Technology, productivity and competition

CMA Microeconomics Unit

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1. Executive summary

1.1 Productivity measures how much output is produced, given the resources used. In the long run, improvements to productivity are the way in which economies grow and living standards improve.

1.2 Advanced economies have experienced a period of weak productivity growth since at least the global financial crisis, and the UK's performance has been weaker than most.[1] Two potential causes are considered important in explaining this gap: lower investment in the UK than in peer economies; and weaker adoption or diffusion of technology or other improvements in efficiency. This paper is particularly focussed on understanding the link between technology and productivity. While the UK does better than many peers in early-stage innovation, it fares relatively poorly in the diffusion of these innovations and translation into broad productivity gains across the economy.

1.3 In this paper, we present the following analysis:

(a) We look at the evolution of productivity[2] since 1997 to understand how productivity varies between the most productive firms and the rest; across the sectors of the economy; and within a given sector.

(b) We explore the association between firm-level investment and Total Factor Productivity (TFP), to examine whether investment improves the ability of firms to convert a given level of resources into output – which can tell us about the impact of investment on the technology that the firm uses.

(c) Finally, we look at the effect of the competitive context on the relationship between investment and TFP, to understand whether more competition may be associated with more effective deployment of technology.

1.4 This report is part of the Microeconomics Unit's ongoing Growth Programme, supporting the government's growth mission by delivering economic research focussed on critical drivers and blockers of economic growth.

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[1] See, for example, Van Reenen & Yang, 2024. ONS (2022) shows that the UK ranked sixth among G7 countries for growth in output per hour worked 2009-2019.

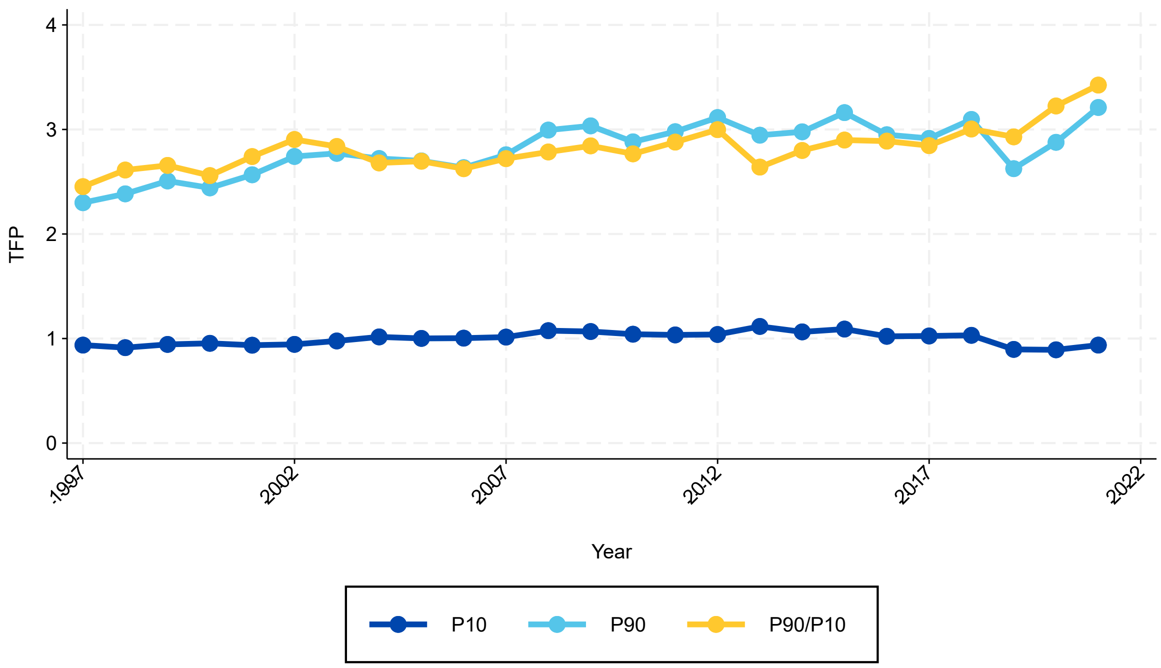
[2] Productivity has several components; in this paper we primarily focus on Total Factor Productivity (TFP) – how much output a firm produces given its employees, raw materials and machinery.

Differences in productivity across firms have increased

1.5 TFP describes how much output a firm produces given its employees, raw materials and machinery – defined as the residual once the contribution of these other factors is accounted for. This means it can capture several elements, including technology, management practices or measurement errors. In this paper, we think of TFP as an indicator of technology – factors that can influence how inputs are translated into outputs – though recognising it can also be influenced by other factors. Differences in TFP between firms reflect, at least in part, differences in the technology available to the firms.

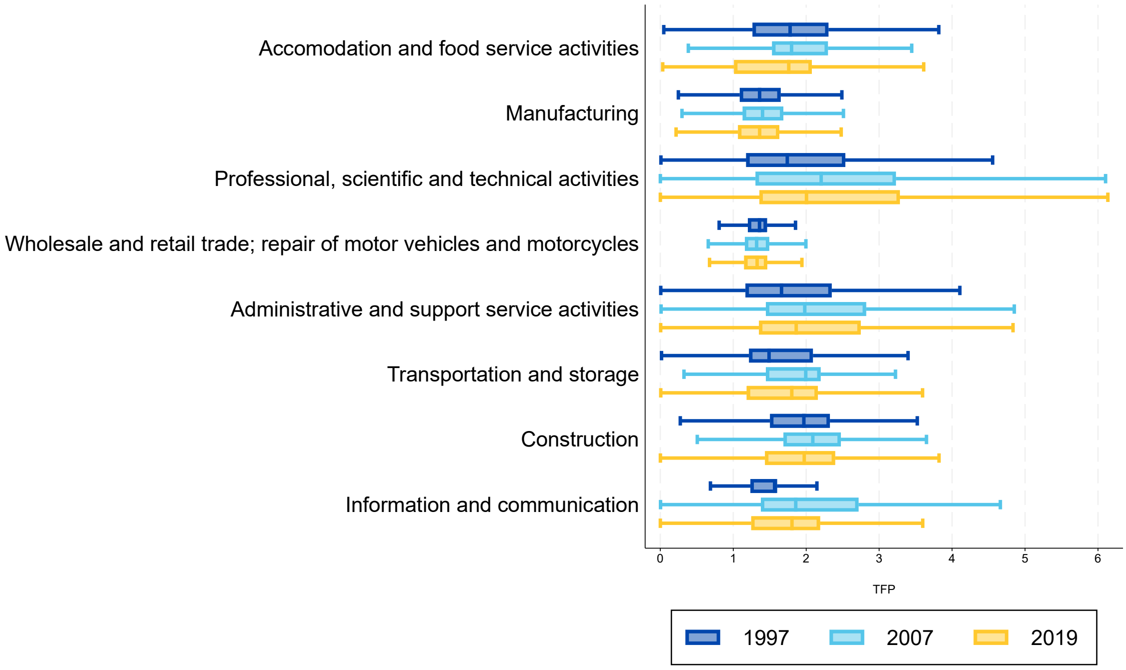
1.6 We find that the gap between the productivity of firms with the highest level of TFP and the rest has increased. This is true across the economy as a whole (as shown in Figure 1-1 below), although it appears the trends differ somewhat between individual sectors (Figure 1-2). This shows the most successful firms making more productivity gains from technology (or other contributors to TFP) and pulling away from other firms in general and within their own industry. That is, the gap between the best and the rest has been increasing. There is therefore an opportunity to improve overall productivity, potentially including through more effective adoption of technology by more firms in a given industry.

Figure 1-1 Widening gap between 90th and 10th percentiles of economy-wide TFP distribution



Economy-wide 10th and 90th percentiles of TFP for firms and the ratio between the two, weighted by employment 1997 to 2021, from ARDx/ABS

Figure 1-2 Patterns and changes in TFP dispersion among firms varies by sector



Boxplots of firm-level distribution of TFP levels within selected SIC sectors where data is suitable for our TFP estimation approach, boxes show quartiles and median, tails show extreme values 1.5x the inter-quartile range, weighted by employment, for years 1997, 2007 and 2019, from ARDx/ABS

Investment is positively associated with technology-related productivity gains

1.7 Having identified this divergence in TFP, we explore the extent to which differences in investment may explain this divergence. The available data in UK business surveys on technology adoption by individual firms has a relatively small sample and does not generally give a measure of the intensity of technology use. We therefore use different measures of investment as a proxy for spending on upgrading technology and then examine the relationship between investment and TFP between 2000-2021.[3]

1.8 We find that the gap between the firms that invest the most, and those that invest the least, has increased over time. We also find that a wider range of investment levels among firms in an industry is associated with wider range of TFP.

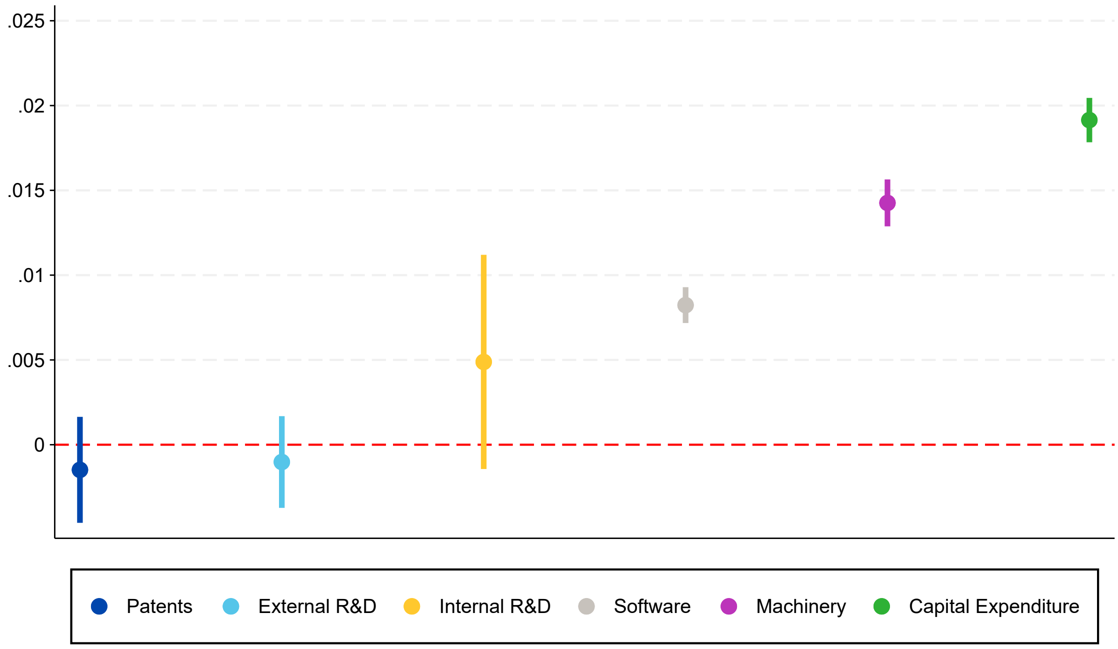
1.9 To explore the relationship further, we regress TFP on investment within a given firm, controlling for differences between sectors over time. We find a

[3] This time period means our analysis doesn't reflect the most recent technological developments, including the recent wave of AI investments.

significant positive association between changes in firms’ investment levels and their TFP. A 10% increase in capital investment by a firm is associated with an average 0.2% increase in their TFP in the same year (see Figure 1-3, coefficients in the chart show the increase in TFP levels associated with a 1% higher investment level). Whilst the magnitude of this effect is relatively small, in the context of annual TFP growth of less than 1% across the period we study, these small increases in TFP levels still represent a meaningful change. These results suggest that investment tends to be productivity-enhancing on average, including by improving the technology available to firms, but the small scale of the relationship indicates that other factors also influence firm productivity.

