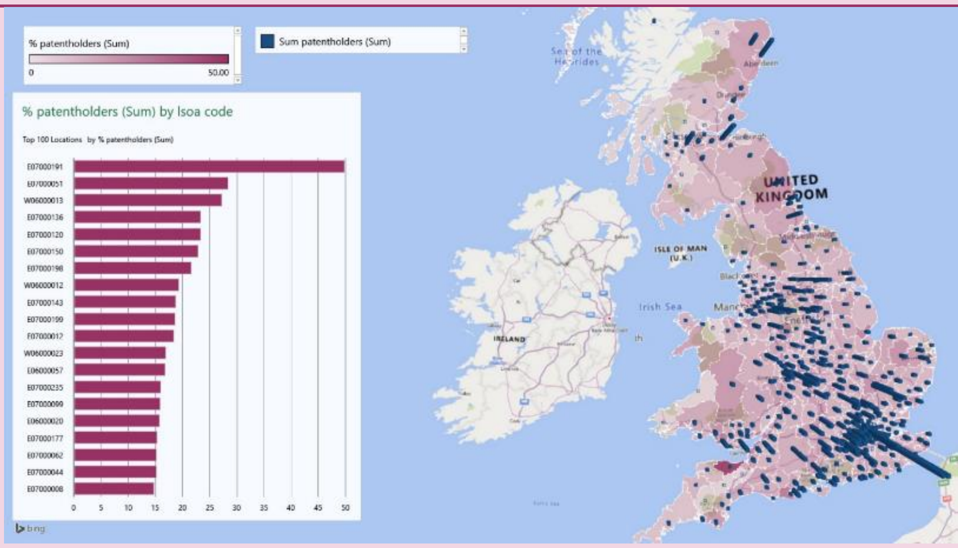
Patents confer IP rights. Economic theory gives insights into why IP exists and how it stimulates innovation. Patent rights act as instruments to incentivise innovation and promote the diffusion of new knowledge. Hall et al (2013) find a correlation between patents and innovation using the ONS microdata linked to the patent register but make important caveats. They note that the links are specific to some sectors and that the innovativeness observed is not a precursor to employment growth.

Figure 3.4 maps the patents held by London businesses. The patents registered in the UK were linked to the holder and – where this is a company – the maps highlight the concentration of patents in business located in London. Other centres are also highlighted.

Figure 3.4: Mapping patents in London

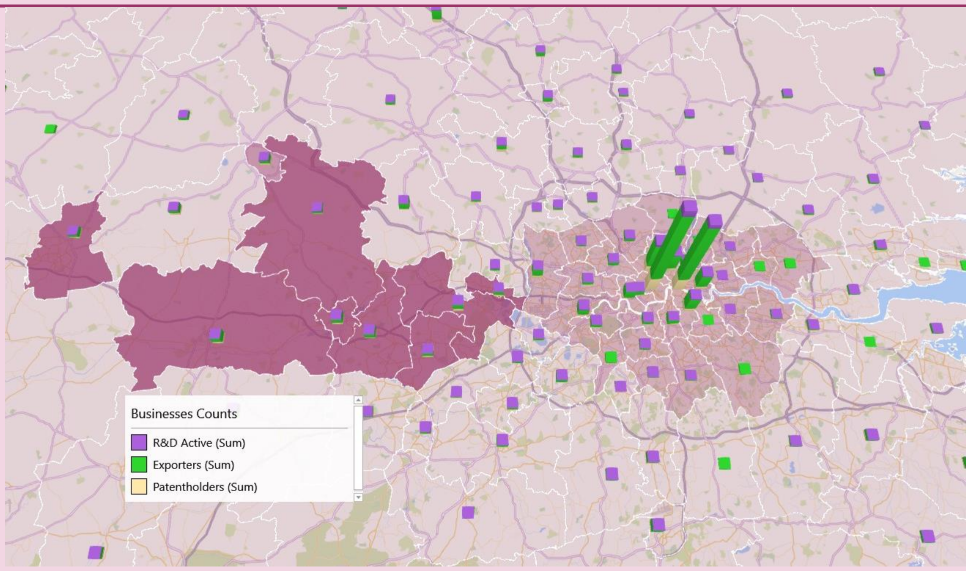
Panel 1: Location of patenting businesses

The map below details the concentrations of patent holders visualised by mapping the sum of patent holders in each region. Patent holder concentrations appear to exist around London and its commuter belt, Birmingham, Manchester, Leeds, Cambridge, Durham, Edinburgh and Aberdeen.



Panel 2: Patenting businesses and their characteristics

The map presents the number of large businesses that have a patent, export and report R&D. Approximately 7,600 of the 63,000 that report full accounts also have a patent and 2,000 report R&D.



Note: Larger versions of the maps are annexed.

A second map then uses the business accounts linked to the patent register to highlight how the patent holders are highly likely to also report exporting. This has a smaller sample of businesses, with many of the smaller patenting businesses unlikely to file full accounts.

Figure 3.5 presents the number of innovations by technology category. Using the IPC and CPC patent classification system, innovations were grouped into 40 categories. Panel 1 reports the numbers of innovations[4] created by London based innovators and firms.[5] The length of each rectangle indicates the number of patents, while the breadth of each captures the value of each innovation area as a proportion of total innovation. Over the 2000-14 period, nearly 30,000 innovations can be attributed to innovators from London. More than a quarter of those come from computer tech, telecoms and AI. Computer tech and telecoms are also among the largest areas for the UK as a whole; by contrast AI is much further behind on rank 9.

It is not surprising that the UK as a whole generated a much larger absolute number of innovations over the 2000-14 period, 342,557 distinct innovations. In per capita terms, the UK on average produces a larger quantity of innovations: 6 as opposed to only 3 for every 1000 inhabitants in London. However, this does not necessarily imply a lower level of innovation activity for the city. It is likely that London is more specialised in service sector industries where patenting is not the predominant form of securing IP. Further, the residential population of London will differ considerably from employment in the city due to commuting. However, as is discussed further below, innovation quality seems to be much higher in London than the rest of the UK.

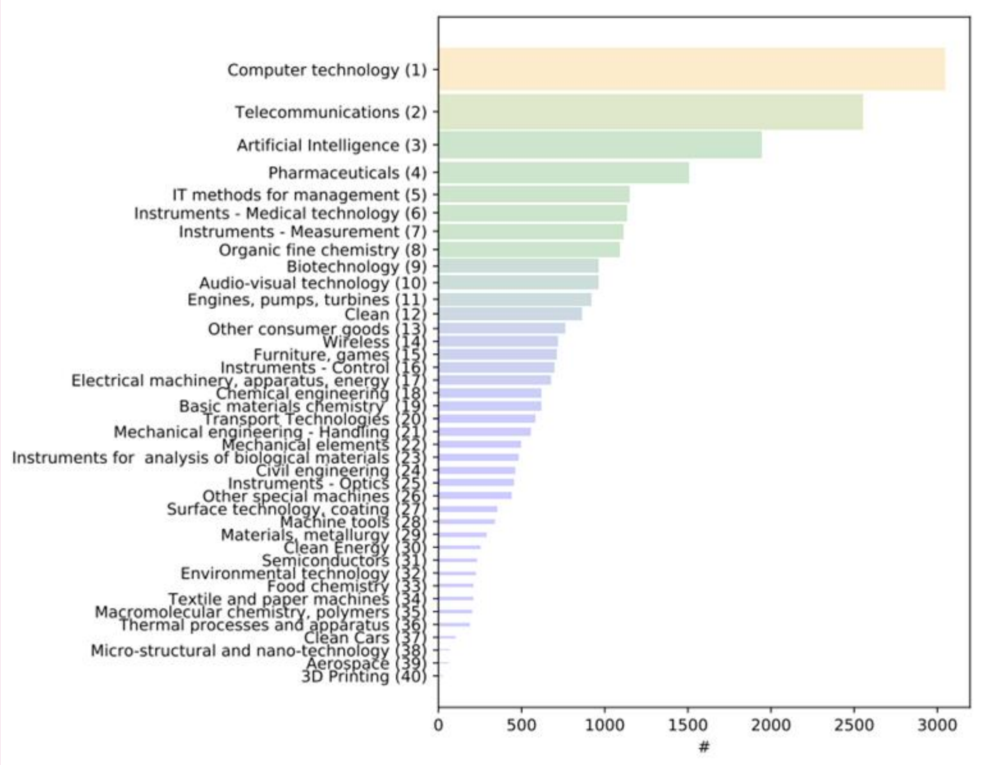
Many of the leading technology areas in both the UK and London are also key areas elsewhere. Therefore, to enhance understanding of where London might have a comparative advantage, the share of an area in total innovation for London is compared to its (weighted) average share across the OECD. This is reported in Figure 3.6. The highest comparative advantage is for 3D Printing, pharmaceuticals and IT Methods for Management where London has shares of more than double the OECD average. Panel 2 reports that 3D printing is similarly as important for the UK as a whole. However, IT Methods for Management and AI are actually smaller than the OECD average.

[4] Innovation is defined as a patent family using the PATSTAT database. A patent family consists of all the patents that refer to the same underlying innovation; i.e. if a company registers the same underlying innovation with several patent offices in various countries then only one innovation is counted.

[5] If available innovations are assigned to a geographic location on the basis of the inventor of an innovation. Note that the inventor is often distinct from the patent holder who in most cases is a firm. If inventor information is not available, the location of the patent holder is used.

Figure 3.5: Recent Innovation in (2000-14)

Panel 1: Recent Innovation in London



Panel 2: UK as a whole

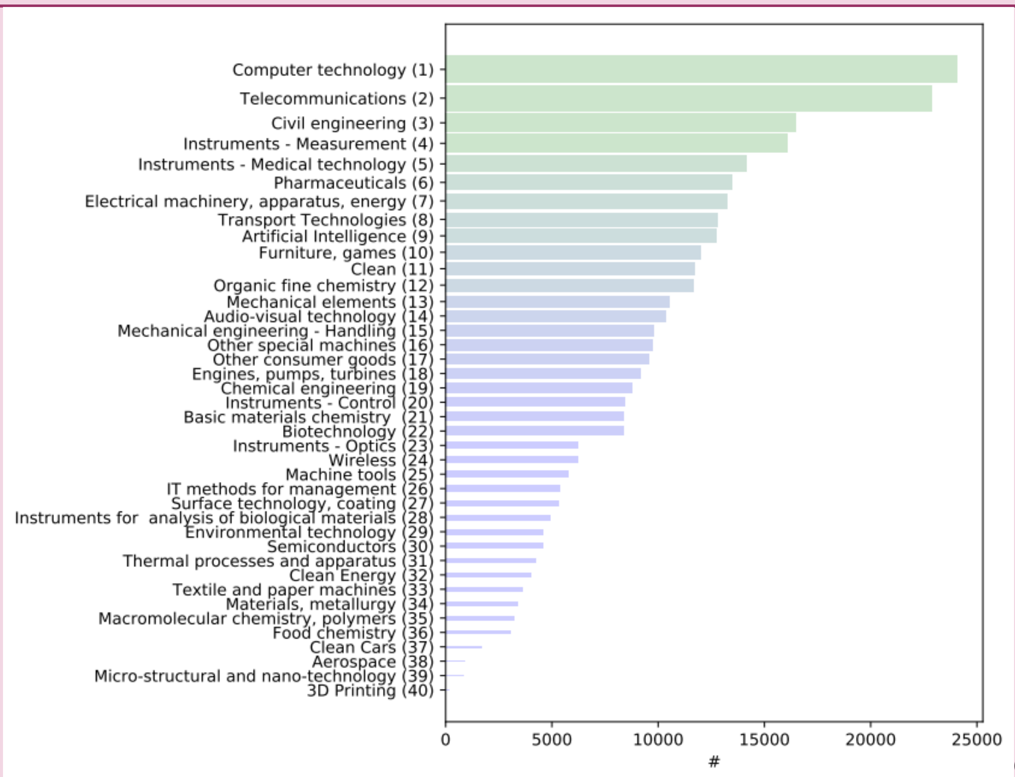


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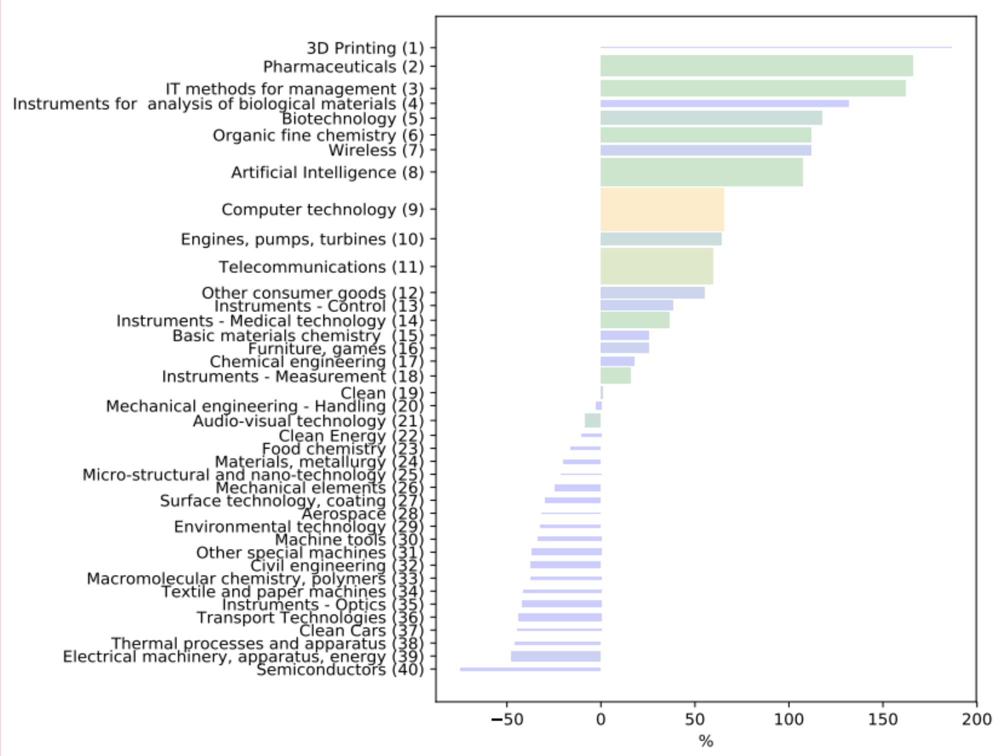
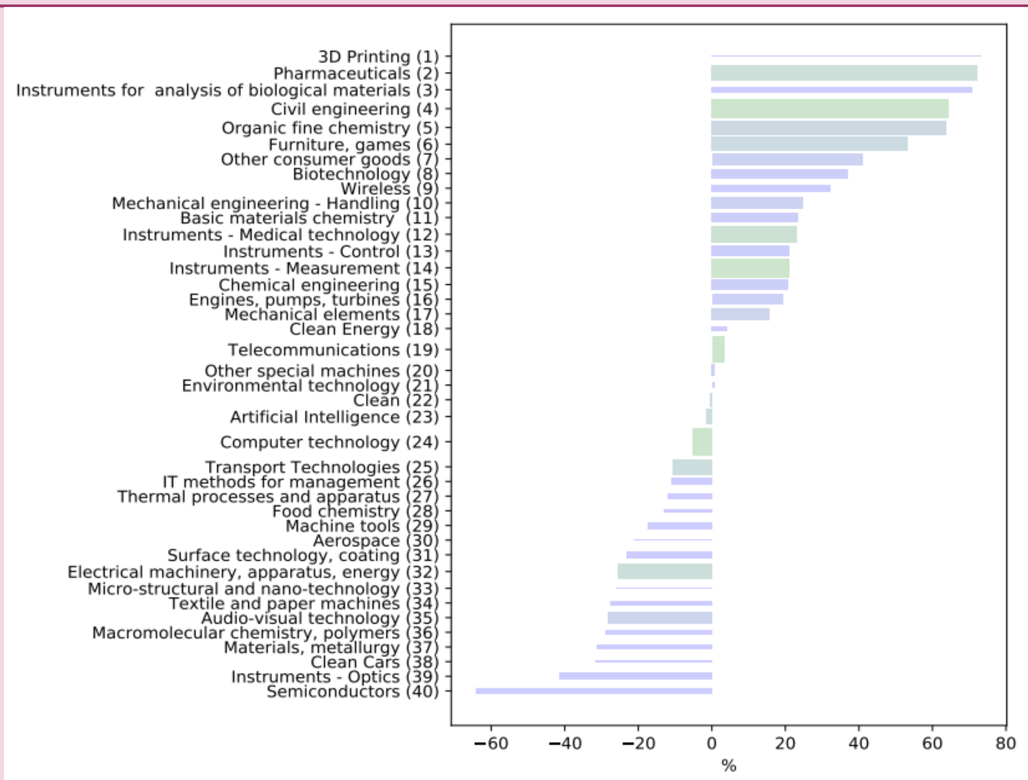
Figure 3.6: Comparative advantage across innovation areas (2000-14)