1.10 We explore different sub-categories of investment and find that investment in machinery and software by a firm is most strongly associated with TFP gains for that firm. We find that the correlation of these types of investment with TFP is also significant in the years following investment, consistent with an extended process where investment in technology improves business processes over time. We find indications of a possible positive relationship between internal R&D expenditure and TFP, though this is not statistically significant. We do not find evidence of an association between a firm’s changes in investment in licensing, patents or other intellectual property, or research and development (R&D) and that firm’s TFP (i.e. the confidence interval goes through zero). This likely reflects that not all R&D is productivity enhancing for the firm carrying it out, and firms would only see productivity benefits from R&D if they adopt their own innovation in a way that improves their efficiency. There is also likely to be an extended timespan between R&D investment and implementation of these innovations leading to productivity impacts.

Figure 1-3 Positive relationships between increases in firm-level investment (in total and in machinery and software) and TFP



Coefficients from regressions of TFP on licensing patents or other intellectual property (2000-2013), software investment (2000-2021), machinery (2000-2021) and total capital expenditure (1997-2021) from ARDx/ABS and Internal and External R&D from BERD. Coefficient shows the percentage impact on TFP levels of a 1% increase in investment. Lines represent 95% confidence intervals around estimated coefficient.

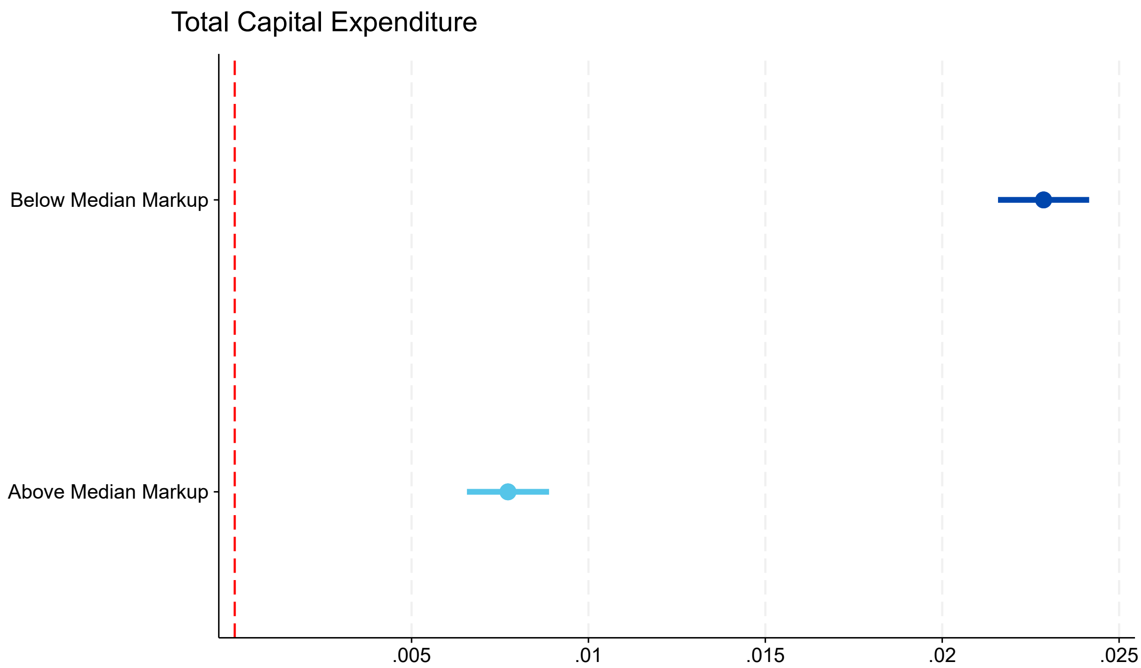
1.11 We find that the positive association between investment and TFP holds for different sub periods, across sectors of the economy, and when looking at industry-level rather than firm-level data. We additionally find a positive association between industry-level Internal R&D expenditure and TFP. However, identifying the direction of this relationship is challenging, and we cannot rule out the possibility that it runs in the opposite direction – i.e. firms that become more productive decide to invest more.

Competition amplifies technology-related productivity gains from investment

1.12 Finally, we want to understand whether the extent of competition that a firm faces makes a difference to the impact of its investments on productivity. Since the level of competition in a sector is not directly observable, we use a firm's markup as a proxy for its market power. Markups are a widely used measure of market power, but it is important to note that they are not a perfect proxy, and can also be influenced by other factors. Changes in technology and firm cost structures leading to lower marginal costs and higher fixed costs, for example, would also be reflected in higher markups.

1.13 We use regression models to examine the influence of competition on the investment-TFP relationship within a given firm, controlling for differences between sectors over time. We find evidence that firms facing more competitive pressure appear to make stronger TFP gains when they invest. Firms with high markups may still see positive TFP gains associated with investment, but these are substantially smaller. When a firm increases its total investment by 10%, the associated TFP gains for firms with lower markups than average for their sector are greater than 0.2%, but less than 0.1% for firms with higher markups. Figure 1-4 below illustrates this relationship,[4] showing that for firms with below median markups, the association between total investment and TFP is substantially stronger than for firms with above median markups.

Figure 1-4 Stronger positive relationship between total capital investment and TFP for firms with markups below the median for their sector



Coefficients from firm-level regressions of TFP on interaction of a dummy for whether the firm was above the median markup with total capital expenditure (1997-2021), from ARDx/ABS. Coefficient shows the percentage impact on TFP levels of a 1% increase in investment. Lines represent 95% confidence intervals around estimated coefficient.

1.14 These relationships are consistent across different types of investment and across different sectors of the economy. We also find the same pattern when examining relationships at the industry rather than firm level, indicating that

[4] Coefficients in the chart show the percentage increase in TFP levels associated with a 1% higher investment level

the general competitive conditions in an industry have a similar effect to an individual firm’s market power.

1.15 Taken together, our results suggest a role for competition in driving firms to make the better use of investment, including in technology. Firms with low market power, or in more competitive industries, appear to face greater pressure to realise productivity gains to outcompete rivals. The strength of this relationship is broadly consistent across time, sectors and types of investment.

2. Introduction

2.1 This paper uses firm-level data to explore technology, productivity and competition. Whilst use of some specific technologies is observable, data on this does not provide a general view of the technological sophistication of firms or the intensity of their technology usage. For this reason, we use estimates of TFP and data on investment to help us understand technology-driven productivity. TFP is often used as a broad indicator of technology and captures the productivity gains firms experience when they adopt better technology. We primarily use firm-level microdata from the ONS's structural business surveys.

2.2 Businesses invest for a range of reasons, including to adopt new technology. By exploring the relationship between investment and TFP, we can show where investment may be associated with technology-driven productivity gains. We can then explore how competition affects this association.

2.3 The paper is structured as follows:

(a) Section 3 describes our framework for considering productivity, investment and competition, alongside recent trends in productivity and investment for the UK and international comparators.

(b) Section 4 investigates the distribution of TFP across the economy and within sectors

(c) Section 5 establishes that investment can be a proxy for technology adoption, and explores the relationship between investment and TFP

(d) Section 6 examines how competition influences this relationship between investment and TFP

3. Productivity, technology investment, and competition

3.1 Productivity growth is the critical driver of long-term economic prosperity. Investment, including in technology, is generally thought to be a key determinant of productivity. There is extensive evidence that competition drives productivity growth and has impacts on investment. This section describes our framework for thinking about productivity, technology investment and competition, and highlights international trends in these areas.

3.2 In this section, we show that advanced economies have experienced a substantial slowdown in productivity growth since the 2008-09 global financial crisis, and the UK's performance has been somewhat weaker than comparator countries. The UK has also had lower rates of investment intensity than others.

Productivity growth has slowed in advanced economies

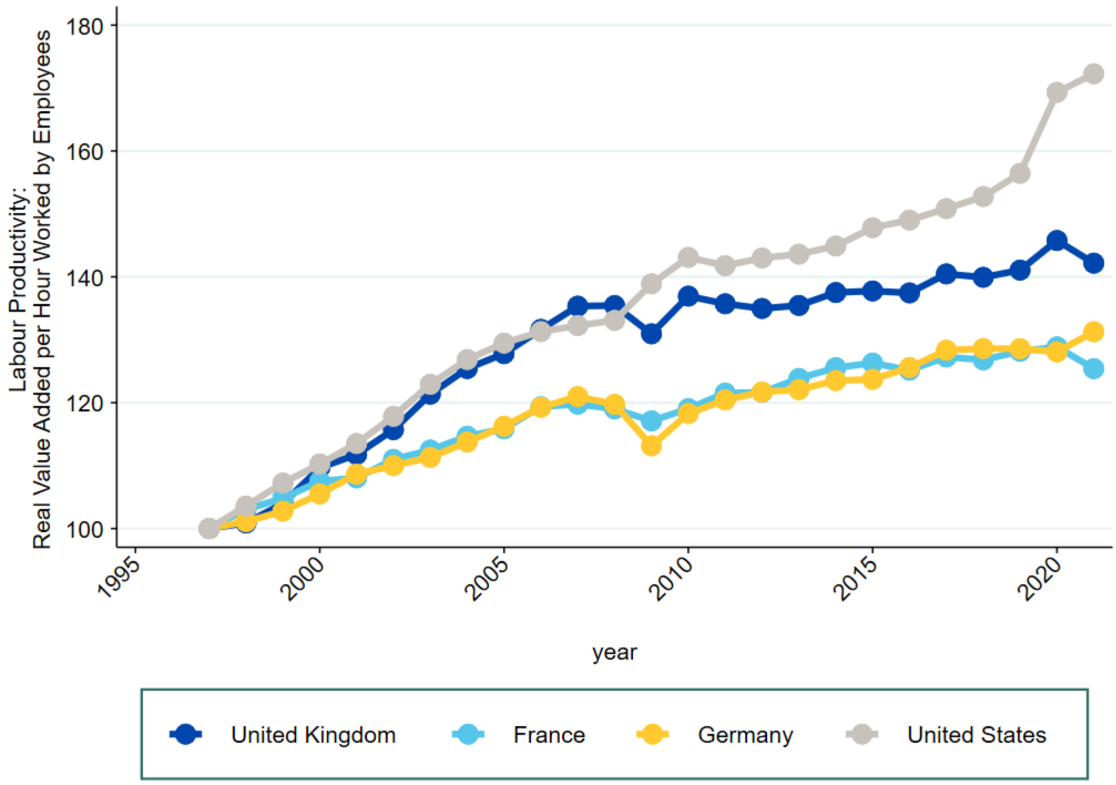
3.3 Firms produce economic output using a mix of capital and labour to transform other inputs (such as materials) into outputs. Capital describes assets used in the production process, including machinery, software and buildings. Labour is the workers employed by the firm.

3.4 Productivity captures how efficiently firms convert inputs into output. This is often measured simply as labour productivity, the value of output produced per worker. In this paper, we focus on TFP, which is the residual productivity impact after capital, labour and other inputs are accounted for.