Panel 1: London comparative advantage by technology class



Panel 2: UK comparative advantage by technology class



[6] The figures show the number of innovations in each innovation area. The width of the bars represents the share of each innovation area in total innovation.

Conclusions

This chapter presents evidence about productivity and efficiency of businesses in London and other areas of the UK. It highlights that there are frontier businesses, but there is also a tail of businesses that could benefit from adopting technologies and practices to increase their productivity levels.

- There appears to be potential to raise productivity by sharing best practice and so raising the efficiency of businesses without recourse to new technologies and innovation.
- This may be less the case in knowledge intensive cities such as Oxford and Cambridge, where a greater share of the large businesses operates at the frontier.
- The analysis places about 20% of London's employment in businesses that are below the median productivity level.
- Analysis then indicates how, if these London-based businesses could raise themselves from being in the productivity tail, a 2-5% productivity enhancement could result.
- London has a strong comparative advantage in IT methods for management as well as 3D printing, pharmaceuticals, instruments for the analysis of biological materials and biotechnology.

4. Innovation Diffusion Pathways in London

This chapter considers evidence about the stages of diffusion mechanisms as innovations spread to businesses. The discussion of diffusion mechanisms in chapter 2 highlights the importance of collaboration between research organisations and businesses, providing a means for research to be commercialised through the transfer of knowledge. A second set of diffusion processes highlight the spillovers from ideas, as research is integrated into a wider set of technologies, processes and products. The evidence from patent citations is analysed using a new set of methods which value the spillovers by correlating the development and spread of an idea with its impact on the market value of a business.

These two analyses produce new insights about:

- How universities in London participate in diffusion through activities such as commercialising IP, engaging in contract research or consultancy.
- The performance of London universities in spin-offs commercialising university research, and start-ups of staff or graduates.
- Spillovers from London as its ideas are cited by other innovations and the net flows into and out of London from these spillovers.

Universities and innovation spillovers

Universities can create innovation spillovers via formal or informal interactions between university research and businesses, and the innovative activities of staff, students and graduates. Some of the key (mainly US based) studies on innovation spillovers from patents are summarised in the box below.

Role of universities in innovation diffusion

There is a body of evidence on university-industry innovation spillovers stemming from Jaffe (1989), who finds evidence of commercial spillovers from university research (to firm patenting or R&D). Subsequent papers provide evidence of localisation in such spillovers, for example Jaffe, Trajtenburg and Henderson (1993), Anselin, Varga and Acs (1997), Belenzon and Schankerman (2013).

A more recent paper by Andrews (2017) uses historical data and exploits quasi random allocation of universities to US counties over the period 1839-1954 to estimate their causal impact on patenting. Interestingly, when exploring the mechanisms behind the positive effects of university funding on patenting, he finds that the largest share of induced patenting came from people who migrated into the university counties, rather than from staff or graduates from the new universities. Also analysing the impacts of university establishment on patenting but in a contemporary setting, Pfister et al (2019) employ a difference-in-difference approach and find that the establishment of the "Universities of Applied Sciences" in Switzerland had positive impacts on patenting quantity and quality.

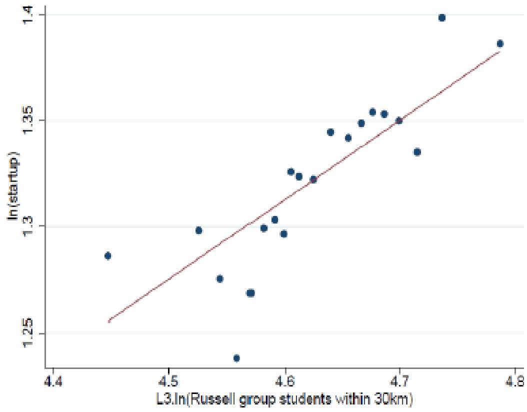
Empirical studies on the relationships between UK universities and innovation tend to focus on the effects of university research on the extent and location of business research and innovation. These studies have found that effects are highly localised and exist for specific sectors. For example, Helmers and Rogers (2015) consider the manufacturing sector and show a positive relationship between university research and the patenting of small firms located near universities (but has no relationship for large firms), and that the quality of university research matters. Studying where firms locate their R&D across eight product groups, Abramovsky and Simpson (2011) find that firms in the pharmaceuticals sector are more likely to co-locate near universities, but there is little evidence of co-location in other sectors.

Using UK data on firms and university enrolments, Valero (2019) relates local area (ward) start-up activity in the innovative high-tech sectors, and economic performance more broadly, to the growth of the university sector. This work finds that "high-tech" start-up activity is higher for wards with a larger university sector in the surrounding area (as measured by students enrolled within a 30km radius). This positive relationship holds after controlling for population and area-specific factors and also for region-year factors that might include changes in local development policies. Positive productivity effects are also found for wards that have higher initial high-tech intensity, and at the firm level – for high-tech firms themselves.

These effects appear stronger for higher quality, research-intensive institutions (as proxied by their Russell Group status, see Figure 4.2) and are also larger in urban areas – in particular London - and areas with higher initial human capital. These findings suggest that the university-industry interactions that drive these relationships are stronger in areas with higher absorptive capacity.

Figure 4.1: Russell Group universities enrolments and high-tech start-ups

- Analysis of the economic impact of universities (size and composition) using HESA data and ONS firm level data over period 1997-2016
- Wards that saw high growth in university enrolment in their surrounding areas also experienced an increase in start-up activity, particularly in high-tech sectors
- Results are stronger for more research intensive “Russell Group” universities (see figure)



NOTES: Scatter plots depict ward level regressions of ln(1+start-ups) on 3 year lagged ln(1+Russell Group students within 30km), controlling for lagged population within 30km, ward and year fixed effects (so variables are residualised). Data are grouped into equal sized bins with the mean of the variables within each bin plotted in the graphs.

Source: Valero (2019)

These findings are consistent with previous literature, which in different contexts and using other measures of university activity has found that spillovers from universities tend to be felt by particular industries considered to be technologically closer to universities. The measure of university presence based on enrolments is a proxy and will not capture heterogeneity across universities in terms of their links with local businesses. The next section explores descriptive statistics from a university level survey that sheds light on this.

Collaboration Indicators

Information on the extent to which universities interact with industry can be extracted from the Higher Education Business and Community Interaction (HE-BCI) survey. This annual survey collects financial and output data related to knowledge exchange and other interactions between universities, businesses and the community at the institution level. Key variables of interest for this study include measures of business income from IP (including income from patents, copyright, design, registration and trademarks), contract research, consultancy, continuing professional development (CPD), and access to facilities and equipment. Further cuts of data allow us to separately identify income of SMEs versus larger businesses.

While some of these activities represent the generation of new innovations which are commercialised (such as IP revenues), others are more indicative of the diffusion of existing knowledge. Consultancy services in this context relate to work with a high degree of intellectual input from university staff, but without the creation of new knowledge. In addition, the survey provides responses about innovation outcomes, including patents and disclosures (confidential documents that seek to determine whether patents should be sought), as well as data on spin-offs and start-ups connected to the university.

While the location of businesses interacting with universities is not given, the literature outlined above and surveys (for example, the CBI London Business Survey, 2019) have found that proximity matters in university-business collaboration, so it can be assumed that a large share of the interactions are with London businesses.

London is home to a large university sector: in 2017/18 there were over 370,000 students enrolled in its universities, and they employed over 80,000 academic and non-academic staff (according to the latest available figures from HESA). Moreover, London is host to a number of world class universities - the latest Times Higher Education World University Rankings has four London universities in the world’s top 40 (Imperial, UCL, LSE and Kings) – and specialised research focused institutions. Within London, larger STEM research-intensive universities tend to dominate on most of the IP related outcomes measured in the HE-BCI survey, where outside London, Oxford and Cambridge are strong performers. But other London universities also stand out on some measures either due to their specialist nature or focused entrepreneurial activities. These include RCA, which highlights the importance of the creative sectors and design in the innovation process.

The Figure 4.2 summarises the main business income streams for the London universities against the rest of the UK, with income from SMEs and larger businesses shown separately. The first panel gives average income per university and this shows that non-London universities appear to have higher income from SMEs across all streams, on average. London universities in particular have higher income from consulting with larger businesses, probably reflecting the large number of headquarters in the city. The data would suggest that London universities could seize more opportunities to increase collaboration with SMEs. IP revenues from larger businesses are also strong, suggesting the city’s universities are successful at diffusing and commercialising the IP outputs of R&D.

Some London universities do particularly well across these indicators, which can be taken as a good proxy for the quantity and quality of the IP they commercialise. Imperial and UCL do well across income streams, the Institute of Cancer Research stands out for IP income from larger businesses, Kings College London on Contract Research and Facilities income, and London Business School for CPD (LBS records the highest UK value for CPD activities with non-SMEs). The Royal Veterinary College also has high consultancy and facilities revenues.

Table 4.2: Analysis of HE-BCI responses about Income Streams

Comparison of London vs non-London Universities by Income Stream, HEBCI data combined with HESA data on enrolments (Panel 2)

Panel 1: Average per University

	IP income	Contract Research	Consultancy	CPD	Facilities
Average from SMEs (£000)					
London	134	285	409	48	272
Rest of UK	252	494	523	168	467
Average from non SMEs (£000)					
London	995	2,966	1,011	845	160
Rest of UK	534	3,015	593	746	445

Panel 2: Average per Student

	IP income	Contract Research	Consultancy	CPD	Facilities
Average from SMEs (£ per student)					
London	65	247	170	15	62
Rest of UK	12	30	82	16	30
Average from non SMEs (£ per student)					
London	3,613	1,320	166	410	26
Rest of UK	28	159	42	67	30

Panel 3: Average per Student, excluding Institute of Cancer Research

	IP income	Contract Research	Consultancy	CPD	Facilities
Average from SMEs (£ per student)					
London	5	25	175	15	64
Rest of UK	12	30	82	16	30
Average from non SMEs (£ per student)					
London	55	164	158	420	27
Rest of UK	28	159	42	67	30

Notes: This analysis is based on 164 HEIs in the UK. In fact, data on 165 HEIs is available in HEBCI in the latest year, but HESA enrolments data were not available for one of these (Hartpury University) so this is dropped from the analysis for consistency. Panel 3 excludes Institute of Cancer Research which has vey high IP income and Contract Research income, but relatively few students. Note IP income here excludes sale of shares in spin-offs.

The data are also merged with student numbers (also from HESA), in order to calculate income per student - a measure of intensity. London universities on average are significantly smaller in terms of student numbers than the rest of the UK, driven by the large number of smaller specialist and postgraduate institutions in London (the average London HEI has just under 9000 full time equivalent students, while the average non-

London HEI has 14,000). Panel 2 in Table 4.2 shows that controlling for university size in this way, London universities tend to have a higher intensity across most income streams – even from SMEs. Average IP income and Contract Research income per student from non-SMEs in London universities are far larger than the averages outside London – this is due to the Institute of Cancer Research, which reports high revenues for these activities but has a relatively small student body. Excluding this institution in Panel 3 shows that London universities still have higher income normalised by students across most streams.

Further analysis has been undertaken at the institution level. For a subset of the institutions in HEBCI (150 of the 164 previously analysed), the data can be merged with data from the Research Excellence Framework (REF) 2014 to explore basic correlations between various metrics of business interaction and REF scores, a measure of the quality of university research. Scatter plots for income in the most recent year (2017-18) indicate positive correlations for most HE-BCI types between revenues normalised by number of students and the percentage of research that is rated 4* (the highest rating) at the institution across most activities.[7] This is particularly the case for revenues from non-SMEs, as shown in Figure 4.3. On many of the measures London universities (marked by the blue circles) have high intensity.

[7] In a small number of cases however, this correlation either does not exist or is driven by an outlier.

Figure 4.3: University Income from Non-SMEs for London and the rest of the UK

Higher Education BCI survey 2017/18 of 150 higher education establishments combined with their student numbers and Research Excellence Framework score, 2015, to look at income per student versus percentage of research rated 4*

Notes: Analysis based on HE BCI survey 2017/18, HESA student numbers data, FTE basis and REF 2014. Per cent research rated 4* is given by subject, and this is weighted by FTE staff per subject to get an instiution level value. Institute of Cancer Research is an outlier in IP income/students and dropped from these charts. Note IP income here excludes the sale of shares in spin-offs.

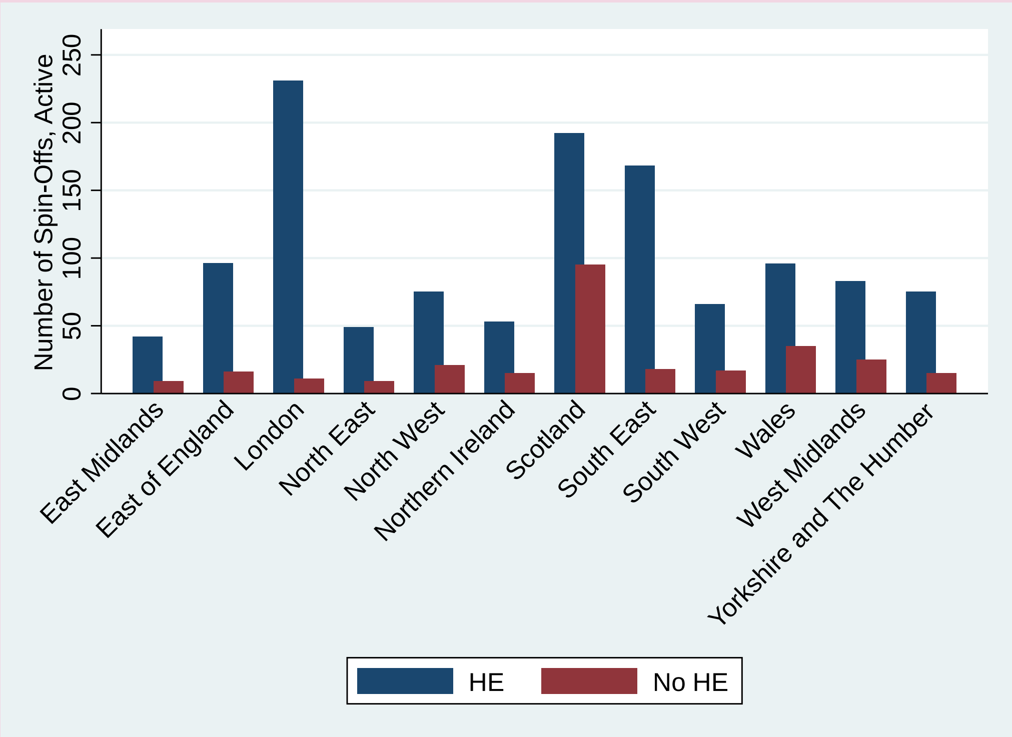
Various measures of innovation – such as patents and disclosures – were also analysed. In line with the income analysis, London universities that do particularly well on these measures are Imperial and University College London. In fact, Imperial has the highest number of patent disclosures across all UK universities. But the RCA is also strong in this area, recent patent support projects include hardware that mimics the feeling of touching internal organs for increased medical efficiency and an artificial wearable gill to increase diving capacity. There are also positive correlations between patents or disclosures normalised by university size, and research quality.

An important channel through which university research and innovation diffuses into the economy – and one which contributes to the business dynamism which is a key driver of growth – is entrepreneurship. This can take the form of spin-offs based on IP from higher education institutions, or start-ups involving university staff or students.

University spin-offs can include companies that are set up to exploit university IP which is still at least part owned by the university, or cases where the HE provider has released ownership of the IP (e.g. through a sale of shares). In the latest year available in the data (2017/2018), London performs better than any other region in the UK in terms of the number of active HE (Higher Education) provider-owned spin offs (Figure 4.4). London's top performers on this measure are Imperial, UCL and RCA. Few universities in London record spin-offs where the university has released ownership, those that do are Kings, RCA, Institute of Cancer Research and City University (Scotland's high number on this measure is driven by the universities of Edinburgh and Strathclyde).

Figure 4.4: University Spin-offs in London vs. other regions in 2017/2018

Higher Education BCI survey 2017/18, total active spin-offs



Notes: Analysis based on HE BCI survey 2017/18.

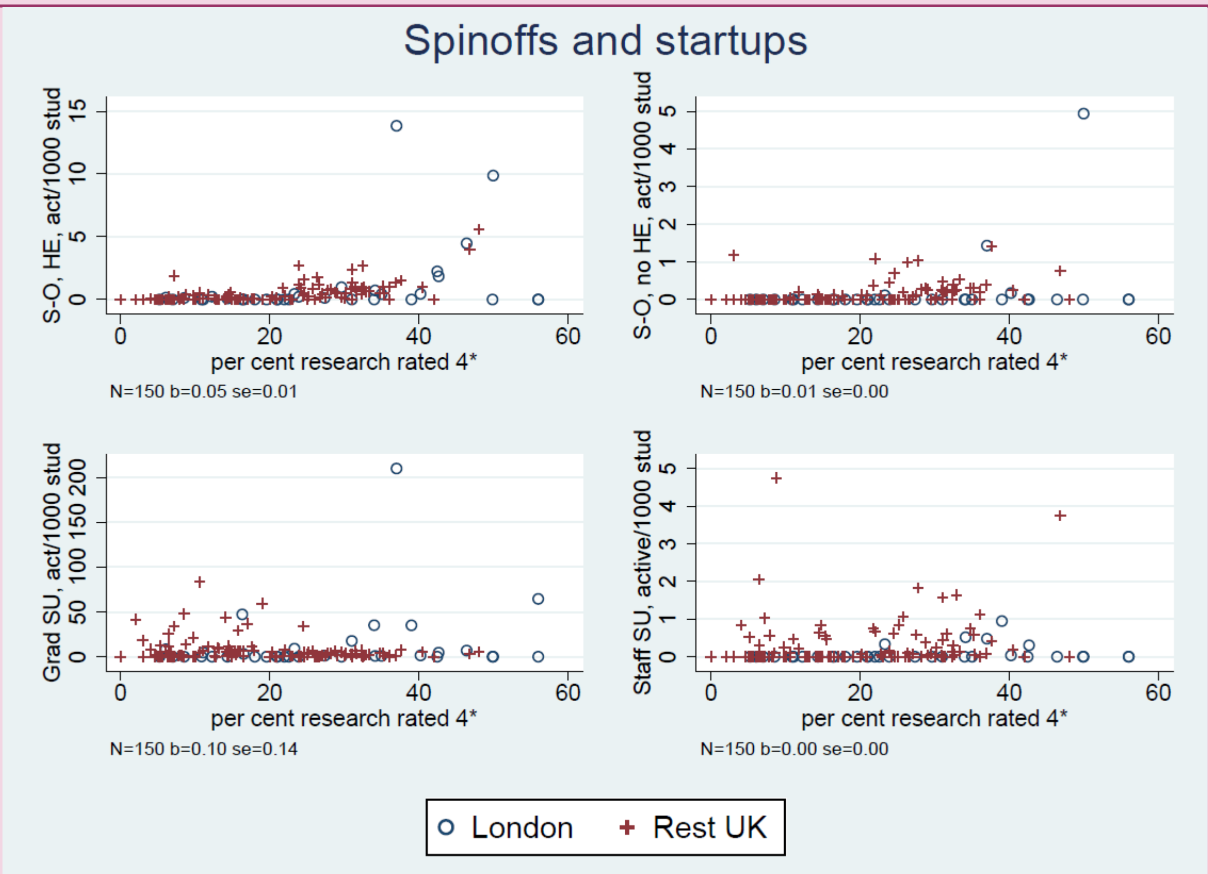
Graduate start-ups are businesses set up by recent graduates that have had formal support from the university, and London has the highest number of active graduate start-ups compared to other UK regions. London's best performers in terms of total numbers of student start-ups are Kingston University, RCA and University of the Arts, London. These universities, like many others, have programmes that support their students towards setting up businesses. To some extent, this is a very common and standard form of diffusion from universities, namely the skilling up of entrepreneurs.

Staff start-ups are new businesses set up by university staff, but not based on university IP, and there are fewer of these in general compared to graduate start-ups. London's best performers on these measures are Queen Mary and UCL. Here, the link could also be discipline based, with specific staff clusters viewing the start-up of a business as both a means to commercialise research and make use of the skills they have developed during research and teaching.

Correlations between spin-off and start-up counts, normalised by students and the REF measure of research quality are given in Figure 4.5. The top two graphs relate to spin-offs. These graphs show that spin-offs (particularly with HEI involvement) exhibit a positive correlation with research quality. But on the start-up measures, the correlations with REF scores are less pronounced. This is unsurprising as starting up a business is often not a consequence of the research undertaken in a university, with many universities specialising in teaching courses where the early steps for graduates involve starting up a business.

Figure 4.5: University spin-offs and start-ups for London and the rest of the UK

Higher Education BCI survey 2017/18 of 150 higher education establishments combined with their student numbers and Research Excellence Framework score, 2015, to look at number of active spin-offs (S-O) and start-ups (SU) versus percentage of research rated 4*



The findings in this section are consistent with a general point that the UK has established hubs of innovation surrounding its research-intensive universities – with London being one of them. The analysis also suggests that on a per student basis, London universities perform better than the rest of the UK on a number of measures that proxy innovation diffusion. However, there is a lot of variance across universities in London: some universities are leading the way and performing well across all indicators, others perform well on specific counts.

As suggested by Haldane (2018), less research-intensive universities could do more in terms of the diffusion of innovation. Policy makers could consider ways to incentivise universities to share their best practices in innovation diffusion with their peers. In a London context, better information sharing on opportunities for collaboration between HEIs and industry, and on success stories, is likely to be beneficial (CBI London Business Survey, 2019).

Indicators of Knowledge Spillovers

Patent citations are often used as a sign of knowledge spillovers. For this study PATSTAT is used, the most comprehensive patent database available that collates information from nearly all patent offices globally along with several other new methods to measure knowledge spillovers. There is a long list of studies looking at citations per patent (for example Jaffe et al., 1993; Jaffe and Trajtenberg, 1999; Keller, 2004; Caballero and Jaffe, 1993; Jaffe and Trajtenberg, 1996). In the UK data, citations per patent range from 0 to 1,470 with a mean of 4.9.

The approach that has been used for this study is the PatentRank approach (see box below), which allows a value of spillovers from patents to be estimated using the citations of an idea. The measures integrate evidence about share price changes after a patent announcement to value patents then providing an estimate of the value of spillovers.

Using PatentRank to quantify innovation spillovers

Dechezlepretre, Martin & Mohnen (2014) and Martin et al (2019) develops PatentRank, building on Google's Page Rank algorithm (which is a measure of the importance of web pages on the basis of the network of hyperlinks). While PageRank models the likelihood of arriving at a particular webpage by following the "random surfer" (somebody that that clicks on random hyperlinks in a browser), the same approach is used to examine how economic value travels around the network of patent citations. The initial estimate of an innovation's specific value is needed which is obtained from an event study on stock market data – i.e. how a firms' stock price responds to the granting of a patent. For innovations from non-stocklisted firms, an empirical model is used which is then calibrated using the stock listed firms and predicts the value of an innovation on the basis of (over 7000) technology classes, patent family size, time period, etc.

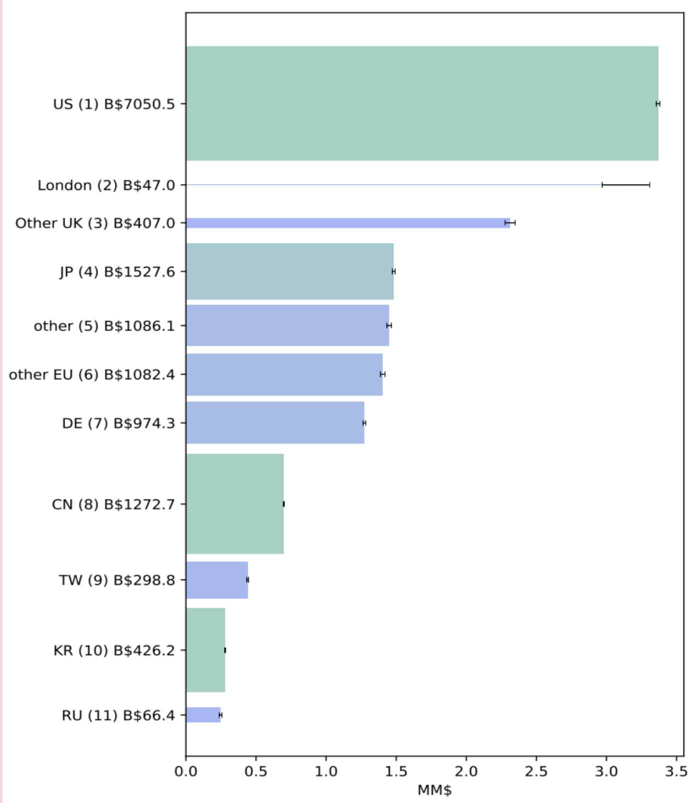
With this basic approach, a number of different types of PatentRank differing in degree of internationalisation are able to be explored. For instance, the UK government might only be interested in spillovers between different innovators that are all based in the UK, rather than spillovers that imply a knowledge transfer from innovators in the UK to innovators abroad. When considering such within country spillovers in conjunction with indirect spillovers it might be the case that two UK innovators are only indirectly connected with each other via a foreign innovator. This can be easily accounted for using the PatentRank algorithm which only takes into account values of UK based innovators. Moreover, this can be done for any level of aggregation, in particular spillovers within London only or spillovers between London and other areas.

An important shortcoming of the existing literature is that it treats all citations of an innovation the same. However, the private value (i.e. the profit the innovator or patent holder can derive from an innovation) can differ substantially from one innovation to the next. Also, an innovation will be more influential if it is cited by an innovation that is itself more highly cited. Ground-breaking patents are sometimes modestly cited due to the small size of an industry at the time of creation, whilst subsequent patents are more highly cited (Maslov, 2009). The computation of PatentRank takes both issues into account.

Figure 4.6 examines the value of spillovers generated in London, compared to other places. Over the 2000-14 period this amounted to a total of $47 bn. The rest of the UK generated $407 bn. Note that the average value of spillovers generated in London is $3 mil, much higher than for the rest of UK which has an average of $2.5 mil. Indeed, the average value of London spillovers is most similar to US spillovers, which tops this ranking. In many studies, spillovers are used to measure the quality of innovations therefore, the high value of London's innovations reveals their high quality on average.