3.5 TFP measures efficiency in the use of capital and labour inputs. TFP can be thought of as an indicator of technological progress, as better technology may allow firm to produce more output from the same amount of labour capital and other inputs. Differences in TFP can also reflect differences in management practices, business processes or economies of scale. Estimates of TFP can also be influenced by measurement errors in inputs and outputs. For example, if firms employ forms of capital (such as intangible assets like intellectual property) not well-captured in official statistics, this would likely overestimate TFP.

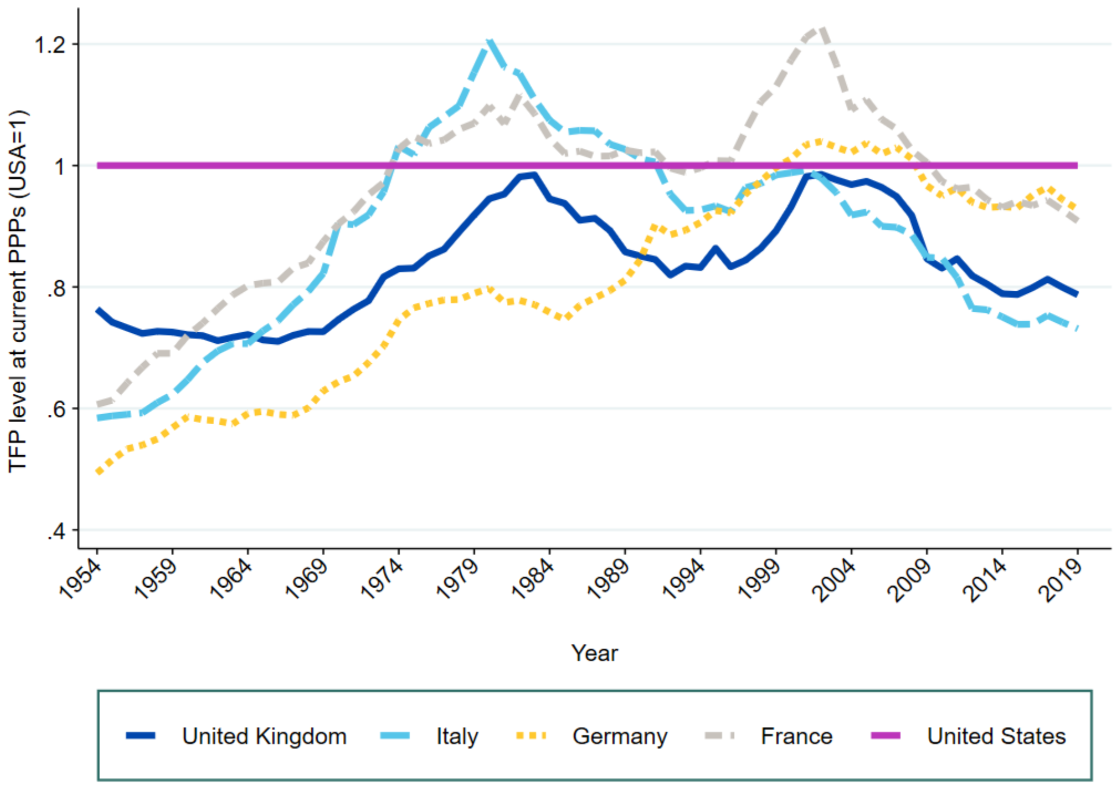
3.6 Advanced economies have all experienced a slowdown in labour productivity and TFP growth since the global financial crisis, though UK performance has been weaker than others. Figure 3-1 below shows slowing growth in labour productivity in the UK, France, Germany and a less pronounced slowdown for the US. Figure 3-2 shows estimates of TFP for the UK, France, Germany and Italy, calculated with reference to the US, showing divergence in TFP levels following the global financial crisis.

Figure 3-1 Labour productivity growth in advanced economies has slowed in recent years



Estimated labour productivity from EUKLEMS, indexed (1997 = 100)

Figure 3-2 TFP levels across advanced economies have declined relative to the US following the financial crisis



Estimated Total Factor Productivity from Penn tables, relative to United States

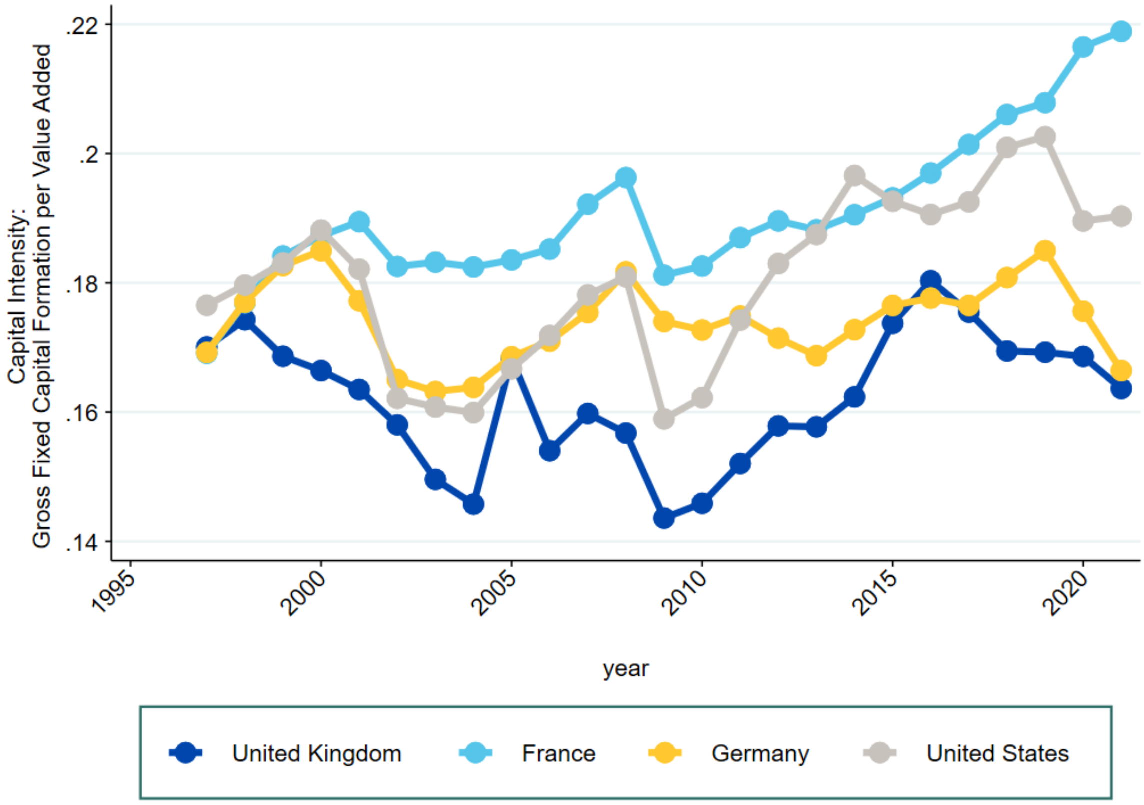
3.7 Around half of the UK's recent labour productivity slowdown has been attributed to slow TFP growth, and the magnitude of this TFP slowdown has been estimated to be broadly similar across comparator countries. The UK also experienced a larger slowdown than peer economies in the growth of capital intensity (Van Reenen & Yang, 2024).

UK business investment is lower than other advanced economies

3.8 Investment in capital can increase productivity through two channels. Firstly, increased investment increases capital intensity (defined as the amount of capital per employee or per unit of turnover) – this is often referred to as "capital deepening" – and so increases labour productivity. Investment can also lead to TFP gains, particularly if it improves the technology available to a firm and leads to overall increases in how efficiently firms use all their inputs – for example if the investment is in a more technologically advanced piece of machinery.

3.9 The UK has persistently had a lower level of business investment than peer economies, leading to lower capital intensity. Figure 3-3 shows investment intensity in the UK has generally remained below that of the US, France and Germany. Similar trends have been set out in other recent studies, such as Valero and Van Reenen (2019), Alayande and Coyle (2023) and Dibb and Murphy (2023).

Figure 3-3 UK investment intensity has generally been below peer economies



Capital investment intensity (gross fixed capital formation as a percentage of gross value added) calculated from EUKLEMS data

3.10 Low business investment matters because it can have an impact on productivity performance. These relationships between productivity and investment or technology adoption have been explored elsewhere, and we discuss some examples from the literature below.

3.11 Some economic literature has described how productivity and TFP are driven by distinct types of investment, though results appear sensitive to the type of investment, data source and analytical approach. For example, ONS (2022) find a positive correlation between TFP and spending on IT and advertising. Karmakar, Melolinna and Schnattinger (2024) find that investment in intangible assets has a positive effect on TFP, but don't find consistent evidence of positive TFP effects for tangible investment.

3.12 An important function of investment is that it funds the adoption of new technologies and ideas. The government's recent Technology Adoption Review (2025) highlights the UK's low adoption of technologies and the importance of addressing barriers such as financing constraints, lack of management skills, and information gaps.

3.13 Previous research has examined the importance of technology in driving productivity. The OECD (2019) found industry-level digital adoption is associated with productivity gains at the firm level. The effect is found to be stronger for more productive firms, suggesting technology adoption can lead to increasing productivity dispersion.

3.14 Brynjolfsson and Hitt (2003) find that computerisation in the late 1980s and early 1990s led to substantial productivity gains for US firms. Matteucci, O'Mahony, Robinson, Zwick (2005) show that the productivity effect of ICT differs across countries, with the effect being lower in the UK. This report provides more recent UK-specific evidence on this relationship.

Existing evidence has explored the relationship between competition, investment and productivity

3.15 It is widely established that competition can enhance productivity by placing pressure on managers to improve efficiency, reallocating economic activity to more productive firms and driving innovation. Previous CMA literature reviews in 2015 and 2025 have highlighted evidence on this topic.

3.16 The impact of competition on investment is complex. Our recently published literature review on Investment and competition over the business lifecycle (2025) discusses this evidence in more detail. The more widely studied relationship is between competition and innovation – such the “inverted-U” hypothesis from Aghion et al. (2005) looking at industry-level differences in competition and innovation. Competition can incentivise firms to innovate, as they seek to gain market share or remain ahead of rivals. However, high degrees of competition can also dampen incentives to innovate, if they reduce the ability of firms to profit from these advances. Some subsequent studies have found support for the “inverted-U” in some settings, but not in others. Although different factors are at play for other types of investment, it seems likely that the potential for competition to have positive or negative effects may hold.

3.17 Competition affects not only the level of investment but also the returns on investment. By reallocating resources to more efficient firms, competition can increase productivity (Acemoglu et al., 2018). When competitive pressures are weaker, less productive firms can survive. As a result, even if firms invest, the overall productivity gains from investment will be smaller on average, since the average firm will be less capable of carrying out productivity-enhancing investment.

3.18 Stronger competition can affect not only the level of investment but also its composition and direction. There is evidence that when firms face weaker competitive pressures, investments are less likely to be directed toward efficiency-enhancing technologies. Instead, managers might allocate resources to rent-seeking ones rather than to those that improve productivity (Acemoglu et al., 2006).

4. How is productivity distributed across and within sectors?

4.1 Productivity varies significantly between firms, depending on a range of factors including technology and competition, but also management practices and labour market factors amongst others. Documenting this variation across and within sectors helps us to understand relative productivity performance across the economy and may contribute to identifying areas with potential for future growth if more productive firms grow or less productive firms catch up to the frontier.

4.2 In this section, we present analysis of firm-level data to draw conclusions about sectoral variation in the firm-level TFP distribution, and variation across the economy as a whole. Differences in TFP may indicate differences in technology and the productivity gains firms can extract from this. We show increasing dispersion in TFP in the years following the financial crisis – suggesting the technological gaps between firms may have grown.

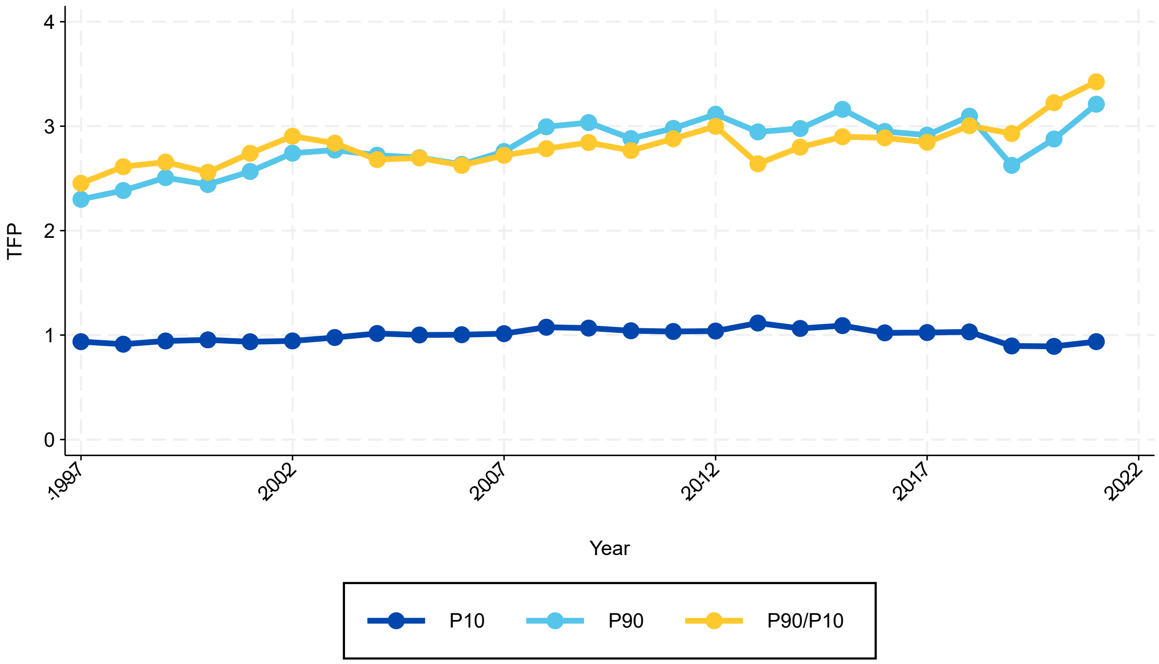
TFP dispersion has increased over recent years

4.3 Our analysis is based on estimates of TFP for GB firms.[5] We produce these by estimating the production function of firms across the economy: how much output they produce, and what combination of inputs they use to produce it. This is the same process used to estimate markups in our 2024 State of Competition report. Our baseline measure of TFP used in this report assumes a translog production function – we describe our estimation process in Annex B.

4.4 Across a range of measures, we find that TFP dispersion has increased in recent years. Figure 4-1 shows a large and expanding gap between the 90th and 10th percentiles of the TFP distribution. This means that the TFP of the top firms has increased, whilst the least productive firms have seen slight falls in TFP. In Annex C we set out alternative measures of TFP dispersion, including boxplots with extended time-periods, which highlight the same trends. ONS(2019) also highlights similar findings on productivity dispersion.

[5] Since some of the Northern Ireland business datasets are not available in the Office for National Statistics' Secure Research Service, our analysis of TFP, cost markups and investment are Great Britain-only.

Figure 4-1 Expanding gap between 90th and 10th percentiles of TFP distribution shows increasing dispersion



Economy-wide 10th and 90th percentiles for GB firms, 1997 to 2021, from ARDx/ABS

4.5 Given that this result is for the aggregate TFP distribution across the economy, it may also be affected by changes in industry composition towards those with generally higher TFP. We explore sector-level trends in the next sub-section.

4.6 There are a number of potential explanations for these trends. They could be explained by factors such as:

- Differences in technology adoption amongst firms. For instance, Lashkari et al. (2024) suggest that technology is a key factor behind increasing dispersion as small firms lag behind the largest firms in terms of software and hardware intensity. Digital technologies may lead to winner-takes-all dynamics, increasing productivity gaps between leading firms and the rest.

- Rising differences in management practices, leading to differences in firms' productivity even if using the same technologies.

- The increasing importance of investment in intangible capital, which is not always easily captured in investment statistics meaning that contributions of these assets to productivity are instead part of TFP estimates (as TFP measures the residual not explained by measured investment).

- Lower business dynamism, allowing less productive firms to remain in the market longer than otherwise.

Declines in TFP within sectors have reduced overall TFP growth

4.7 Economy-wide average TFP can change for a variety of reasons, and by separating out these reasons we can start to explore potential drivers of changes in TFP. Even if sector average TFP has not changed, overall TFP can increase if more productive sectors grow at the expense of less productive ones. In well-functioning markets, resources tend to shift towards more efficient firms or sectors, and policies often aim to support this process by encouraging growth in high-productivity areas. We explore this by breaking down changes in TFP into three components:

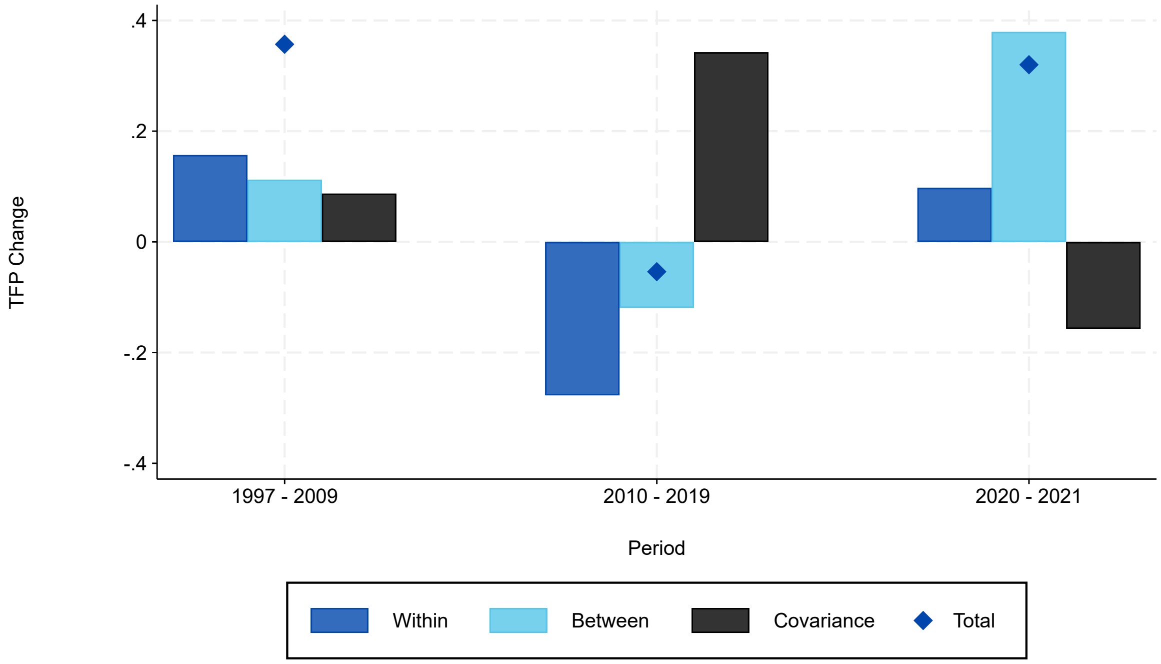
(a) Changes to productivity within each sector, holding the relative size of that sector constant ("within variation").

(b) Changes to the relative size of each sector, holding its productivity constant ("between variation"). For example, if more productive sectors expand, then overall productivity will increase.

(c) Simultaneous changes to both the productivity and relative size of each sector ("covariance").

4.8 Figure 4-2 shows that, in the period 1997-2009 we estimate the UK experienced modest TFP growth, driven by a combination of the three components described above. During the period 2010-2019 (i.e. between the global financial crisis and the onset of the Covid-19 pandemic), we estimate UK TFP growth was marginally below zero. This appears to be driven primarily by a fall in average productivity within sectors and a smaller reduction in re-allocation to more productive sectors, only partially offset by some sectors increasing in both productivity and relative size. There appears to be a small rebound in TFP growth around the Covid-19 pandemic, mainly due to re-allocation of activity to more productive sectors.

Figure 4-2 Decomposition of TFP changes into within, between and covariance components



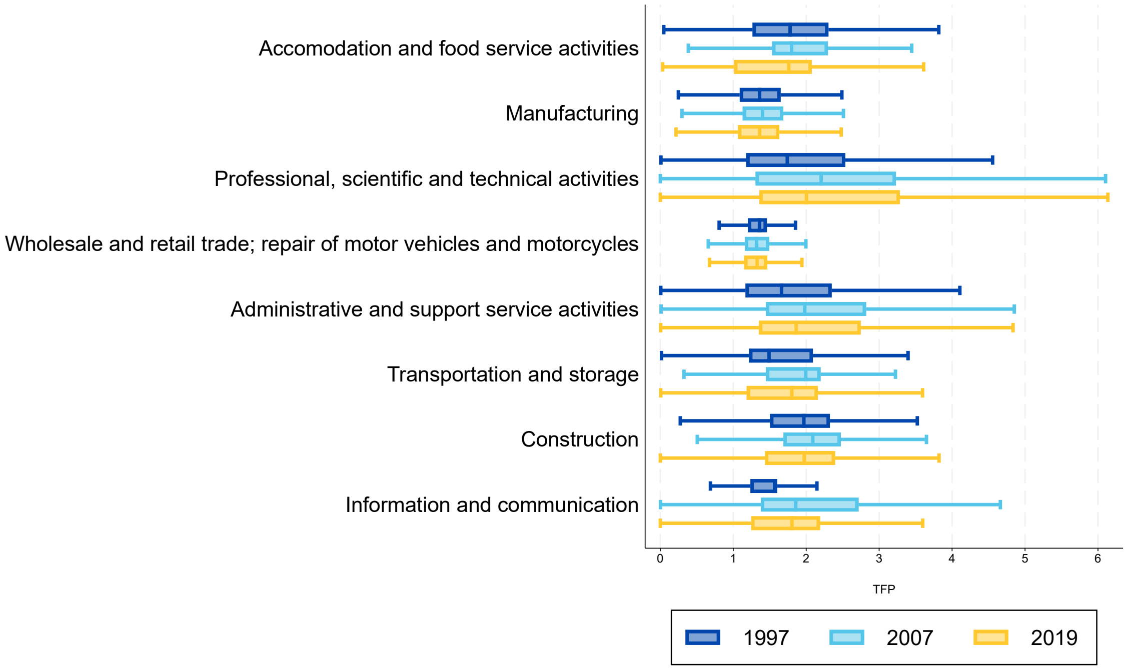
Decomposition of GB average TFP growth, weighted by employment, 1997-2021, from ARDx/ABS

Changes in TFP dispersion vary between sectors

4.9 Sectors may have systematically different levels of TFP, reflecting differences in production processes. To further understand trends in TFP distribution, we explore differences between firms within the same sector. This allows us to examine whether trends in TFP differ in different parts of the economy. We examine the distribution of firm-level productivity across 8 high-level sectors.