Figure 4.6: Value of global spillovers, all patents (2000-2014)

- The plot indicates the average spillover from a number of countries and regions on the x-axis
- The average value of spillovers from London patents is high, as high as the US which tops this indicator and higher than the rest of the UK
- The height of each bar reflects the number of patents originating from the location, so the area of the bar is overall value
- The value of the spillovers from patents originating from London is $47bn, about 5% of the US total and about 11% of the rest of the UK
- Spillovers from other countries highlight the traditionally and newly innovative countries: Germany and Japan are strong, and China also delivers patents with considerable spillovers in value



[8]

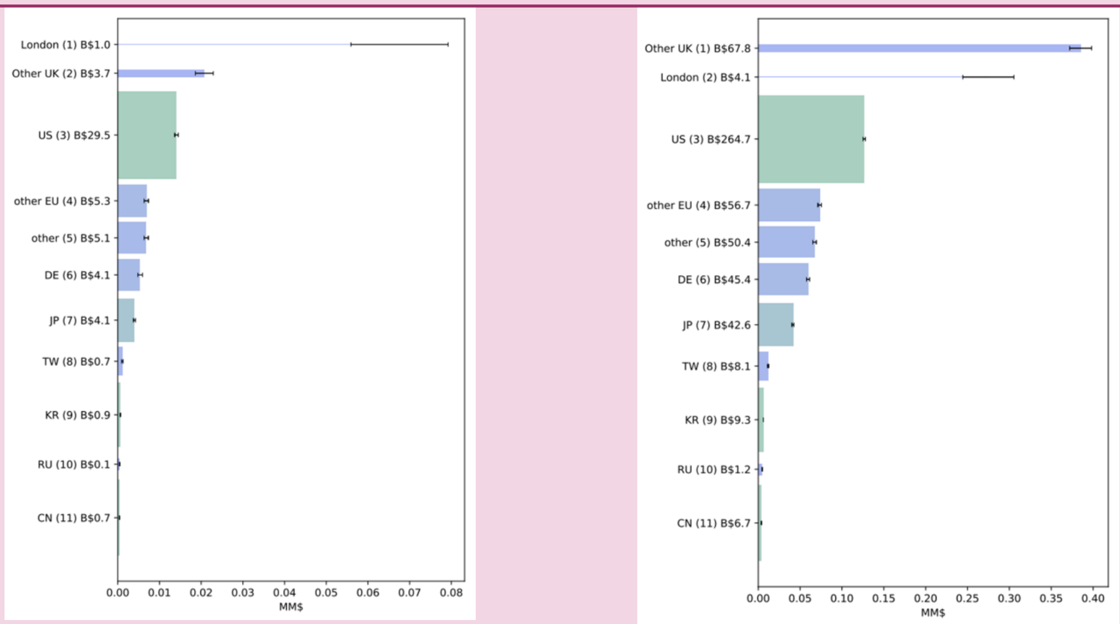
In Figure 4.7 spillover flows are examined between London and various countries including the rest of the UK. Panel 1 illustrates where the spillover flows that benefit innovators in London came from between 2000 to 2014. The biggest source is the US at nearly $30 bn. London received $3.7 bn of value from the rest of UK. Note that this is dwarfed by receipts from Germany, the rest of the EU and Japan. Also note that London generates $1 bn of spillovers for itself. Contrasting with the total value of spillovers generated in London from Figure 4.4 ($47 bn), this illustrates that London overwhelmingly benefits other regions and countries (in terms of knowledge spillovers); i.e. London is a national and global spillover machine. It is therefore not entirely surprising that the rest of the UK receives more from London ($4.1 bn) than it gives ($3.7 bn) despite London's much smaller size.

As with London, the biggest source of spillovers to the rest of the UK is the US with $265 bn. Spillovers from the EU amount to just over $56 bn and $43 bn from Japan. Also note that the average value of spillovers from London to the rest of the UK is nearly $300,000 higher than from the UK to London, a sign of the high quality of London's innovations.

[8] JP: Japan, DE: Germany, CN: China, TW: Taiwan, KR: South Korea, RU: Russia.

Figure 4.7: Spillovers flowing into London and the UK, all patents (2000-14)

Panel 1: Value of Ideas into London	Panel 2: Spillover Flows to non-London UK



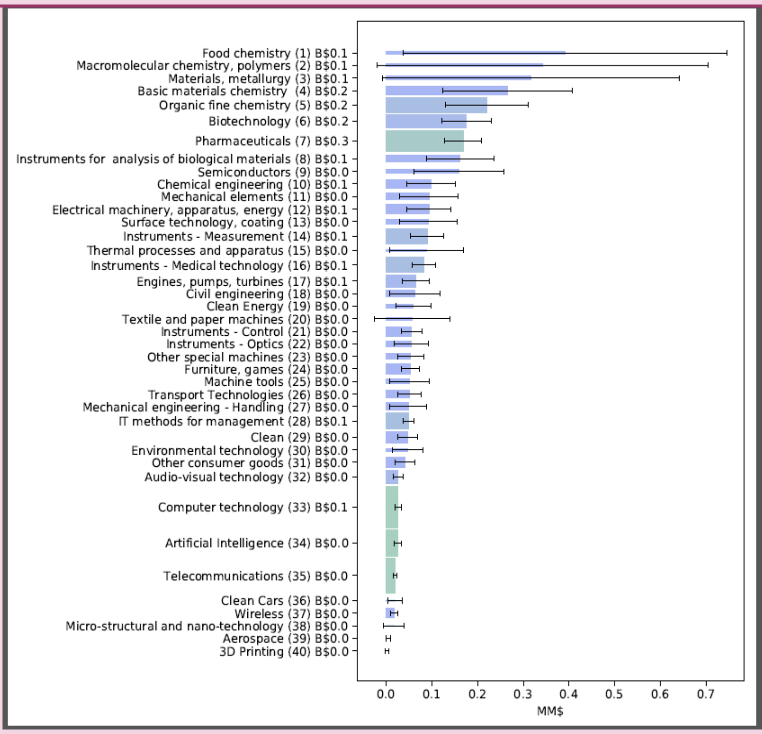
Note: In panel 1 the London value indicates spillover flows within London. In panel 2 the London value indicates flows from London to the rest of the UK; Other UK is the spillovers flows within the rest of the UK.

The finding that there is a good research base within London is then paralleled by a wider ecosystem of incubators, SMEs involved in the supply chain to the sector and large multinational businesses. The strong presence of multinationals in the city might be part of the explanation as to why London innovation generates on average, high levels of global spillovers, because these multinationals are able to help the diffusion of knowledge of international borders (Shireen 2011). Interviewees reported that the wider, global impact of the city in this sector is pronounced. For example, in the biotechnology sector, innovation is not just about labs and chemistry; it is also about the broader economy and how to capitalise on London as the biocentre of the EU and bring employers or employees into London, such as the presence of multinationals with global innovation footprints.

Figure 4.8: Value of the Spillovers within and from London, all patents (2000-2014)

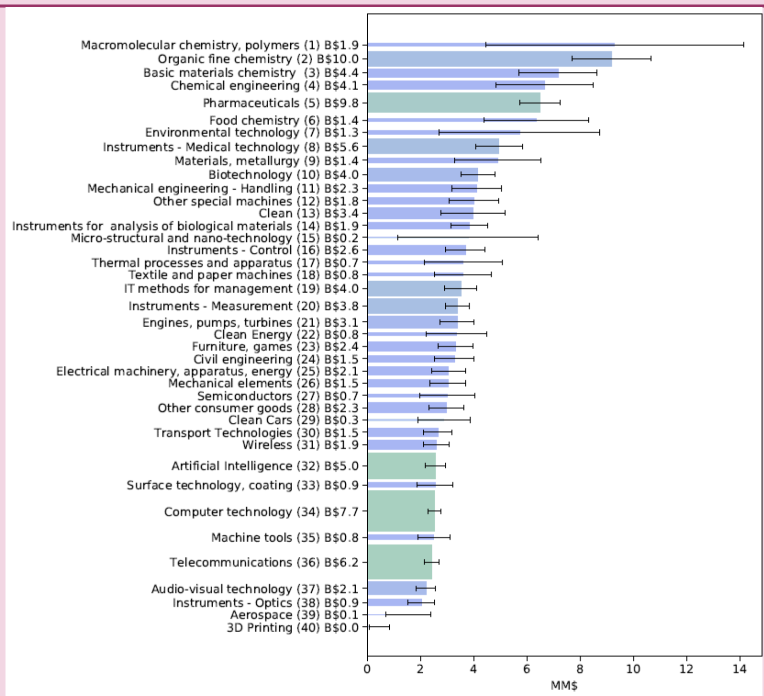
Panel 1: Spillovers within London

- Using new method – called patent rank – to measure spillovers that tracks patent citations both directly and indirectly (where an idea feeds into an interim set of patents)
- This provides powerful evidence of the implementation stage of diffusion
- Figure shows the value of spillover flows within London, where both the originator and recipient are in London
- Biotech and pharma are high, but more modest in engineering including AI



Panel 2: Global spillovers from London

- Necessarily the London spillovers will be smaller than the global. The figure highlights $1.9bn from Macromolecular chemistry and polymers-20 times greater than spillovers in London
- Evidence on the value of patents is derived through econometric analysis of the change in share value as patents are published
- The flow of value from ideas that enter into the patent can then be backed out using citations



In Figure 4.8 the technology classes responsible for spillover generation in London are examined. Panel 1 presents the spillovers within London (i.e. where the beneficiary of a

London spillover is directly or indirectly another innovator in London) and Panel 2 looks at spillovers from London irrespective of the recipient location. Macromolecular Chemistry is among the top 3 in both cases in terms of average spillover value. In terms of total volume of spillovers generated, Pharmaceuticals is dominant irrespective of the level of internalisation and generates more than $300mil worth of spillovers within London and just under $10 bn overall.

Modelling policy impacts

The presence of knowledge spillovers implies that the private sector underinvests in R&D which is therefore the primary motivation for government involvement in this field. The results so far have indicated that spillovers vary considerably between different sectors which in principle can provide a justification for the so-called vertical intervention where the government specifically targets some types of sectors or firms over others.

However, to consider the impact of policy, the varied sectoral responses must be taken into account. This is achieved by examining the effect of a hypothetical policy experiment: what would be the marginal response to a given amount of government research subsidy across technological fields? The answer to this question is analysed by fitting a structural model to the database of patents and private values that have been used above. In this model, variation in two factors between different technologies is allowed. A first is the average R&D investment required to generate a new innovation. Secondly, an idea generation function is modelled: some sectors may have larger amounts of unexploited positive ideas than others and so, holding all else equal, government funding should be able to unlock more of these positive ideas.

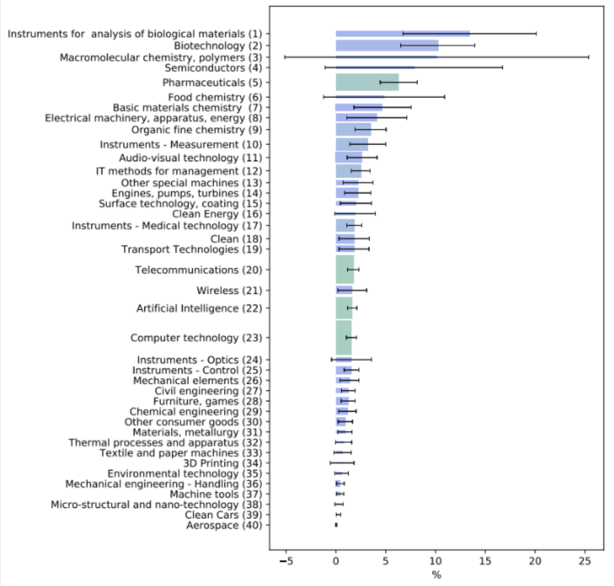
Figure 4.9 reports results from this exercise, showing the social return (in %) to a given amount of extra government R&D spending across technologies. Social return is defined here as the increase in business profitability (based on actual or simulated stock-market valuation) accruing to businesses in a particular geography, including all spillovers. The results differ if spillovers are only considered between London inventors (Panel 1) compared to national spillovers within the UK (Panel 2). Also note that the returns are naturally much higher if national spillovers are taken into account. Instruments for the analysis of biological materials has the largest social return in both cases with a local return of nearly 15% (on average) and a national return of more than 40%. Biotechnology and Macromolecular Chemistry are the runners up when looking at localised returns. Pharmaceuticals replaces macromolecular chemistry when considering the national social return.

While there is some overlap in the ranking between panels 1 and 2, there is also a good amount of divergence. This can be used as a motivation for having a localised industrial policy. If the ranking of returns were the same, it would suffice to have a national one size fits all industrial strategy. On the other hand, taking into account differences between the national and London perspective, there might be a case for London to focus on semi-conductors, macromolecular chemistry or food chemistry which are all further behind in the national ranking (of course assuming that at the national level a strategy guided by the national level ranking is pursued).

Figure 4.9: Social returns to government R&D support across technology fields

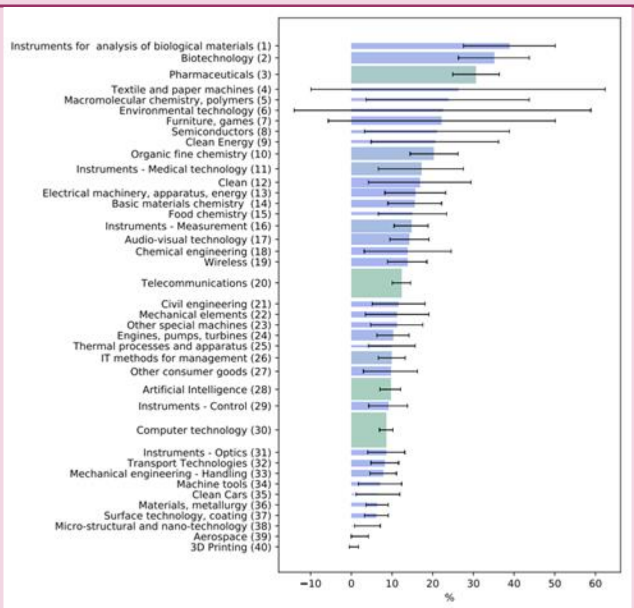
Returns internalised within London

- Plot indicates the marginal social impact of R&D subsidies across technology types
- Depends on spillovers, adjusted for the private returns and business responsiveness to subsidies
- It is noticeable that the variation seen in spillovers above, when costs are deducted, mean that impacts sometimes are significantly different from zero
- The variation in marginal impacts reflects that some classes have a few very successful patents and many less successful



Returns internalised within the UK

- Moving from London impacts to national impacts greatly increases the case of support overall
- Unlike in Panel 1 pharmaceuticals is among the top 3 areas in terms of social returns



Conclusions

This chapter presents evidence about the diffusion and innovation spillovers from London ideas. It uses evidence from the interaction of UK universities and businesses and the results from a survey of universities on this topic.

- London has a strong record of income from consultancy, probably reflecting the large number of headquarters in the city. IP revenues are also strong, suggesting the city's universities are able to commercialise the IP outputs of R&D.

- A university's research diffusing into businesses is often through the starting up of businesses or spin-off businesses from higher education institutions. Spin-offs (with HEI involvement) exhibit a positive correlation with research quality and London's best performers are Imperial and UCL.
- London's best performers for student start-ups – RCA and Kingston University – have programmes that support their students towards setting up business, more to use their training than their research. To some extent, this is a very common and standard form of diffusion from universities, namely the skilling up of entrepreneurs.
- On staff start-ups, London's best performers are Queen Mary and UCL.