4.10 We find that the change in distribution of firms' TFP varies for different sectors, between 1997 and 2019. We restrict the time-period up to 2019 to avoid overlapping with Covid-19 impacts; the extended time-period analysis is included in Annex C. Figure 4-3 shows boxplots of TFP amongst firms within sectors, highlighting the quartiles of the TFP distribution (the box) and outlying values (the tails).

Figure 4-3 TFP dispersion among firms varies between sectors



Boxplots of firm-level distribution of TFP levels within SIC sections C, F, G, H, I, J, M & N; 1997, 2007, 2019, from ARDx/ABS

4.11 As TFP can indicate differences in broad technology adoption, a rising gap between firms within a sector may suggest increasing technological differences or a weakening of technology diffusion. Our results may suggest sectoral differences in these dynamics.

TFP dispersion has increased more in IS sectors compared to non-IS sectors

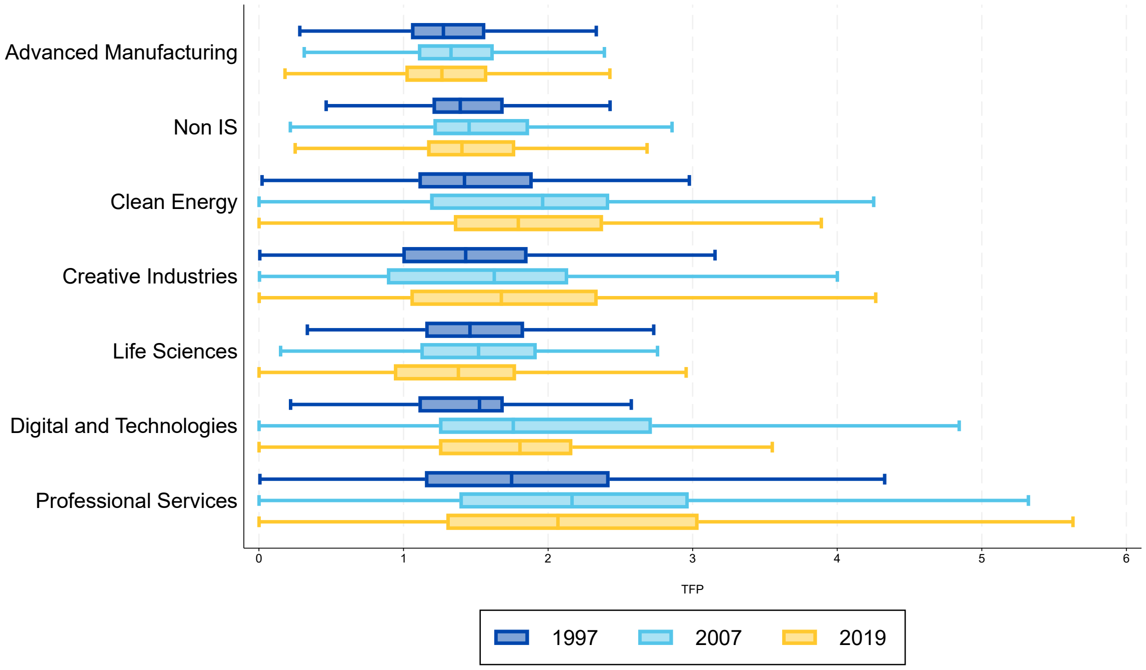
4.12 To further explore differences in TFP in different parts of the economy, we have examined the sectors prioritised in the government's Industrial Strategy (IS) – the 'IS-8'.[6] Understanding TFP dispersion in these sectors could indicate where there may be greater technological gaps between firms. Where these gaps exist, there could be potential for less productive firms to catch up by adopting better technology, or for the re-allocation of economic activity to more productive firms with better technology.

[6] These sectors are Advanced Manufacturing, Clean Energy Industries, Creative Industries, Defence, Digital and Technologies, Financial Services, Life Sciences and Professional and Business Services. Sectors definitions are here: Industrial Strategy Sector Definitions List - GOV.UK. Where available, we use SIC codes listed in the Industrial Strategy Sector Definitions as a measurable proxy. For Clean Energy Industries, we use our assessment of SIC code most likely to capture activity in this sector.

4.13 Data limitations mean we are not able to look at all of the IS-8. In particular, we exclude defence and financial services because measurement of inputs and output is problematic for these sectors and therefore our TFP estimates would be misleading.

4.14 Figure 4-4 shows boxplots of the distribution of TFP among firms within an industry. We see that TFP dispersion appears to be higher in several of the IS-8 sectors than the rest of the economy, taken as a whole. We also show increases in dispersion across many of the six IS-8 sectors we are able to study when comparing the start and end of our period of analysis.

Figure 4-4 IS sectors have higher levels of TFP dispersion than the rest of the economy



Boxplots of firm-level distribution of TFP levels within each of the IS sectors and the rest of the economy, weighted by employment, 1997, 2007, 2019, from ARDx/ABS

4.15 Wider gaps between more and less productive firms in at least some IS sectors could be due to several factors. One possibility is stronger growth from leading firms and/or weaknesses in diffusion of frontier technologies increasing TFP gaps between firms. Consequently, there may be potential for significant TFP growth in these sectors, from either reducing barriers to technology adoption, or re-allocation of economic activity to firms with higher TFP.

5. How does technology investment affect productivity?

5.1 Investment that changes the technology employed by firms is a critical contributor to productivity growth. In this section, we examine investment and technology usage measures and explore the extent to which measures of investment could act as a proxy for technology adoption.

5.2 We look at the relationship between investment and TFP, to identify the impact that investment has on technology-related productivity growth, noting that this relationship could also reflect other factors such as organisational changes due to capital investment. We also explore this relationship across time to understand delayed impacts of investment. We test whether this relationship differs between sectors.

5.3 We also explore other features of this relationship. First, we look at whether a firm's previous TFP level influences the productivity gains they get from investment, to help understand the nature of possible diminishing returns to investment. This might also explain catch-up effects, where firms further away from the technology frontier experience greater productivity improvements by adopting technology already used by leading firms. Second, we investigate whether wider differences in investment within an industry can impact overall productivity, by looking into the relationship between investment dispersion and industry TFP levels.

Measuring technology investment and adoption

5.4 Our data includes a set of investment and technology measures, with the earliest measures starting in 1997, and the latest ending in 2021. This aligns with the period for which we have metrics measuring competition. We draw on four surveys that provide indicators of investment and technology adoption. Our primary analysis uses measures of investment in capital and R&D. We supplement this with some indicators of specific technology usage and innovation outcomes. Our data looks at investment up to 2021 and so does not capture the recent wave of AI investments.

5.5 We measure investment using data from the GB Annual Respondents Database (ARDx) and Annual Business Survey (ABS). This includes data on firms' capital expenditure, and for a smaller sample selected sub-categories of investment in computer software, machinery and equipment, and patents. Between 60-70% of firms in this sample carry out some form of capital investment.

5.6 We measure expenditure on internal R&D (done within the firm) and external R&D (acquired from outside the firm) using the GB Business Expenditure on

Research and Development (BERD) survey which covers the subset of firms performing R&D.[7]

Looking at investment and TFP can also provide insights applicable to the adoption of technology

5.7 There are different approaches to measuring technology adoption. TFP, as described in Section 3 above, gives a picture of the extent to which firms derive productivity gains from technology, and so partially reflects the results of technology adoption. However, this measure is somewhat indirect, as it captures productivity outcomes and not the actual adoption of technology, and other factors can influence TFP.

5.8 Available data on specific technology usage typically only measures whether or not businesses use a named broad technology, rather than allowing us to explore the intensity of usage and the impact of this. It also tends to cover established technologies with already high levels of uptake, which means we cannot explore impacts of more nascent technologies. For these reasons, we instead use data on investment as a proxy for technology. In this section we show that this is a reasonable assumption.

5.9 We use total capital investment as our main measure because it provides a long and consistent time series and is available for a large sample of firms. This measure contains technology-related investments, though will also incorporate other investments (such as in buildings) which may be less technology-relevant. It is also worth noting that not all technology adoption will require capital expenditure.

5.10 Figure 5-1 below highlights the proportion of capital investment comprising machinery and software, showing machinery generally represents around 65% of total investment (excluding 2021 which is likely heavily affected by Covid-19), and software a small but meaningful share of around 5-10%. Machinery encompasses a wide range of capital equipment and assets, including computers, electronic equipment and tools. Other elements of total capital investment will most likely also include new technologies, but these cannot be separated from the total.

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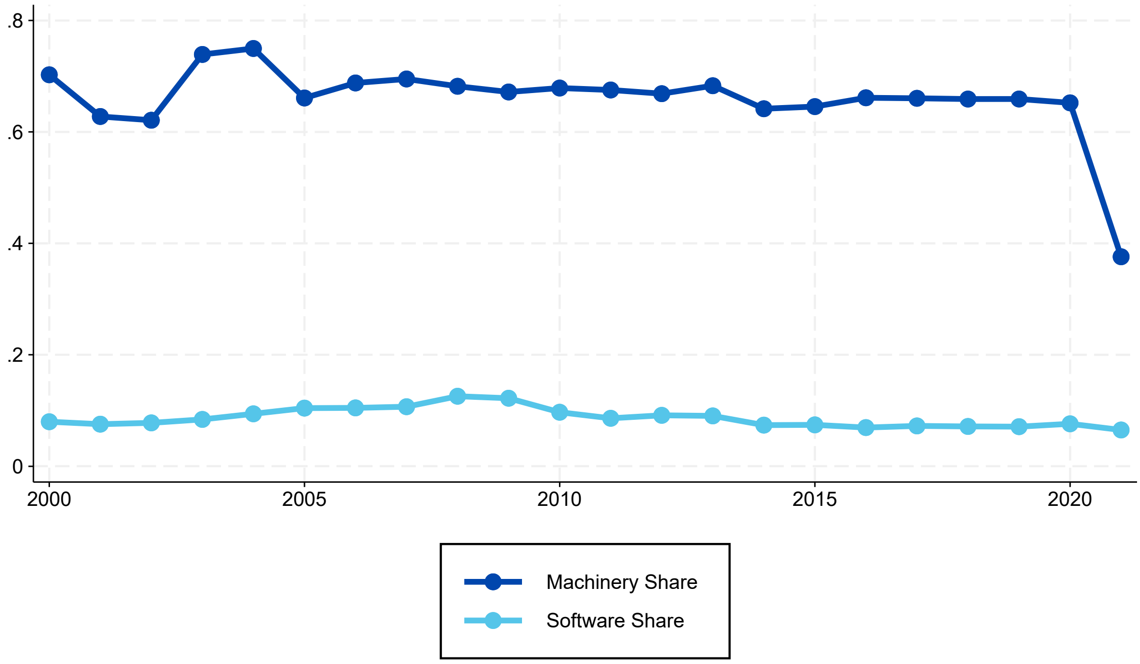
[7] Recent methodological improvements by the ONS suggest that the total value of expenditure on R&D by UK businesses was greater than estimated by BERD. Therefore, our analysis of historical R&D expenditure may not cover all firms that were engaged in R&D. Our primary analytical approach looks at within-firm effects of changes in R&D spending for those firms identified as having positive R&D expenditure, but it should be noted that there may be other R&D active firms not reflected in this data, and so not included in this analysis.

Figure 5-1 Firm use capital expenditure on machinery and software technology investments



Average total investment in machinery and software, as a proportion of total capital expenditure, across the years that firms were asked about them, weighted by employment, 2000-2021, from ARDx/ABS

5.11 Alongside total capital investment, we also look at specific types of capital investment as alternatives – machinery, software and intellectual property. These investments are spread across a smaller sample of firms, for example Annex C, Figure 7-6, shows around 40%-50% of companies in our dataset invest in machinery and software. We also examine R&D expenditure from a separate source – both internal (carried out within the firm) and external (purchased from outside the firm). These investment sub-categories are available for a smaller, but still substantial sample of firms.

5.12 To understand the relationship between investment and measures of specific technology use, we measure business use of specific technologies using the E-commerce and ICT survey. This allows us to identify firms using specific technologies over time, though the nature of this survey means only established technologies can be tracked over time. As might be expected, some technologies such as PCs and websites have consistently very high usage rates, whereas newer technologies such as cloud computing and CRM have grown in prevalence since 2010. Our Annex C, Figure 7-7, also covers specific technology measures from the E-commerce survey. These measures have much reduced coverage and are limited to binary variables, which lead us to focus on measures of investment.

5.13 To verify that these investment measures are likely to also be informative on technology adoption, we examine their correlation with these indicators of specific technology use. Table 5-1 shows a set of correlation coefficients between our measures of investment and variables measuring specific technology usage or the propensity to introduce new products or processes . The first set of these variables measure whether firms use a particular named technology, taken from the E-commerce survey. The second set of variables (taken from the UK Innovation Survey) measure whether firms have introduced a product or process that was new to market ("product/process innovator") or just new to the business ("product/process adopter").

5.14 We find that firms that invest more are also more likely to adopt technologies. Though the correlation is relatively weak, reflecting the range of other factors that will influence technology adoption decisions, and the low variation in some of these indicators (e.g. almost all firms were PC users throughout our sample period). However, the consistent positive and statistically significant relationship gives us further confidence that looking at the relationship between investment and TFP can also give insights on technology adoption.

Table 5-1 Significant and positive correlations between investment variables and specific technology or innovation variables

Specific technology users → *Investment type ↓*	PCs	Websites	Cloud computing	CRM - customers	CRM - business	Product adopter	Product innovator	Process adopter	Process innovator
Total capital expenditure	**0.0321**	**0.0666**	**0.1404**	**0.1221**	**0.1164**	**0.0427**	**0.0554**	**0.0353**	**0.0466**
Machinery investment	**0.0261**	**0.0604**	**0.1223**	**0.1043**	**0.1039**	**0.0614**	**0.0693**	**0.0605**	**0.0659**
Software investment	**0.0232**	**0.0613**	**0.127**	**0.1032**	**0.1138**	**0.0354**	**0.0398**	**0.019**	**0.0328**
Patents investment	0.0083	**0.0257**	0.0038	0.0206	**0.293**	**0.0258**	**0.0478**	0.0078	**0.0295**
Internal R&D	0.0055	**0.0218**	**0.0608**	**0.0943**	**0.0746**	-0.0228	**0.0264**	**0.0288**	**0.0334**
External R&D	0.0018	0.0091	**0.0562**	**0.0488**	0.0078	-0.014	-0.0056	**0.0398**	0.0063

Correlations of investment variables from ARDx/ABS with indicators of technology use from E-commerce and product/process innovation from UKIS. Shaded/bold correlation coefficients are significant at 5% level.

Increases in capital expenditure are associated with TFP increases, though effects are smaller when we control for differences between industries and firms

5.15 Our main approach to assessing the relationship between investment and TFP is to carry out fixed-effects regressions for the set of firms that carry out investment (i.e. excluding firms that report zero investment in a given category). This allows us to control for unobserved differences between firms, sectoral trends and size differences. In effect, our main results show the average association between changes in the level of a given firm's investment and the level of TFP. This does restrict the sample of our main regressions, as it requires firms to appear more than once in our dataset.

5.16 Before discussing our main results, we first illustrate the effect of these controls. We also include more detail on our method in Annex B.

5.17 Figure 5-2 sets out results from a series of regressions of TFP on total capital investment, amongst firms that report investment above zero. The points show the estimated coefficient, which can be interpreted as the average increase in a firm's TFP level associated with a 1% higher level of capital expenditure using our sample of firms. This result is presented initially as the average association between investment and TFP across all firms, that is without controlling for any other factors. Focussing on capital expenditure we show a positive relationship, meaning that firms with more capital investment will also tend to have higher TFP.

5.18 Next, we account for a firm's number of employees, to capture any differences in the relationship between investment and TFP that are driven by a firm's scale. We then also control for sector-level trends, through sector-year fixed effects, to remove impacts that are due to changes over time affecting all firms in a sector.

5.19 Finally, our main specification (used as the basis for the remaining analysis in this section) includes firm fixed effects which allow us to examine how investment and TFP levels change within a given firm, removing effects caused by unobservable firm characteristics. This shows that when a firm increases its total capital investment level, it also has higher TFP, though the magnitude of this effect is smaller when we control for the factors described above. The smaller effect may also suggest there are spillover effects from firm-level investment to overall sector TFP.

Figure 5-2 Relationship between total capital expenditure and TFP weakens (but remains positive and significant) with the addition of controls

Coefficients from regressions of TFP on total capital expenditure (1997-2021), from ARDx/ABS. Coefficient shows the percentage impact on TFP levels of a 1% increase in investment. Lines represent 95% confidence intervals around estimated coefficient. Pooled represents no controls and fixed effects in the regression specification, then we add employment controls, then year-SIC sector fixed effects, then firm fixed effects.

5.20 Focussing on capital expenditure, our main specification leads to a smaller effect size with the inclusion of more controls. This is because there are a range of firm-specific factors that influence TFP. When we control for these unobserved differences between firms, the strength of association between a firm's investment level and its TFP diminishes. Nevertheless, the association between TFP and capital expenditure remains positive, and is statistically significant at the 1% level.[8]

5.21 In Annex C we show equivalent results for our other five investment variables. These show the same pattern, with a stronger (and always significant) correlation without controls.

5.22 Our rationale for focussing on firm fixed effects, and thereby comparing TFP and investment within a given firm rather than across firms, is to better isolate specific impacts of investment. Unobserved differences between firms

[8] Meaning that if the sampling process for firms and the method was repeated, we would expect to find a positive relationship in at least 99% of iterations.

including management structure or labour characteristics might influence both a firm's TFP and its level of investment.

5.23 Applying firm fixed effects for the remainder of our regressions means that we can isolate the association between investment and TFP gains, for a given firm, and we have established that the relationship between investment and TFP may also provide insights on technology. However, we cannot rule our reverse causality in this association, and do not know if firms investing and adopting technologies will become more productive, or if the productive firms happen to invest more.

5.24 Using firm fixed effects does involve restricting our sample to firms that appear in multiple years of a given survey. This also changes the composition of our sample, as firms that appear in multiple years are larger on average.

Increases in a firm's capital expenditure are associated with TFP increases

5.25 We have explored whether investment is associated with technology-related productivity gains across the six different investment variables described above. This tests whether increases in different types of investment are associated with increases in TFP.

5.26 Figure 5-3 shows the increase in a firm's TFP associated with a 1% increase in its total capital expenditure, some components of capital expenditure (in machinery, software and patents) and internal and external R&D, controlling for unobserved differences between firms, and sector-level trends over time. We find a positive, statistically significant, but relatively small in magnitude association between total capital expenditure and TFP. We also find a positive association between machinery and software investment and TFP. This suggests that these investments result in efficiency gains for firms, likely in part be due to technological advancements. These initial results are for contemporaneous associations between investment and TFP, and so do not capture delayed impacts on TFP as investments in technology are further integrated into businesses, or other improvements in efficiency take place. Below we explore how these effects evolve over time.

5.27 These results suggest that a 10% increase in these types of investment would result in a 0.1-0.2% increase in TFP levels. Whilst this effect appears to be relatively small, in the context of average annual TFP growth of less than 1% across our sample, changes in TFP levels of the scale suggested by our results are meaningful.

5.28 We also find indications of a possible positive relationship between internal R&D expenditure and TFP, though this is not statistically significant on our baseline specification controlling for differences between firms.[9]

5.29 We do not find evidence of an association between a firm's changes in investment in licensing, patents or other intellectual property, or research and development (R&D) and that firm's TFP (i.e. the confidence interval goes through zero). This likely reflects that not all R&D is productivity enhancing for the firm carrying it out, and firms would only see productivity benefits from R&D if they adopt their own innovation in a way that improves their efficiency. There is also likely to be an extended timespan between R&D investment and implementation of these innovations leading to productivity impacts, particularly for early-stage R&D. Other research has found productivity gains from R&D investment after a period of time.[10] The possible difference in effects between internal and external R&D may be suggestive evidence of the role of R&D in enabling the absorptive capacity of firms to adopt technology,[11] as firms purchasing external R&D do not benefit from the institutional knowledge gained from research in the same way as those carrying out internal R&D.

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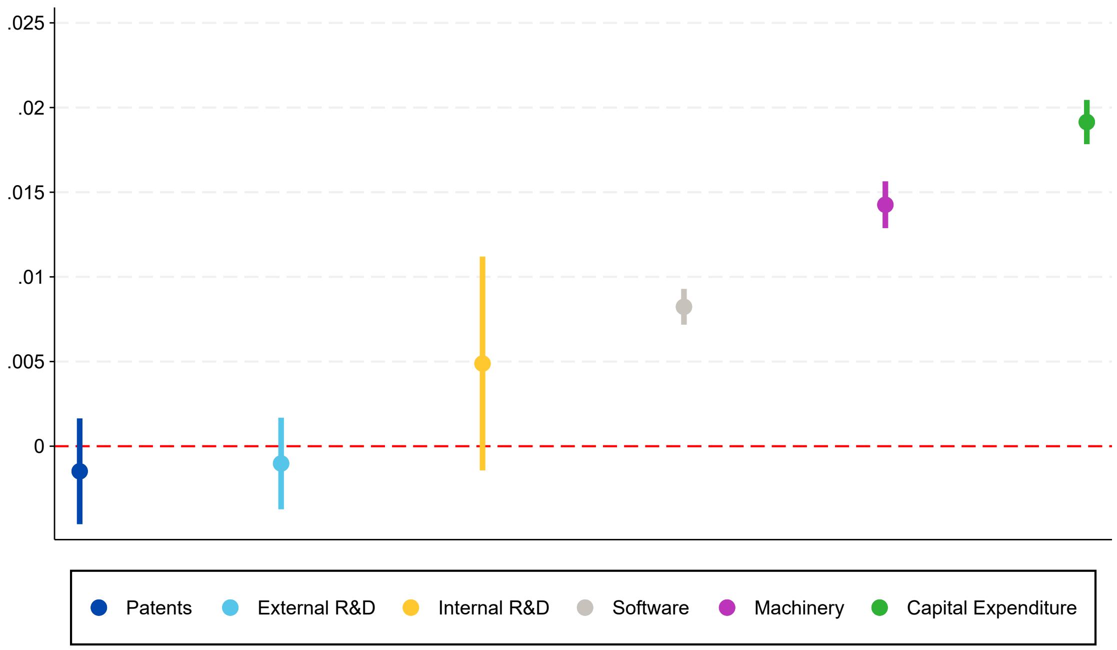
[9] As noted above, this analysis covers all firms who had positive expenditure on R&D in our dataset, excluding those that do not invest in R&D. This may omit some firms who were R&D active but not covered by the historical BERD data.