The evidence then looks at measures of the spillovers from innovation which traces patent citations as an underlying idea spreads into other patented innovations. As there is also analysis about how much value is added with the release of a patent to listed buildings, the citation indices can also be valued:

- The average value of spillovers from London patents is high, as high as the US which tops this indicator and higher than the rest of the UK.
- The value of the spillovers from patents originating from London was $47bn, about 5% of the US total and about 11% of the rest of the UK.
- Biotech and pharma are high. After these technology areas, in terms of patent spillover value from London, lies computer technology, telecoms and AI.

Analysis can also be undertaken comparing the value of spillovers and private value from a patent with the typical R&D costs associated with the patent. This can then assess the marginal social value and whether there is a case for public subsidy to compensate investment into an idea for the spillovers beyond the private value:

- The modelling is indicative of the case for policies encouraging R&D investments at a London and national level.
- There is a case for city-level policies for some technologies like life sciences, and fundamental research on macromolecular chemistry.
- Telecom-related technologies prove to have a more persuasive case for support from the national perspective. Spillovers accrue for these technologies outside of London as many businesses in the sectors that innovate in this class are located outside of the M25 and benefit from ideas originating in London. Artificial intelligence and computer technology may have a similar case from the national perspective.
- There are some technology classes – the "clean" class of technologies which deals with products that reduce negative impacts on the environment – where there is an overlap between significant spillovers and the delivery of sustainable growth agendas of city authorities such as the GLA.

This analysis of spillovers has shown that London is responsible for substantial amounts of knowledge spillovers, however there are significant differences between different technology types and by industrial sectors, providing a case for targeting limited (local) government resources for R&D. A key consideration is the government's objective function and whether it accounts for global, UK wide or only within London spillovers. Therefore, a calculation of returns to government R&D support was provided for each case.

5. Policy Levers to Diffuse Innovations

The existence of a significant tail of low productivity businesses in the UK drives a policy interest in innovation diffusion. Interventions that can encourage wider and faster adoption of technologies and organisational best practice can raise overall productivity. This chapter reviews the policy options to support this aim, looking at whether they might be considered suitable for London.

The chapter considers the following evidence:

- The justification for policies to encourage diffusion
- Levers to address diffusion barriers in seven policy areas, assessing their effectiveness and applicability to London

Justifying policy action in diffusion

The promise of greater profitability and the nature of competition will mean businesses have incentives to improve their productivity using new approaches, and hence new ideas and technologies can spread even without policy action. However, where there are market imperfections, there may be barriers to adoption that policy levers could seek to address (OECD, 2013a and chapter 2). Key examples include lack of information on the relevant best practice and financing constraints that prevent businesses making new investments. Such barriers tend to apply in particular to smaller firms. The first justification for policy action is therefore to address market failures that prevent the diffusion of innovation in the economy.

A second motivation for policy action on diffusion is the desire to maximise spillovers from innovation. In the same way that spillovers can justify public sector support for R&D, tackling absorptive capacity constraints would represent a complementary policy at the adoption stage. This would help maximise the diffusion of innovation into the everyday economy, with associated productivity benefits. It could also increase demand, which in turn could also stimulate additional innovation.

Thirdly, policy action is justified in parts of the economy where the public sector is active, and therefore government procurement decisions can create incentives for innovation. For example, the GLA is responsible for public transport and so has an interest in how the adoption of new technologies can improve public services (Peter et al., 2013).

Policy responses to promote innovation diffusion

Seven policy areas (PAs) where particular levers might be deployed to promote the diffusion of innovation in the London context are reviewed. For each, the evidence on likely effectiveness based on evaluations or case studies from the UK or abroad is set out, as is some evidence from the stakeholder interviews. This discussion is then linked to the barriers for adoption and the different stages of the adoption process at which barriers can materialise. The early adopter is constrained if there are delays in finding out about innovations or if the research into a new approach is undertaken in a closed innovation system where the derived knowledge is not shared widely. Such an issue was reflected in discussions with stakeholders.

Barriers more relevant for later stages in the adoption process include those related to market conditions. Adoption of innovative technologies or practices may require new skills, the existence of complementary infrastructure (e.g. broadband) and the appropriate regulatory structures (e.g. data security).

Policy area 1: Collaborative research and research settings

In the UK there is substantial public support for R&D and government has committed to raising R&D as a share of GDP to 2.4% by 2027. Research Councils fund R&D in higher education institutions, Innovate UK provides support to businesses and firms are provided with tax incentives for R&D. Earlier chapters indicate London's importance in generating ideas. The analysis of spillovers has shown that London is responsible for substantial amounts of knowledge spillovers. However, there are significant differences in this between different technology types and by implication industrial sectors. This provides a case for targeting limited (local) government resources for R&D.

What is most interesting from a diffusion perspective is how research design including the setting where research is undertaken can aid the transfer of knowledge from research to business. Approaches include promoting collaboration in research and the sharing of facilities. These policies tackle the barriers faced by businesses in **accessing information about innovation** and **increasing business absorptive capacity**.

A number of policy mechanisms can facilitate collaboration between research bodies, innovative firms and firms on the adoption pathway. The box on testbeds (below) provides some examples. Demonstration facilities, or testbeds, allow business and production processes to be explored in a real-world environment (BMWI, 2019), minimising risk through testing (OECD, 2019). They are often located near universities, with shared facilities and provide a means to translate research outputs to products and services.

The Catapult network was initiated following the Hauser Review, which reviewed the impacts of comparable organisations around the world (Hauser, 2014). That evidence supported other countries' experience of institutions focused on the collaboration and technology transfer between universities and industry. A recent evaluation of the Catapult network has been carried out by Ernst & Young (2017), suggesting that they "have the potential to drive innovation and economic benefit to the UK", but governance, evaluation and collaboration between centres could be improved.

Testbeds and supply chain support to enhance research diffusion

Interviewees viewed innovation testbeds such as the Nesta Testbeds as stimulating innovation. Where it is difficult to test in live systems, such as in large-scale transport systems, testbeds replicate the conditions needed to perform tests without any disruption. Positive examples provided by individuals consulted for this study are technologies to measure air quality in Greenwich and in Queen Elizabeth Olympic Park.

In 2016 in the UK the NHS, in partnership with industry, created a testbed for digital technologies to facilitate service delivery. After this trial, successful innovations were then made available to the NHS. Such testbeds have also been pivotal in the diffusion of innovations such as self-driving vehicles in Austria ALP Lab, DigiTrans (OECD, 2019).

Another way to enhance research diffusion is through the establishment of an incubator or accelerator programme to engage with innovative start-ups at their early stages of development by providing them with support for a certain period. Walmart has created Store No. 8, a technology start-up incubator located in Silicon Valley. It aims to identify new technology developments that will reshape the retail industry. The incubator is also seen as a tool to attract new digital talent (OECD, 2019) and hence the potential for further innovation.

Universities are strong at multidisciplinary and business collaborations. London's RCA does this via Innovate RCA, which is a centre for enterprise and entrepreneurship and has helped to launch 56 start-ups thus far. The university also has SME support and mentoring, providing targeted support such as reviewing graduate design outputs to check for IP protection needs.

Policies supporting collaborative research can be a means to encourage business to business and university to business diffusion. Funding has recently targeted supply chains. The Advanced Manufacturing Supply Chain Initiative has primarily focused on supporting research and development, skills training and capital investment to help UK supply chains achieve world-class standards, so focusing on adoption in primes and in their supply chain. Early evaluative evidence suggests that effects are additional and about half of the diffusion facilitating R&D would not have occurred without the policy (BIS, 2015).

Other schemes include University Enterprise Zones (UEZ), where Farla et al (2018)'s interim evaluation of the initial pilot of 4 UEZs indicates early positive impacts on business-university engagement. Government recently announced an extension to this programme, with 20 new zones. More generally, the literature on incubator schemes suggests that university involvement improves outcomes for firms (for a summary, see Madaleno et al., 2018).

Application to London

On settings for research, London is performing well. There are two Catapults located in London: Future Cities and the Digital Catapult. Each provides access to testbeds for the sectors they focus on. In addition, London has numerous incubators and research facilities, often providing space for SMEs and start-ups.

Interviewees, however, saw a gap in the settings for research available for innovating in delivering public services in London. This would support the GLA's delivery of these public services. A possible area was the circular economy, where policy could drive innovation and diffuse technology into the construction sector. An issue is whether developers understand or demand this technology. This could tie into London's strengths in design, with a focus on materials used, alongside user experience design issues and intelligent mobility, to diffuse best practice designing products following innovations.

Initiatives to enhance diffusion in supply chains has limited research, but evidence indicates potential. The barrier is that frictional costs, inevitable in complex supply chains, prevent the co-ordination and collaboration needed to adopt technologies. The policy intervention is support for collaborative research, often using a mix of loans and grants, targeting capital intensive sectors where access to finance is an issue. For London, lessons from advanced manufacturing may read across to construction where the GLA has a key role and where a drive to diffuse technology through collaboration is marked.

Recommendations:

- The GLA explores options to support supply chains in collaborative research, particularly targeting the sectors – such as construction – where access to finance may enable greater adoption of technologies
- The GLA could review the potential for testbeds and incubators associated with R&D in GLA policy and delivery priorities, with circular economy technologies being a potential area.

PA2: Knowledge Transfer

A number of policy mechanisms can aid the transfer of knowledge from research to business, ranging from deploying researchers into businesses through to awareness raising or sharing facilities. Research bodies have also developed intellectual property (IP), which then create spin-outs to commercialise the IP. Like the policies that enable the diffusion of innovation into the economy, these policies tackle the barriers faced by businesses in **accessing information about innovation** and **increasing business absorptive capacity**.

Case studies of awareness raising policies

There are a number of international examples of awareness-raising schemes aiming to inspire firms to engage in digital transformation by diffusing lessons learned by similar firms. In France, Germany and Japan there exist virtual maps with exemplar SMEs in different sectors. The focus is digital technologies, with SMEs engaged in Industry 4.0 transformations. Such maps allow first-hand experiences of the benefits and challenges faced by firms, alongside how such issues were addressed and overcome (OECD, 2019).

In Italy in the Friuli-Venezia Giulia region, the Industry Platform 4 FVG offers businesses access to testing equipment, prototyping tools and demonstration labs (Salvador, 2019). Similar facilities have been introduced in Germany through the SME 4.0 Competence Centres. This facility offers small and medium-sized companies access to demonstrations of Industry 4.0 technologies such as 3D printing to increase technological adoption and hence the diffusion of such technologies to SMEs, which would not have ordinarily had access to such technologies (BMWI, 2019).

Direct support for diffusion is provided via Innovate UK’s Knowledge Transfer Partnerships (KTPs). Funding researchers to work between a business and a university can enable academic outputs to be translated into a business. WECD (2015) and Regeneris (2010) evaluated the impact of KTPs finding they increase the absorptive capability of businesses, allowing them to introduce product and process innovations leading to productivity improvements. A recent development has been to select businesses for KTP participation by asking about applicants’ productivity and then targeting KTPs at those applicants in the middle of the productivity distribution (so not at the productivity frontier) and likely to improve through knowledge transfer.

Interviewees observed a need to marry up the technical knowledge from research with business skills, enhancing collaboration between business and science schools. Innovate UK is now supporting KTPs focused on management, seeking to partner businesses with associates based in management schools. The support is less to embed a technology or new process, but to promote business changes as adoption occurs.

Peer networks are important drivers of innovation diffusion between organisations interviewed for this study. They share ideas, increasing business demand for R&D and collaboration (House of Commons, 2017). There was a recognition that business models are diverse, and the peer network can accommodate this. An example of effective peer networks is the RCA working with global companies and their inclusion of RCA alumni. The arts sector is characterised by a large SME and freelancer community, with peer networks providing routes for diffusion. Evaluation evidence on networks include Van Cauwenberge (2012), studying the PLATO Network in Belgium, and demonstrating an increased productivity which is attributed to the creation and diffusion of knowledge.

Application to London

There is evaluation evidence about the value of specific support for knowledge transfer, such as KTPs or collaborative research. For London, a first step to encourage awareness and so use through peer networks or other collaborations across relevant stakeholders.

Collaboration between key stakeholders has a positive effect on innovation diffusion identified during interviews of stakeholders. Currently the London Infrastructure Plan, which is a joined-up approach across different parts of the public sector such as housing, transport and green infrastructure, is effective in allowing the sectors to come together and to think about the different long term needs and costs, therefore enhancing collaboration and innovation. This collaboration has also seen management practices being shared, increasing knowledge transfer through project collaboration.

There is some evidence about the benefits of collaboration networks between London universities. For example, the RCA collaborated with universities outside London on design aspects of urban renewals for Battersea and Wandsworth Borough Councils. This collaboration also has the effect of being the bridgehead to crossing culture collaboration.

Recommendations:

- There are discipline-based peer networks that the GLA might engage with, either convening or supporting the networks acting across research bodies, policymakers and industry
- Convening or supporting the development of networks across different sectors, across supply chains or between researchers and industry may also be helpful to enable wider innovation diffusion.
- GLA considers develop funding opportunities with Innovate UK for knowledge transfers and increase awareness of opportunities such as KTPs.

PA3: Skills and training

Training and skills development help address the barriers faced by businesses in **accessing the skills needed to adopt new technologies or work practices.** One of the key reasons that innovation fails to diffuse evenly across the economy is because of the absence of the right skills (OECD, 2019). A number of studies in the economics literature link skills to technology adoption. When a new technology becomes available, it is not adopted immediately by all agents, rather it is adopted in environments where complementary factors are cheap and plentiful. See for example, Beaudry et al. (2010) which finds that US cities with low skill premia adopted computers more intensively. Feng and Valero (2019) find that firms closer to universities, and hence facing a higher supply of skills, employ more skilled workers and have better management practices (Bloom and Van Reenen, 2007).

At the management level, innovation diffusion is often constrained by the business leadership having weak management practices. Recent evaluations, such as the ERC (2019) study of Goldman Sachs' '20k Small Businesses' and evidence cited by Be the Business (BTB) have shown positive impacts from leadership training. This could be specific to a business growth priority, such as the need to know how to do business across cultures. Some institutions have recognised this need and created training schemes on specifics, such as how a research body could spin out an entity where there is interest from abroad, and navigating across cultures becomes essential (Refs BR24, BR26, BR27).

Targeting SMEs with leadership training has been the focus of BTB, which offer an executive training course, giving SMEs access to expertise from large businesses. There is also a mentoring programme, linking an SME leader with a mentor working in large companies which is currently being evaluated. The benefits of this type of support were reinforced in the interviewee responses, who observed how mentoring advice drives business ideas. For early stage businesses, interviewees mentioned that courses are effective [for stimulating business ideas].

The Mayor's Construction Academy (MCA) established in 2018 with the aim of helping Londoners train in the skills necessary to access construction sector vacancies on housing construction sites. The rolling out of higher standards in construction may necessitate public-funded training to encourage the adoption of such innovative technologies. Policies targeting particular sectors are often also defined using evidence on where a local area has particular innovation advantage and the earlier analysis of spillovers – while focusing on sectors that use patenting as they innovate – does indicate that London differs in the technologies where innovation spillovers are high from the rest of the UK and this may assist in targeting sectoral interventions.

Readying employees for new techniques

The box focuses on an example of staff training supporting technology diffusion. Malaysian public hospitals introduced a Hospital Information System (HIS) to accommodate an escalating number of patients requiring public medical services (Ismail et al., 2015). There was low adoption of HIS (15.2%), despite proven value through the use of enhanced IT applications. Evaluation found that the most effective diffusion policy was improving skills leading to uptake. In another key study in the public sector setting, Garicano and Heaton (2010) find evidence of complementarity between IT and skilled workers in US police departments.

Application to London

Since August 2019, the Mayor is responsible for the commissioning, delivery and management of London's Adult Education Budget, with sectoral priorities and digital skills met through the Skills for Londoners Innovation Fund. The increased local level planning for skills offers opportunities to encourage adoption designing into training the skills needed to deploy innovations or use best practice. This can range from management practices (see for example Bloom and Van Reenen, 2007, about the positive correlation between workforce skills and management practices) to digital skills important to enable adoption of digital technologies.

As an advanced local government body with strong capabilities, the delegation of training will provide an opportunity to place local knowledge of innovation strengths and weaknesses at the centre of policy making. There will also be a need to maintain and develop the capabilities, such as through routinely evaluating policies about whether they achieve the desired innovation adoption aims.

Recommendations:

- Training around new technologies combined with the increased delegation to the GLA of training responsibility provide an opportunity to design into skills development technology adoption. A first step is to support Adult Education Budget action plans with evidence to target where innovation diffusion can be supported, perhaps looking at technologies where London's spillovers are high.
- New training programmes should be designed with evaluation in mind to add to the body of evidence of what works.

PA4: Financial incentives

Financial incentives such as subsidies and grants can encourage innovation diffusion. The focus of these policies is usually to increase access to finance barriers, decrease risk aversion and to finance the costs of investment in new technologies and/or associated restructuring. Hence this is related to **improved business absorptive capacity**, meeting costs to ready a business for adoption, but financial incentives can also be used to nudge firms to use and **access information about innovation.** Innovation vouchers are non-repayable grants provided to SMEs, used to purchase services from knowledge providers to introduce small-scale innovations. The box provides a place-specific example from Ireland. In the UK, two large voucher schemes have been tested in the last decade: the creative voucher scheme and the growth voucher scheme.

The Nesta-funded creative voucher scheme provides small businesses in Manchester with funding to purchase services from other local creative businesses. The pilot focused on the creative sector as there is a body of research to suggest that the purchase of creative services is linked with higher levels of innovation.

An evaluation of the pilot, which followed a randomised experiment model, found that being awarded a voucher increased businesses' use of creative services by 84 percent (Bakshi et al 2013). This was also predicted to increase their likelihood of introducing product and process innovations and reporting sales growth. It did not, however, lead to a permanent increase in innovative activity among those firms that participated. Suggested future versions of the scheme should follow a brokerage model to facilitate the relationship between SMEs and creative suppliers (Spencer Thompson et al, 2016).

The Growth Vouchers Programme (GVP) was a randomized control trial rolled out in the UK between 2014 and 2015, which offered advice and vouchers to over 10,000 small and medium-sized enterprises to help them purchase further business advice. Vouchers could be used on five themes of advice: sales and marketing, raising finance, leadership and management, expanding the workforce and digital technologies. The impact evaluation is currently being revised, however initial findings suggest use of the voucher is associated with improved capability in the areas of "people management" and "developing and implementing a business plan", though not in the other capabilities surveyed. In terms of observable 'hard' impacts, the only area where there is an observable difference as a result of receipt of advice is in terms of reported turnover growth. The use of Growth Vouchers has however played a role in increasing the appetite for seeking advice and paying for it in the future. These results suggest that financial incentives in the form of vouchers are not enough to nudge businesses to adopt new ideas and practices, but they can be a good way to increase access and appetite for information about new ideas and practices.

Policies use finance to act as a 'pull factor' towards innovation diffusion. Wide-ranging integrated development policies with a diffusion focus have been pursued in developing countries. In more advanced economies, taxes function as a 'push' factor away from non-innovative alternatives and were suggested by the interviewees as options to enhance

Place Specific Incentives to test vs large-scale support

In Ireland, there exists a trading online innovation voucher scheme which assists SMEs in developing their e-commerce capabilities by providing up to €2500 to match their own funding (DCCAE, 2018). To adopt innovation, often this requires firms to acquire innovative digital technology. By governments providing financial support for digital technology, this enables SMEs to fully engage in a digital transformation.

innovation diffusion (DR29). Schwoon (2006) explains the impact of taxes on conventional cars to drive innovation diffusion of fuel cell technology. Similar interventions are common in the UK, encouraging diffusion particularly at consumer level (e.g. Transport for London and Borough level charges on vehicles, incentivising low pollution technologies).

Application to London

Evaluation evidence suggests that vouchers have mixed impacts: they do increase innovation activity through sustained innovativeness translating to more long-term outcomes putting businesses on higher productivity trajectories. This lever could complement other digital skills initiatives, such as the Mayor's Digital Talent Programme, supporting investments in business capabilities that complement an incentive to adopt.

Recent GLA, London School of Economics, CognitionX and Capital Enterprise work, funded through BEIS Business Basics has sought to introduce AI technologies, targeting businesses in retail and hospitality. The experience from this should provide a good basis for widening the intervention, especially if it is possible to tackle some common issues such as difficulties in recruiting businesses to technology adoption programmes.

Recommendation: The GLA could consider innovation incentives for London businesses building in the lessons learnt and caveats from the Business Basics experience and the Growth Vouchers Programme.

PA5: Regulation

Government bodies, including at city level, often have regulation-setting powers. Uptake of technologies can be encouraged through regulations being updated regularly so that standards are based on achievable or stretching technology levels. This can address a diffusion barrier, that **legal and regulatory conditions** can deter adoption.

There may be some areas where this could help SMEs, as interviewees highlighted how smaller organisations can understand and assess local challenges better than larger government organisations and are therefore better at innovation adoption. There is an increased incentive to innovate as it provides an opportunity for a business to try new approaches.

The box considers some examples of regulatory policies to support diffusion. A regulatory sandbox provides an alternative, often less restrictive, regulatory environment, designed to encourage digital technology experimentation and adoption. The less restrictive environment provides increased flexibility for firms to test new products.

Regulatory policies are particularly important for stimulating innovation in highly regulated industries such as financial services, transport, energy and health. Interviewees for the study identified that there is an increasing recognition that competition does not only come from within a sector but also from larger organisations who are able to utilise the wealth of data and information they are able to access on the interaction between people and places. This creates a need to change the way that such information is understood [which may involve working with larger data companies]. There also is a role for regulatory bodies to allow managed increases in access to data. Sandboxes for Transport for London's travel data provide controlled access to data to allow developers to experiment in ways that would require further data protection should there be widespread adoption.

Regulatory improvements may sometimes be required because of the pace of diffusion, with public bodies reacting to the rapid spread of new approaches. A good example of this is the response to the sharing economy. Innovation by Airbnb, for example, enables homeowners to capitalise on their unoccupied homes or rooms through short-term rentals. This is often advantageous for the customer where it is cheaper than other

Regulatory changes facilitating or responding to diffusion

The Financial Conduct Authority in the UK pioneered this approach upon launching the fintech regulatory sandbox, encouraging innovation in the field of financial technology (OECD, 2019). It is early in this policy, but the approach has been to support SMEs in a sandbox that provides access to banking data to develop new services and technologies using the data. While not evaluated yet, it is being taken up by other bodies and may offer some lessons for other regulators, including city bodies.

For the sharing economy, the District of Columbia pioneered regulatory changes designed around innovative aspects of the travel apps, e.g. Lyft, Uber and Sidecar. Under this bill, Uber drivers are mandated to be over 21 years old, have no criminal record, have adequate insurance and have their vehicle inspected on an annual basis (Ranchordas, 2015).

accommodation (Fang et al., 2016), but disadvantageous for local hotels and licenced B&Bs who suffer from lower income. Wider concerns include impacts on the availability of rental property.

The sharing economy exemplifies another dimension to regulatory policies and innovation diffusion. There is sometimes a conflict between the need to encourage innovation and the need to protect consumers from unfair conditions of service, workers from negative labour market effects and other businesses from unfair competition. Innovation can rapidly diffuse, undercutting traditional industry, instead of making traditional industry more productive (Ranchordas, 2015). Ranchordas (2015) suggests that tackling this requires the establishment of broader, principle-based regulation specific to the sharing economy. This approach has informed London’s steps in this area, simultaneously protecting existing industry, maintaining quality and productivity while protecting consumer and worker rights.

Application to London

The GLA is a statutory body enforcing national and city-level regulation in many spheres of policy. In some areas, such as transport, construction and planning, there is a strong technology focus to this. The encouragement of technology adoption is a key lever for the city to meet objectives and, alongside incentives (PA3), regulatory levers are commonly used.

Key to considering how regulatory levers might influence adoption in London is to carefully define the scope of any new initiatives, over and above systems already in place. Regulation change is a significant and complex process, involving its own evidence gathering, consultation processes and then various legal and enforcement levers being implemented. Where there is a technology dimension, these processes would inform changes so that London's businesses and other bodies are encouraged to use best practice. The evidence suggests there is a role for opening up data, as it can facilitate information focused innovation being integrated into services. There are several borough and city-level initiatives to enhance the provision of data to city bodies as they undertake regulatory duties such as in planning processes, licensing, building regulations. Also, widening data usage will involve steps that should complement the existing regulation policies. This will usually be in areas where regulatory changes are planned, so that innovative data use can parallel and support changes.

Recommendation:

- The GLA may review how to ensure diffusion is encouraged as regulatory powers are being used, especially focusing on data and digital innovation such as the Smarter London Together Plan.
- The GLA can then consider where regulation development would be paralleled by environments (sandboxes) for the development of innovative uses of data. The GLA could integrate the technologies where the city has comparative advantages into this targeted use of regulatory sandboxes.

PA6: Procurement & Innovation Policy

The procurement of goods and services by public bodies can incorporate the latest techniques to provide incentives to suppliers to adopt technologies or best practice. This can parallel standard setting.

A good example is in the construction sector. Building Information Modelling (BIM) is a form of technological innovation, which provides a digital representation of the building process, to facilitate exchange and interoperability of information in a digital format (Forbes and Ahmed, 2010). BIM technology enables modelling to visualise how the construction will change over space and time (Buchmann-Slorupp and Andersson, 2010). This technology increases feedback opportunities, planning efforts and the quality and validity of plans produced, whilst also improving project time, performance and predictability (Gledson and Greenwood, 2017).

The Cabinet Office reviewed BIM and recommended that BIM uptake should be increased over a three-year period as part of a plan to improve the performance of government estate in terms of costs, value and carbon performance (BIM Industry Working Group, 2011). The government construction strategy stated that the Government requires fully collaborative 3D BIM as a minimum standard by 2016 (HMG, 2011). However, despite such policies, the diffusion of BIM is not automatic and environmental conditions such as low industry profit margins and attitudes to risk may continue to limit diffusion and hinder innovation adoption (Gledson and Greenwood, 2017).

In addition, procurement can be used for policy experimentation of innovation policy. Bravo-Biosca (2019) reviews the state of innovation policy and argues that, if the main aim of innovation policy is to support experimentation with new technologies, products, processes, or business models, and accelerate their diffusion throughout the economy and society, paradoxically, innovation policy itself is not very experimental. The GVP described above is a great example of how a business support program can be conceived as a policy experiment. Procurement can be leveraged to drive experimentation in innovation policy in continued collaboration with IGL.

Application to London

The scope for integrating diffusion levers into procurement may be greater than for other city-level powers, such as regulatory changes. Procurement by the GLA and other London public bodies can provide a market to businesses that are adopting technologies. Clear, achievable and high technology levels in procurement can widen adoption.

Recommendations:

- The GLA can make more use of procurement to set technology standards of suppliers.

Where procurement is a lever to diffuse best practice, by setting requirements in line with technology frontiers where appropriate, GLA procurement will more routinely look forward, defining the innovation needed to compete in future procurement allowing businesses to prepare/adopt. The GLA team can then convey these to the networks, and facilitate the interventions needed (R&D, knowledge sharing, training, etc) through networks.

The evidence base on innovation and innovation diffusion will then become important. This study has found that evaluation evidence on adoption is sparse and, the procurement effectiveness could be aided if the monitoring and evaluation of any initiatives can then feed back into the procurement process, testing whether London's use of suppliers is encouraging adoption and use of best practice.

Recommendations:

- The GLA's procurement should more routinely be evaluated for its innovation adoption impact.
- Innovation policy development would be assisted be a general aim to enhance the evidence on adoption, using robust evaluation approaches including experiments.

PA7: Place-based interventions

Place-based interventions such as building or strengthening innovation clusters are closely linked to innovation diffusion. This involves investments such as the establishment of technology transfer offices, science parks or incubator facilities to translate research into marketable innovations in close proximity to research centres. These mechanisms seek to address a **number of barriers to technology adoption**, in particular the lack of information and skills.

However, cluster policies, even light touch ones, can have unintended consequences and highly uneven distributional impacts. Nathan (2019) evaluated the impact of the Tech City programme in London. He finds that the policy increased cluster size and density, especially for ‘digital tech’ plants, where revenue/worker and high-growth firm activity also rose. But for a larger set of incumbents ‘digital content’ plants, the policy also led to de-concentration and lower revenue productivity. He concludes that even light touch cluster programmes require cautious implementation.

With respect to the role of research universities in particular, it has been argued that it is their complex, inter-related features that have been crucial for their success as sources of new knowledge and hubs that connect disparate parts of society (Owen-Smith, 2019). Interviews with stakeholders indicated examples. The inter-relatedness is evident in Boston, the current leader of life sciences, where the clustering of universities and businesses in the Life Sciences Corridor allows for enhanced collaboration which in turn, encourages innovation.

Application to London

There is a growing body of evidence about London’s place-based intervention where a focus has been innovation.