[10] See, for example, the discussion of private sector productivity returns to public investment in R&D after 6 years, in DSIT 2024

[11] As summarised in Aghion & Jaraval 2015, and explored more recently for the UK in Roper & Nana-Cheraa 2023.

Figure 5-3 Positive associations between a range of investment types and TFP



Coefficients from regressions of TFP on patents (2000-2013), External R&D (2000-2021), Internal R&D (2000-2021), software investment (2000-2021), machinery investment (2000-2021) and total capital expenditure (1997-2021), from ARDx/ABS and BERD. Coefficient shows the percentage impact on TFP levels of a 1% increase in investment. Lines represent 95% confidence intervals around estimated coefficient.

5.30 In Annex C, we present other results on the relationship between R&D and productivity. We show that there is a significant positive correlation between R&D expenditure and TFP across firms when we do not include our full set of controls – meaning that firms that have increased R&D spending also tend to have higher TFP. However, the fact that this effect is not significant in our most restrictive specification suggests that there may be other firm-specific factors which influence this correlation, beyond the pure impact of increases in R&D expenditure within a given firm that is already R&D active.

5.31 We also show a significant positive relationship between turnover and R&D expenditure when controlling for firm size and including our set of fixed effects controls. This suggests R&D expenditure has a positive association with overall labour productivity, as for a given number of employees, when firms increase R&D spending they also increase output.

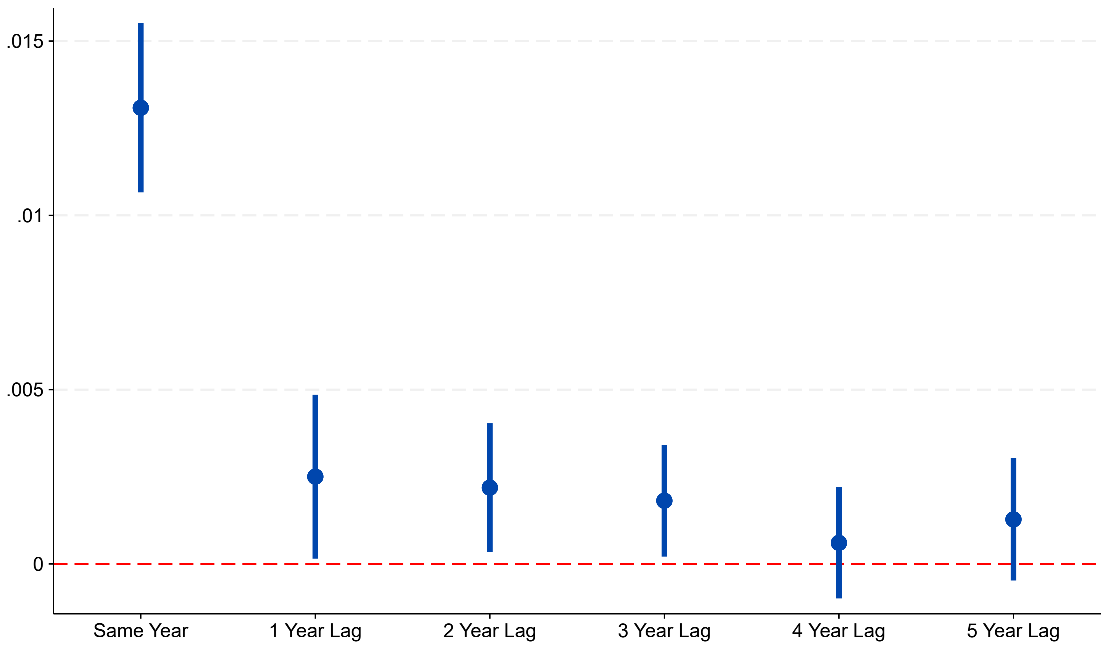
5.32 Also in Annex C, we show a range of ways in which we test the robustness of the relationship between investment and TFP. We find these positive relationships between total investment, machinery and software are consistent across subperiods (2000-2005, 2006-2010, 2011-2015, 2016-2021) and when applying alternate transformations of our variables which do not remove firms with zero investment. We also show that capital expenditure has a positive relationship with labour productivity.

Increases in a firm's capital expenditure are associated with TFP increases in the following three years

5.33 Our main results focus on the contemporaneous association between investment and TFP. However, we would expect that some technology investments take time to be integrated into business processes and result in productivity gains. We investigate this by looking at the relationships between TFP, and capital investment in previous years.

5.34 We find that the level of TFP in a given year is positively associated with both capital investments in that year, and in the prior 3 years. This shows that investment has immediate impacts on TFP as well as further increasing future TFP. Figure 5-4 shows the effect of capital expenditure on a firm's TFP, for the set of firms where we can track this effect over at least a five-year period. We find that for a given firm, in a given year, current TFP is positively associated with capital expenditure in the current year and the previous three 3 years. Each lagged investment term reflects the additional contribution of investment made to current TFP. The cumulative impact on TFP in any given year represents the sum of individual impacts from investments made in the current and previous years.

Figure 5-4 Capital expenditure increases are associated with positive TFP returns in the following three years



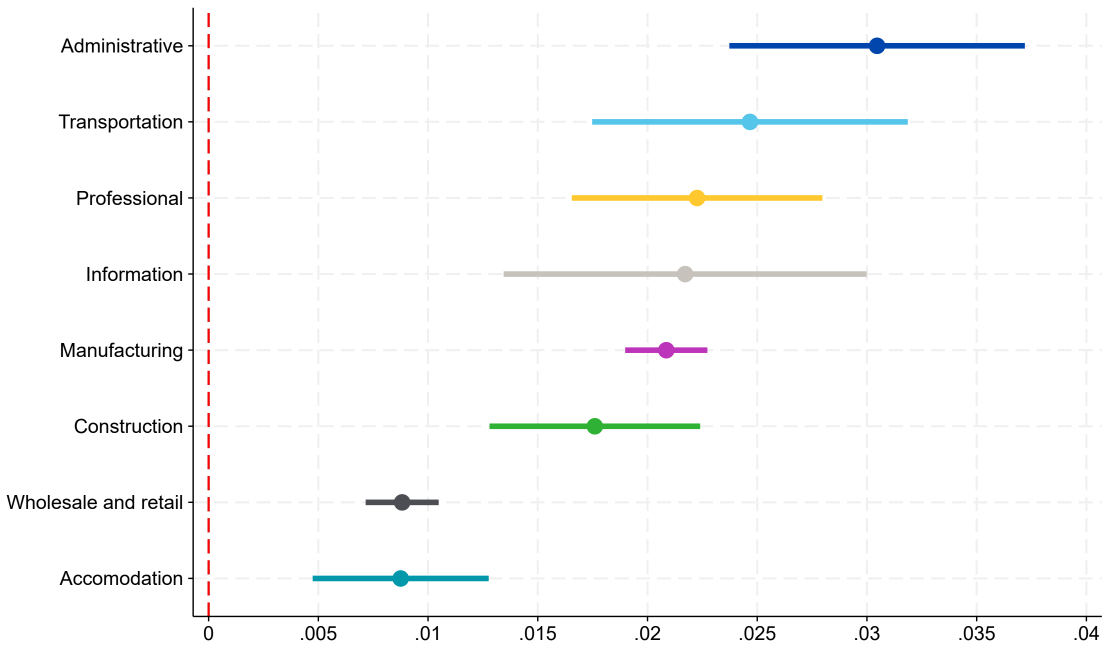
Coefficients from regressions of a firm's TFP in the current year and its capital expenditure in the current year and previous years, 1997-2021, from ARDx/ABS and BERD. Coefficient shows the *percentage impact on TFP levels of a 1% increase in investment. Lines represent 95% confidence intervals around estimated coefficient.*

Increases in TFP are associated with increases in capital investment across all sectors, with some variation in effect size

5.35 Typical technologies and production approaches vary substantially between sectors and industries. We have taken this into account by including fixed effects to generate average results that control for this variation. However, our average effects across the entire economy might mask industry heterogeneity. We have therefore explored how the relationship between investment and TFP varies for different sectors of the economy.

5.36 We break down this relationship between capital investment and TFP across high level sectors (SIC-sections). Figure 5-5 shows coefficients and 95% confidence intervals for a series of regressions for firms within each broad sector. Our finding of positive associations between TFP and investment holds across all sectors. This shows that our overall results hold across different parts of the economy, rather than being driven just by some sectors, though there appears to be some variation in the strength of association between different sectors.

Figure 5-5 Capital investment is more strongly associated with TFP in the administrative sector



Coefficients from regressions of TFP on capital expenditure (1997-2021), by industry, from ARDx/ABS. Coefficient shows the percentage impact on TFP levels of a 1% increase in investment. Lines represent 95% confidence intervals around estimated coefficient.

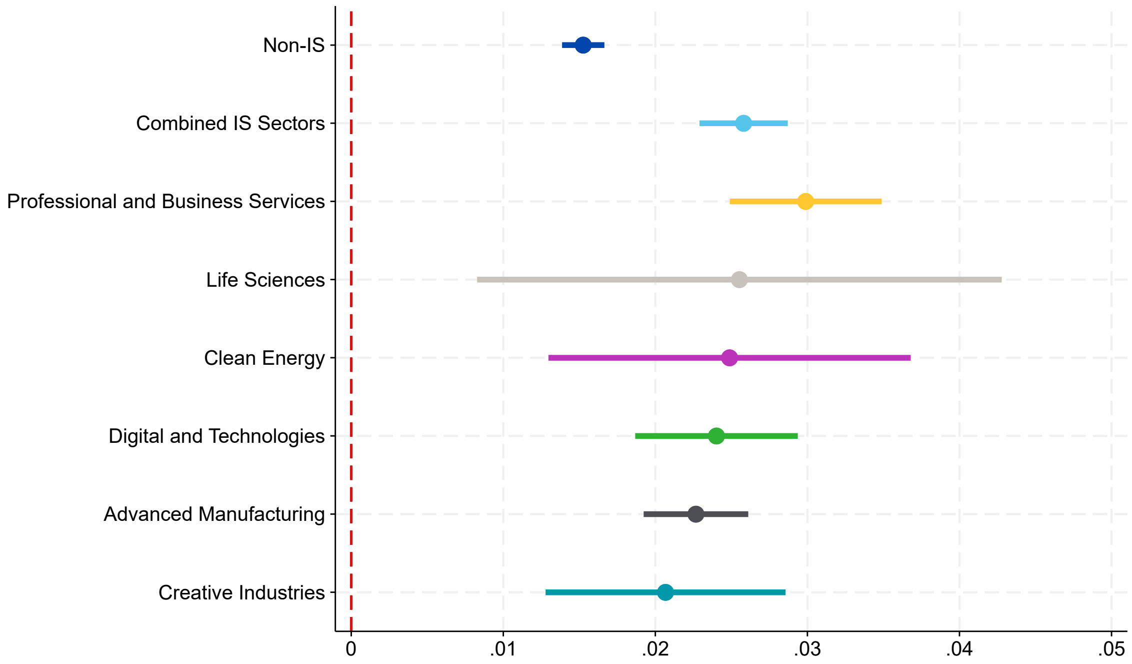
IS sectors see a stronger association between TFP and capital expenditure

5.37 As discussed in Section 3, we are also interested in exploring relationships in the IS-8 sectors which are the focus of the government's Industrial Strategy. This section sets out results for the six of the IS-8 sectors that we are able to analyse.