A successful localised scheme in London has been the Knowledge Quarter (KQ) of Camden/Islington, with recent Science and Innovation Audit (SIA) evidence highlighting the scale of the innovation capacity (as described in the box).The audit described the KQ as a magnet for business due to the highly skilled workforce linked to institutions that undertake world-leading scientific research. The KQ has also been considered an innovation district, “an enclave that merges the innovation and employment potential of research-oriented anchor institutions, high-growth firms, and tech, and creative start-ups in well-designed, amenity-rich residential and commercial environments” (Katz & Wagner 2014).

The KQ is also a leader in the number and value of research; number of highly cited publications; number of patents awarded; number of drug discoveries; and number of start-up companies, including university spinouts. The SIA cites the knowledge ‘spill-over’ evidence as the “large supply of highly-skilled graduates, postgraduates and postdoctoral researchers (in total, circa 30,000 per year), many of whom go on to work outside the KQ; and also the founding of highly innovative businesses, which settle elsewhere in London or other parts of the UK” (BEIS 2019). Additionally, “KQ’s universities have been responsible for spinning-out more than 100 small businesses in recent years” (BEIS 2019). Interviewees familiar with the KQ focus in the biotechnology sector highlight that innovation is “not just about labs and chemistry”, but also about the broader economy and how to capitalise on London as the biocentre of the EU and bringing employers or employees into London.

London is home to world class research universities, as is evident from the data presented in Chapter 5, performing well on a number of metrics of collaboration with industry. Also, London has long been a magnet for top international talent, in industry, academic and the arts. Human and knowledge capital is key for innovation but also its diffusion and creating

Innovation audit for London's Knowledge Quarter

London's Knowledge Quarter builds on the area's universities and cultural institutions clustered around the Kings Cross transport hub, but with much of its growth more recent especially the transformation of the area with commercial investment by firms such as Google, and the advent of new institutions, such as The Francis Crick Institute. The next phase for KQ is focused on projects which target diffusion, progressing policy levers that are identified in the rest of this chapter:

- Developing a start-up ecosystem led from University College London and City University
- Specific projects to share knowledge involving peer networks
- Investing in facilities focusing on healthcare where KQ has innovation strengths

A focus for KQ has been to provide a world-class resource for innovation and research commercialisation and the recent Science and Innovation Audit indicates the assets and capabilities providing this. In particular, the study tests and provides evidence on two hypotheses: that close proximity in an urban setting facilitates open innovation and the importance of place-based network brokers, facilitating relationships across peers, including the Catapults, learned bodies, sector bodies, academia and industry.

spillovers in general (Moretti, 2004). While National Government will set the UK's new immigration policy in light of the Brexit outcome, the GLA can use its powers to ensure that London continues to be an attractive place to live and work.

Recommendations:

- The next Mayoral Development Corporation spatial investment should consider the lessons from other innovation clusters in London for the East Bank Development with its focus on a culture and education district.
- The GLA can use its convening power to promote information sharing between London Universities and London industry, highlighting examples of successful collaboration, and opportunities from both sides.

Conclusions

The previous sections have introduced policy levers in terms of the adoption barriers that they address, exploring evidence about their effectiveness. The sections have then indicated the applicability to London and for the GLA as a policy body. Table 5.1 summarises the recommendations.

In making recommendations, the analysis has balanced between three factors:

- Where the GLA has a power to either lead or participate in the use of a diffusion policy.
- Where there is evidence that the policy lever is effective in terms of diffusion.
- Where the lever has applicability for the specific London context in terms of the city's sectoral make up or innovativeness.

Lever		Description	GLA role	Recommendations	Effectiveness evidence
PA1	**Innovation policy**	Subsidy, loans and fiscal incentives for collaborative R&D		Encourage supply chain collaboration	Evaluation evidence
PA1	**Innovation policy**	Testbeds allow businesses to explore and test new ideas in real-world environments		Focus on one GLA delivery sector	Independent review
PA2	**Knowledge transfer**	KTP funding researchers to work between a business and a university		Raise awareness	Evaluation evidence
PA2	**Knowledge transfer**	Informing firms and entrepreneurs about the opportunities through peer networks		Focus on one GLA delivery sector	Evaluation evidence
PA3	**Skills & Training**	Diffusion of innovation through training around new ideas and management practices		Build on existing GLA policies	Evaluation evidence
PA4	**Financial incentives**	Enable SMEs to adopt innovations using small grants to secure advice or collaboration		Creative sector application	Evaluation evidence
PA5	**Regulation**	Use regulatory/sandboxes, apps/data access, to test new products or business models		Support data exploitation	No
PA6	**Procurement and Innovation**	Mission led bodies procuring with diffusion of technologies at the core		Standard setting and evidence gathering	No
PA7	**Place-based interventions**	Place-based package of interventions around anchor innovation bodies		Lessons from Knowledge Quarter	Review evidence

GLA Role: Green indicates across sectors there is a potential for GLA; amber that the role may be in some sectors; red are areas where other bodies lead the lever and GLA may influence this.

On innovation policy, the table highlights how the GLA is unlikely to have a role in the financial incentives to undertake R&D, such as tax incentives to businesses. Such policies are led by national bodies. Lower in the table, PA4, considers the subset of financial incentives that target diffusion, rather than supporting R&D more generally. Here, the GLA may progress policy more actively. Encouraging businesses to start on the pathway of adoption of new techniques through vouchers has been undertaken at city-level with encouraging results.

The potential to speed diffusion from research, especially in testbeds, can be at a city-level. There are facilities located in the city already and the GLA engagement with these bodies is important. However, testbeds are funded by central initiatives, especially because they often operate at a national scale. The amber rating indicates that there are sectors in which the GLA leads public service delivery – such as waste and re-use – and where diffusion is identified as valuable because innovation is occurring (in this example due to circular economy research). There may be some benefit from an active GLA role.

The GLA is the spatial planning lead for London, and so area-based interventions are given a green rating. The evidence from recent London schemes is encouraging also, with diffusion being central to the developments near Kings Cross. Also, as skills and training provision for adults in London is under the GLA, levers for diffusion could be developed either for specific sectors (low paid) or skills (digital). The green assessment also reflects a range of evidence about the effectiveness of interventions in this area.

6. Conclusions

Innovation diffusion is the spread of new products, values, policies or processes beyond the locus of their original success (Rogers, 2003). This study looks at innovation diffusion in London, providing evidence – from existing literature, empirical analysis and stakeholder interviews – about the importance of diffusion, policy levers that can be used to address barriers and areas the GLA might explore to target action.

Chapter 2 presents evidence about diffusion mechanisms and the barriers to diffusion. As businesses consider adoption, they may face market failures such as skills shortages, system barriers such as difficulties collaborating with research organisations and emergence failure, where the adoption of an innovation requires changes in numerous areas.

Chapter 3 presents firm-level evidence about productivity in London and beyond. It highlights that there are frontier businesses, but that there is also a tail of businesses that could benefit from adopting technologies and practices to raise their productivity levels. The chapter also presents new measures of London's innovativeness, categorised according to technology group. London's patents in computer technology, telecommunications and AI have most impact. IT methods for management is fifth in London, much higher than its rank of 26th in the rest of the UK. Compared to the OECD, London has a comparative advantage in 3D printing, pharmaceuticals and IT methods for management.

Chapter 4 considers evidence on knowledge transfer between research organisations and businesses and the spillovers from innovations produced in London. London universities have a strong record of income from consultancy. IP revenues are also strong, suggesting that the city's universities can commercialise the IP outputs of R&D. Spin-offs (with university involvement) exhibit a positive correlation with research quality and London's best performers are Imperial and UCL. London's best performers for student start-ups – RCA and Kingston University – have programmes that support their students towards setting up business. On staff start-ups, London's best performers are Queen Mary and UCL.

The chapter uses an innovative approach to value diffusion, tracing the citations of a patent and valuing this onward adoption of ideas. The average value of spillovers from London patents is high, as high as the US which tops this indicator and higher than the rest of the UK. The value of the spillovers from patents originating from London (2000-14) is $47bn, about 5% of the US total and about half the rest of the UK, with biotech and pharma particularly high. The value is slightly lower in engineering, including AI.

The analysis provides a case for public subsidy in some areas, encouraging R&D investments at a London level and at a national level. More specifically:

- There is a case for London policies for some technologies like life sciences, instruments and fundamental research on macromolecular chemistry.
- Telecom related technologies prove to have a more persuasive case for support from the national perspective. Spillovers accrue for these technologies outside of London as many businesses in this sector are located outside the M25 and benefit from ideas originating in London. Artificial Intelligence and Computer technology may have a similar case from the national perspective.
- There are some technology classes – the “Clean” class of technologies which deals with products that reduce negative impacts on the environment – where there is an overlap between significant spillovers and the delivery of city authorities such as the GLA.

Chapter 5 presents evidence about which policy levers might be used to tackle diffusion barriers and facilitate the spread of ideas. It also looks at the applicability of these policies in London, considering evaluation evidence about the effectiveness of each lever and the degree to which the GLA has control over that lever. The GLA might consider:

- *The potential to speed diffusion from research, especially using city-level testbeds.* There are sectors in which the GLA leads public service delivery – such as waste and re-use – and where diffusion is identified as valuable because innovation is occurring. There may be some benefit from an active GLA role.
- *Learning lessons from recent diffusion focused place-based interventions.* The GLA is the spatial planning lead for London, and so area-based interventions are being promoted and delivered, such as the East Bank developments, which could incorporate lessons.
- *How adult skills and training provision in London might encourage diffusion.* This lever is under the GLA‘s control and could be used to target specific sectors (low paid) or skills (digital).

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ANNEXES

Annex A: Analysis of the productivity tail

The analysis for this study considered the maximum potential to close the productivity gap. To understand this, estimates have been made of:

- The fraction of workers who would be affected, i.e. how many are working in firms below the frontier, and how this varies between sectors.
- What would happen in the counterfactual event that the government has a policy tool at its disposal that will allow laggard firms to reach a productivity level at the frontier (either the median or the 75th percentile of a firm's sector in a particular year.
- What happens taking into account business dynamics; i.e. a large fraction of lagging businesses will (within a certain time frame of say 5 years) either leave the market or move up in the productivity distribution.

Productivity is:

$$P_{it} = \frac{TO_{it}}{L_{it}}$$

For firm i at time t. The basic Tail Potential Index (TPI) can be described as

$$TPI_t = \frac{\left[\sum_i \frac{L_{it}}{L_t}\left(P_{it}\left[1 - 1\left\{P_{it} < P_{F_{s(i)}t}\right\}\right] + P_{F_{s(i)}t} 1\left\{P_{it} < P_{F_{s(i)}t}\right\}\right)\right] - 1}{P_t}$$

Where $P_{F_{s(i)}t}$ is the frontier productivity (e.g. the median or the 75th percentile of productivity) in sector s that firm i belongs to, $L_t = \sum_i L_{it}$ and $1\{.\}$ is the indicator function.

By contrast the Dynamic Tail Potential Index is defined as follows:

$$DTPI_t = \frac{\sum_i \frac{L_{it}}{L_t}\left(P_{it}\left[1 - 1\left\{\left(P_{it} < P_{F_{s(i)}t}\right) \& \left(P_{it-g} < P_{F_{s(i)}t-g}\right)\right\}\right] + P_{F_{s(i)}t} 1\left\{\left(P_{it} < P_{F_{s(i)}t}\right) \& \left(P_{it-g} < P_{F_{s(i)}t-g}\right)\right\}\right)}{P_t} - 1$$

where g is the time window that is allowed for. The figures below use $g = 5$, implying that we only consider a firm as part of the low productivity tail when it was also in the low productivity tail 5 years earlier. The figures below present the results for both indexes with respect to the firm in the 75th of productivity as the frontier firms. Industries are defined by the SIC 2-digit level industry sector classification. A sectoral DTPI (and TPI) is also computed for each sector separately to understand a sector's contribution to any aggregate productivity gain from raising the tail to the 75th percentile; i.e.

$$DTPI_{st} = \frac{\sum_{i \in s} \frac{L_{it}}{L_t}\left(P_{it}\left[1 - 1\left\{\left(P_{it} < P_{F_{s(i)}t}\right) \& \left(P_{it-g} < P_{F_{s(i)}t-g}\right)\right\}\right] + P_{F_{s(i)}t} 1\left\{\left(P_{it} < P_{F_{s(i)}t}\right) \& \left(P_{it-g} < P_{F_{s(i)}t-g}\right)\right\}\right)}{P_t}$$

The estimate of the share of employees trapped in the tail is:

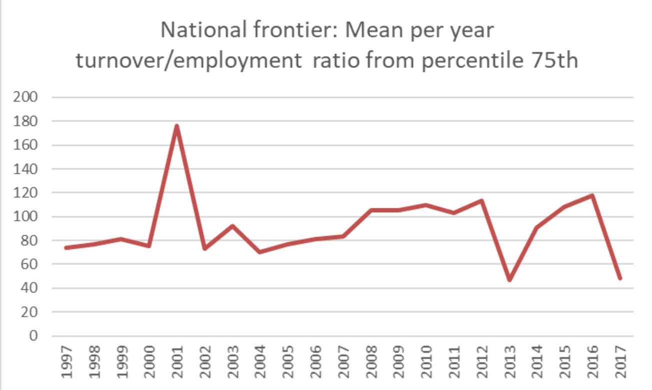
$$DTRAP_t = \sum_i \frac{1\left\{\left(P_{it} < P_{F_{s(i)}t}\right) \& \left(P_{it-g} < P_{F_{s(i)}t-g}\right)\right\} L_{it}}{L_t}$$

Panel 1: UK Frontier Productivity over Time

To define the frontier, the analysis splits the business population at levels of productivity which are the median and 75th percentile. This is undertaken for each sector and each year.

The figure indicates the level of turnover per employee for this cut-off.

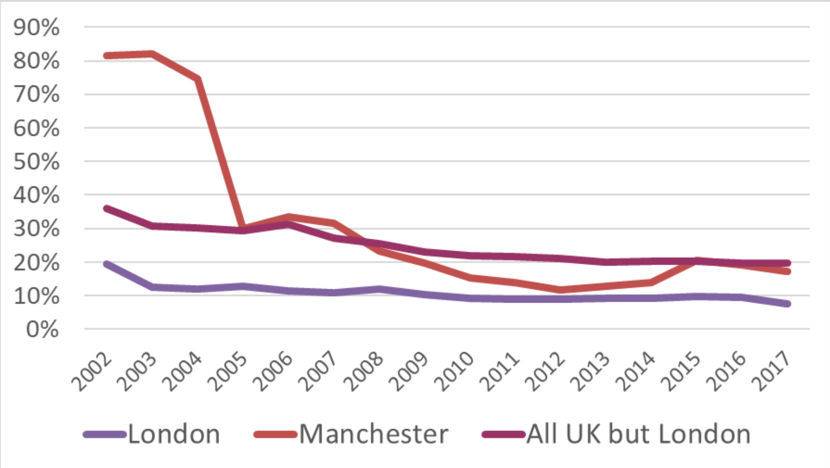
There is a slight upward trend and there are some erratic years



Panel 2: Tail Potential Index, 2002-17 using P75

The figure shows by how much productivity would grow if the productivity of firms below the 75th percentile would be increased to the 75th percentile. This is done separately for London, Manchester and the UK without London.

It is evident that an underperforming tail is much less of a problem in London. The issue has also lost in relevance in recent years.The period considered includes the recession after the financial crash.



Panel 3: Dynamic Tail Potential Index, 2002-17 using P75

The figure indicates the increase in productivity that would occur if businesses who are persistently (i.e. also 5 years prior) below the P75 productivity level raised their productivity to that of the frontier (i.e. P75) business.

A similar pattern as in Panel 2 is seen although the improvement potential is about 50% lower compared to Panel 2 for London and about 25% lower for the rest of the UK This suggests a good deal of dynamism in the tail. It also suggests that there is substantially more (twice as much) “tail dynamism” in London .

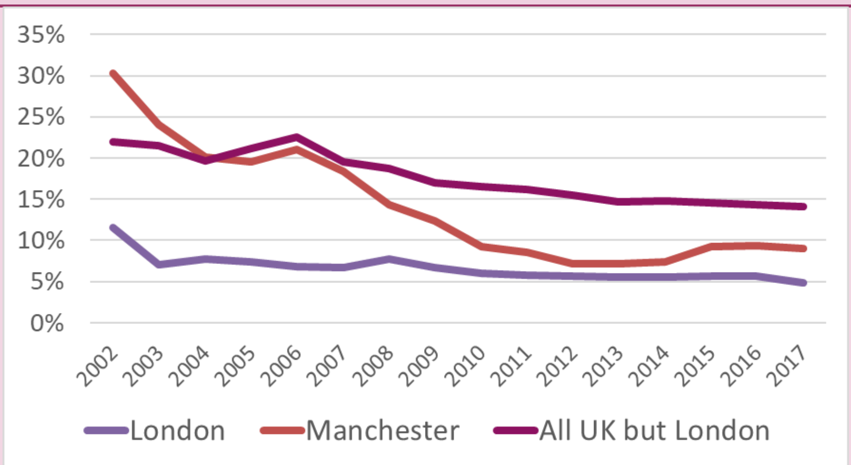


Table A1: Indexes for the UK

Year	DTRAP (p75)	DTRAP (median)
2002	0.431	0.281
2003	0.436	0.286
2004	0.429	0.281
2005	0.435	0.298
2006	0.445	0.31
2007	0.452	0.315
2008	0.439	0.306
2009	0.454	0.311
2010	0.459	0.312
2011	0.457	0.321
2012	0.452	0.313
2013	0.443	0.297
2014	0.442	0.288
2015	0.442	0.279
2016	0.434	0.277
2017	0.432	0.274
2018	0.432	0.276
Year	**DTPI (p75)**	**DTPI (median)**
2002	0.182	0.063
2003	0.209	0.071
2004	0.177	0.068
2005	0.168	0.069
2006	0.185	0.075
2007	0.191	0.076
2008	0.163	0.071
2009	0.166	0.069
2010	0.149	0.063
2011	0.142	0.064
2012	0.138	0.061
2013	0.132	0.057
2014	0.127	0.055
2015	0.128	0.053
2016	0.128	0.053
2017	0.127	0.054
2018	0.119	0.052
Year	**TPI (p75)**	**TPI (median)**
1997	0.248	0.074
1998	0.317	0.075
1999	0.468	0.08
2000	0.261	0.079
2001	0.265	0.095
2002	0.258	0.095
2003	0.324	0.105
2004	0.257	0.099
2005	0.255	0.097
2006	0.25	0.105
2007	0.258	0.105
2008	0.226	0.098
2009	0.224	0.097
2010	0.2	0.086
2011	0.188	0.085
2012	0.184	0.082
2013	0.179	0.08
2014	0.174	0.076
2015	0.176	0.076
2016	0.178	0.077
2017	0.174	0.076
2018	0.163	0.071

Table A2: Indexes by region

DTRAP	DTRAP (p75) - National Frontier			DTRAP (median) - National Frontier		
Year	Manchester	London	All UK but	Manchester	London	All UK but
2003	0.367	0.311	0.442	0.264	0.209	0.291
2004	0.309	0.298	0.441	0.22	0.195	0.289
2005	0.336	0.325	0.443	0.235	0.224	0.304
2006	0.389	0.33	0.44	0.248	0.235	0.306
2007	0.341	0.335	0.451	0.263	0.241	0.31
2008	0.338	0.333	0.446	0.259	0.244	0.309
2009	0.305	0.352	0.463	0.22	0.246	0.317
2010	0.324	0.338	0.468	0.229	0.239	0.319
2011	0.298	0.338	0.468	0.202	0.246	0.329
2012	0.307	0.335	0.46	0.206	0.236	0.32
2013	0.3	0.329	0.45	0.211	0.23	0.303
2014	0.288	0.319	0.45	0.171	0.199	0.298
2015	0.287	0.312	0.453	0.173	0.195	0.287
2016	0.307	0.299	0.445	0.184	0.192	0.285
2017	0.292	0.313	0.441	0.187	0.193	0.281
2018	0.298	0.321	0.439	0.19	0.201	0.283
DTPI	DTPI (p75) - National Frontier			DTPI (median) - National Frontier		
Year	Manchester	London	All UK but	Manchester	London	All UK but
2003	0.303	0.116	0.22	0.093	0.032	0.08
2004	0.24	0.071	0.215	0.108	0.024	0.084
2005	0.201	0.077	0.197	0.095	0.025	0.083
2006	0.196	0.074	0.212	0.091	0.029	0.09
2007	0.211	0.068	0.226	0.103	0.026	0.093
2008	0.184	0.067	0.196	0.099	0.026	0.086
2009	0.143	0.077	0.187	0.075	0.033	0.078
2010	0.124	0.067	0.17	0.063	0.03	0.072
2011	0.093	0.06	0.165	0.044	0.029	0.075
2012	0.086	0.058	0.162	0.041	0.026	0.071
2013	0.072	0.057	0.155	0.034	0.025	0.067
2014	0.072	0.056	0.147	0.031	0.024	0.063
2015	0.074	0.055	0.148	0.031	0.023	0.061
2016	0.093	0.057	0.146	0.041	0.024	0.061
2017	0.094	0.057	0.143	0.041	0.025	0.061
2018	0.09	0.048	0.141	0.04	0.021	0.061
TPI	TPI (p75) - National Frontier			TPI (median) - National Frontier		
Year	Manchester	London	All UK but	Manchester	London	All UK but
2003	0.816	0.195	0.359	0.14	0.054	0.12
2004	0.82	0.125	0.307	0.193	0.042	0.122
2005	0.746	0.121	0.301	0.163	0.041	0.118
2006	0.298	0.129	0.295	0.15	0.048	0.126
2007	0.336	0.115	0.313	0.17	0.044	0.128
2008	0.316	0.108	0.271	0.163	0.043	0.119
2009	0.233	0.121	0.256	0.121	0.051	0.111
2010	0.198	0.103	0.229	0.094	0.045	0.098
2011	0.153	0.092	0.219	0.063	0.041	0.099
2012	0.14	0.088	0.216	0.064	0.04	0.096
2013	0.118	0.089	0.21	0.054	0.041	0.094
2014	0.128	0.091	0.2	0.057	0.04	0.088
2015	0.14	0.092	0.203	0.059	0.039	0.088
2016	0.204	0.097	0.202	0.102	0.042	0.087
2017	0.192	0.094	0.197	0.093	0.041	0.086
2018	0.173	0.075	0.196	0.082	0.033	0.085

Annex B: Analysis of FAME data

The analysis used an extract of the most recent accounts of UK businesses, taken from FAME. The focus was the businesses that completed accounts which provided remuneration and employees (with most UK businesses exempted from reporting detailed accounts).

Using Companies House number, the SIC code and postcodes, the accounts data was linked to:

- Whether the business was in a knowledge intensive manufacturing or service sector as defined by Eurostat
- Whether the business held a patent or had received Innovate UK funding
- Local authority codes, especially whether a business is located in Greater London, Manchester, Oxford, Cambridge and the M4 corridor

Table B1: Summary Statistics about businesses in 2018

Variable	All	Businesses were remuneration per employee >£100k	
		All	Knowledge intensive
Remuneration per employee (£'000)	110	38	49
London (%)	30%	27%	30%
Reporting R&D in their accounts (%)	1.5%	1.5%	4.9%
Reporting overseas sales (%)	26.9%	27.2%	48.3%
Patentholder (%)	5.6%	5.8%	15.4%
Reporting full accounts	38.5%	37.1%	40.0%
Employees	439	463	309
Knowledge-intensive (%)	15.5%	15.2%	All
Number of businesses	63,249	57,932	8,802

A frontier was estimated for the knowledge intensive businesses, using the log remuneration per employee and the efficiency of individual businesses estimated from the modelled frontier. Plots of the distribution of this efficiency measure are in the report and Table B2 indicates the estimate of the frontier underpinning the plots.

Table B2: Frontier modelling for Knowledge Intensive businesses

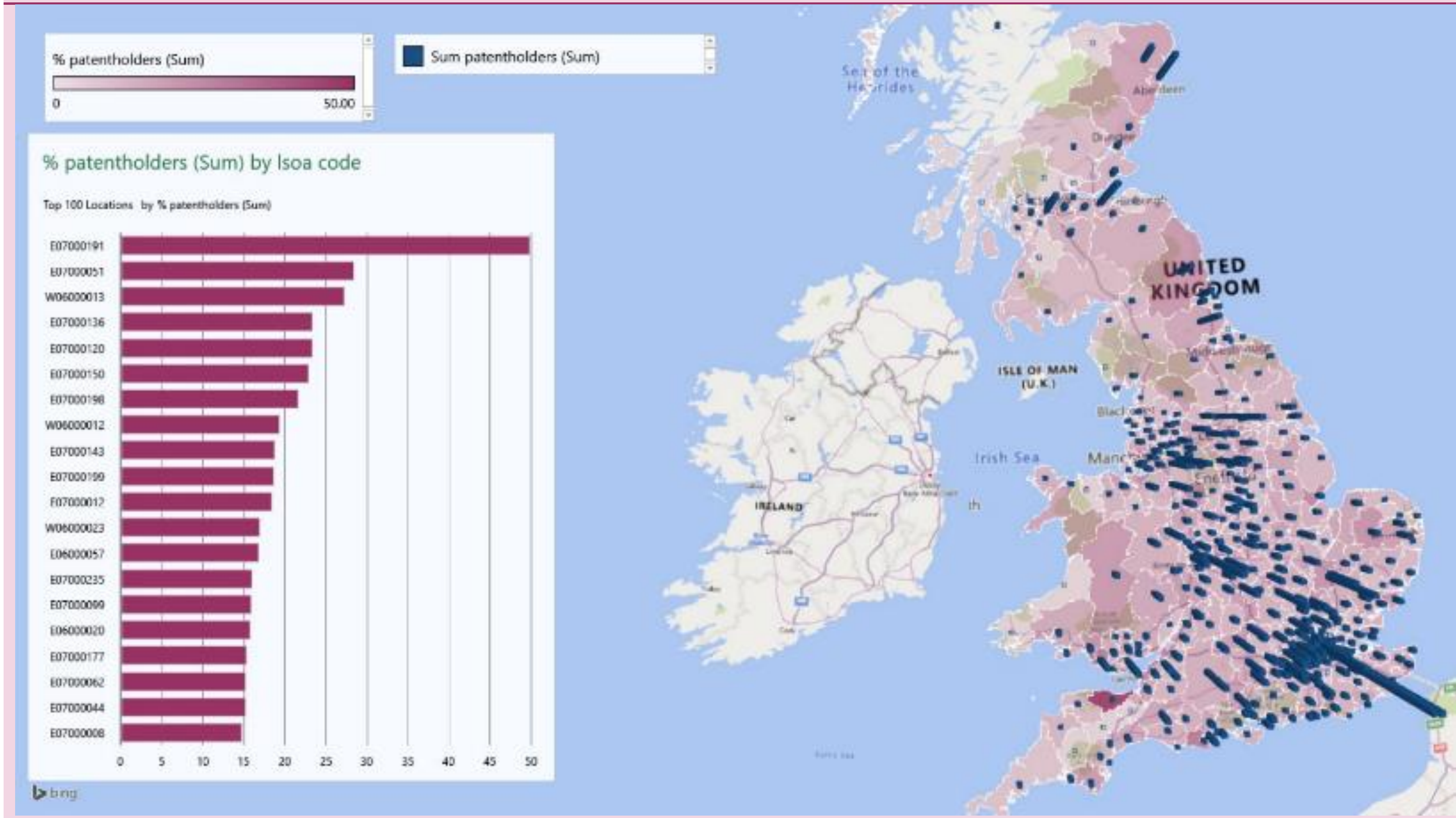
Variable	Coeff	Significance	
		Sd	Z
London	0.16	0.009	17.45
Reporting R&D in their accounts	0.06	0.021	2.99
Reporting overseas sales	0.025	0.008	2.97
Patentholder	0.023	0.012	1.91
Reporting full accounts	0.038	0.009	4.26
Employees	-0.0000	0..000	-0.58
Constant	4.29	0.01	412.37
Number of businesses	63,249	57,932	8,802
Likelihood test	**Chi**	**2.4*** **	
Sigma v	0.169	0.005	
Sigma_u	0.776	0.006	
Sigma2	0.631	0.012	
Lambda	4.566	0.012	

The stochastic frontier model is used in a large literature of studies of production, cost, revenue, profit and other models of goal attainment. The model as it appears in the current literature was originally developed by Aigner, Lovell, and Schmidt (1977). The canonical formulation that serves as the foundation for other variations is their model, $y = \beta' x + v - u$, where y is the observed outcome (goal attainment), $\beta' x + v$ is the optimal, frontier goal (e.g., maximal production output or minimum cost) pursued by the individual, $\beta' x$ is the deterministic part of the frontier and $v \sim N[0,\sigma_v^2]$ is the stochastic part.

The two parts together constitute the “stochastic frontier”. The amount by which the observed individual fails to reach the optimum (the frontier) is u, where $u = |U|$ and $U \sim N[0,\sigma_u^2]$ (change to $v + u$ for a stochastic cost frontier or any setting in which the optimum is a minimum). In this context, u is the “inefficiency”. This is the normal-half normal model which forms the basic form of the stochastic frontier model

Annex C: Mapping patents in London

Panel 1: Location of patenting businesses



Panel 2: Patenting businesses and their characteristics