5.38 Figure 5-6 shows the increase in a firm's TFP associated with a 1% increase in their total capital expenditure in the same year, on average across IS sectors combined, for each of the IS sectors individually and for non-IS sectors. We find that the association between capital expenditure and TFP is stronger for IS sectors than for non-IS sectors. There is some variation between individual IS sectors, but this is within a relatively narrow band. Where a firm in an IS sector increases investment by 10%, this is associated with 0.2-0.3% higher TFP. In non-IS sectors, this is around 0.15%. The relative size of the sectors affects the certainty we have over these estimated coefficients. For instance, we have relatively few firms in the life sciences sector in our sample, and hence a wider confidence interval.

5.39 These stronger associations are consistent with higher productivity returns on investment within IS sectors, which suggests these may have higher potential for TFP growth from additional investment. In line with our economy-wide results, we do not find a significant association between TFP and R&D expenditure within any of the IS sectors – these results are set out in Annex C. This does not imply that R&D investment doesn't have productivity benefits, but that our short-term analysis is not able to detect an effect within firms.

Figure 5-6 TFP's associations with capital expenditure are particularly strong in certain IS sectors



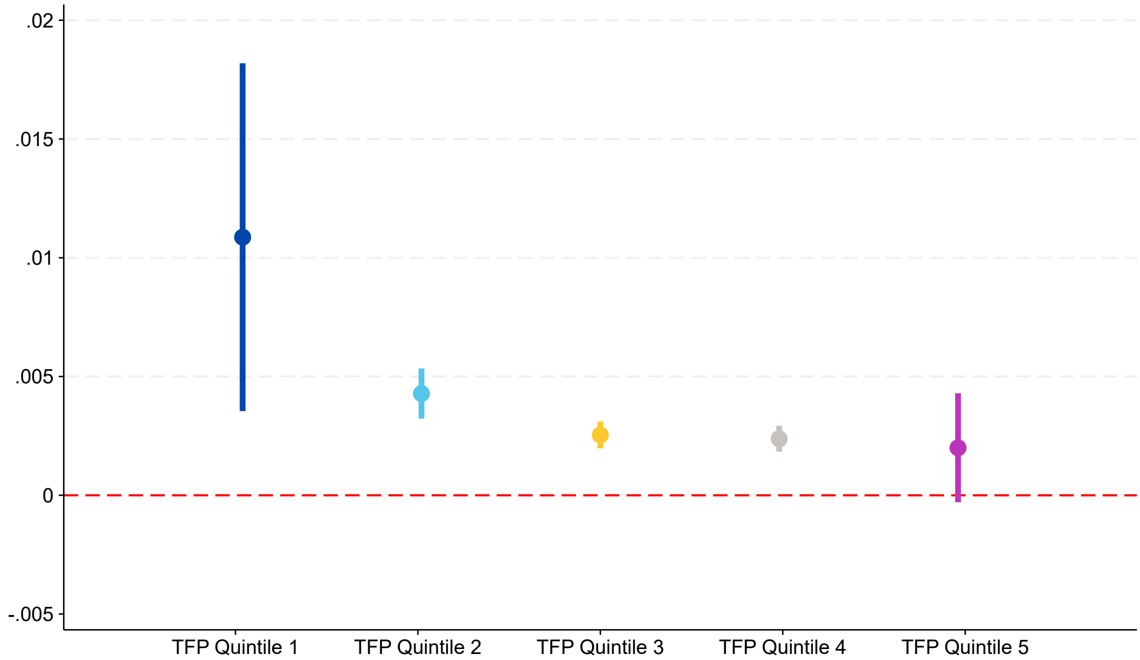
Coefficients from regressions of TFP on capital expenditure (1997-2021), by IS sector, from ARDx/ABS. Coefficient shows the percentage impact on TFP levels of a 1% increase in investment. Lines represent 95% confidence intervals around estimated coefficient. Lines represent 95% confidence intervals around estimated coefficient.

TFP gains from investment may be slightly greater for firms with initially lower TFP

5.40 Firms at different points of the TFP distribution might expect to see different productivity gains from investment. This is because firms with high TFP are likely to be at or close to the technological frontier, whereas firms with lower TFP have greater potential to catch up through adopting better technologies.

5.41 In Figure 5-7 we show how this association differs depending on a firm's starting level of TFP. We find that this association may be somewhat stronger for firms with initial TFP in the bottom 20% of the distribution ('Quintile 1'), though there is uncertainty about the size of this effect. Many of these firms do not invest, but those that do appear to experience greater TFP gains from increased investment that those in the top 20% of the TFP distribution ('Quintile 5').

Figure 5-7 TFP has a stronger association with capital expenditure for firms with lower initial TFP



Coefficients from regressions of a firm's TFP on its capital expenditure (1997-2021), for firms at different quintiles of the TFP distribution, from ARDx/ABS. Coefficient shows the percentage impact on TFP levels of a 1% increase in investment. Lines represent 95% confidence intervals around estimated coefficient.

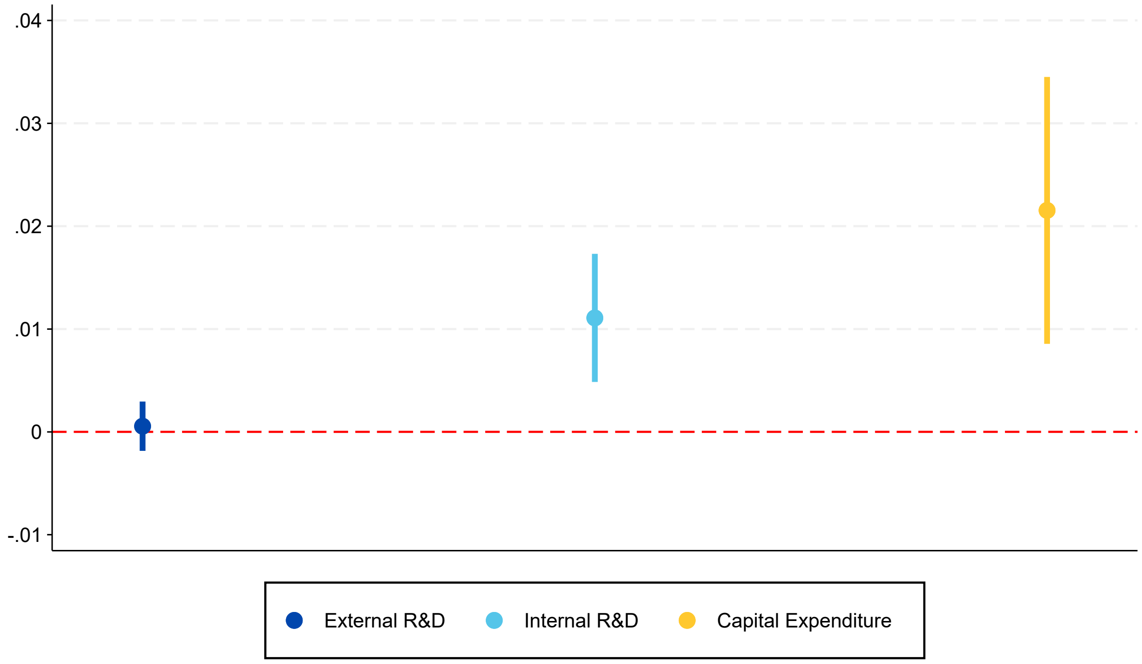
Increases in an industry's capital expenditure and internal R&D are associated with TFP increases

5.42 An alternative way of examining this relationship is to look at industry-average levels of TFP and investment, to explore whether industries with higher average investment also tend to have higher average TFP.

5.43 Our finding of a positive relationship between capital expenditure and TFP holds when we test the associations across industries, rather than firms. Figure 5-8 shows that 10% increases in weighted average capital investment within an industry are associated with approximately a 0.3% increase in the weighted average TFP of that industry. Unlike our firm-level analysis, we additionally find a statistically significant association between industry-average Internal R&D expenditure and TFP.

5.44 These industry-wide estimates account for spillovers between firms in the same industry that are unaccounted for in firm-level analysis. For example, investment among firms can lead to productivity spillovers as firms learn from each other. This may explain why we find a significant relationship between Internal R&D – reflecting productivity gains for firms in a given industry that stem from one firm's investment in R&D.

Figure 5-8 Industry TFP is associated with its capital expenditure and Internal R&D



Coefficients from regressions of an industry's employment weighted average TFP on its employment-weighted average capital expenditure (1997-2021), internal and external R&D (2000-2021), from ARDx/ABS and BERD. Coefficient shows the percentage impact on TFP levels of a 1% increase in investment. Lines represent 95% confidence intervals around estimated coefficient.

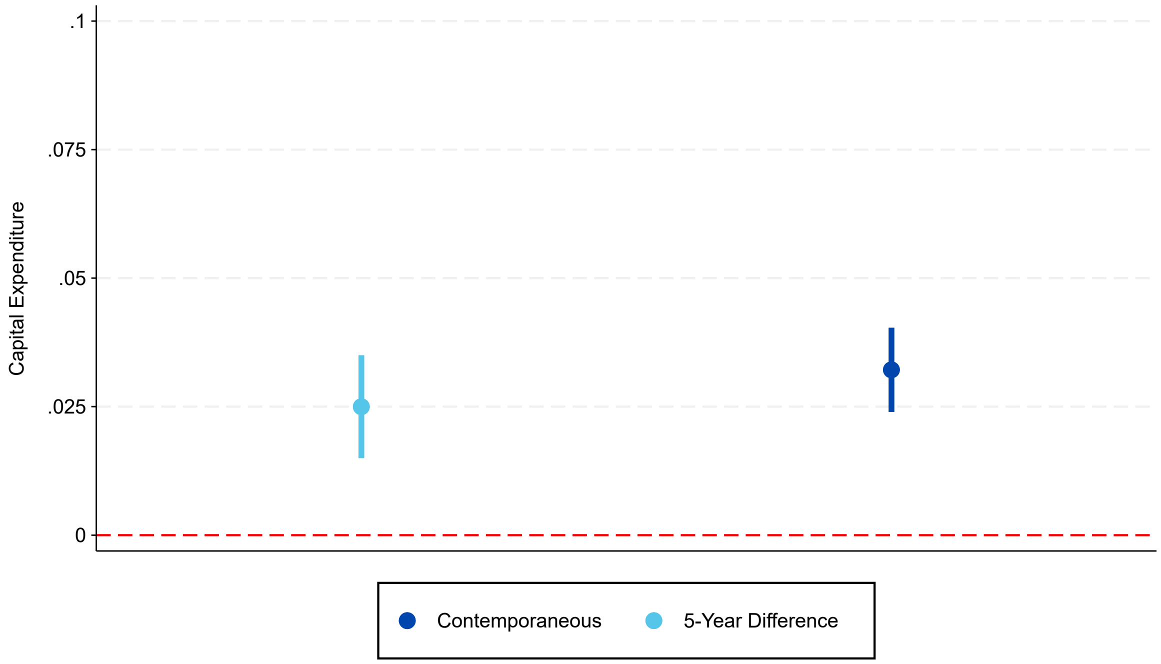
Investment dispersion is associated with more TFP dispersion, but does not have a clear impact on overall industry TFP

5.45 Looking at dispersion of investment and TFP within industries tells us about differences among firms that may not be captured in average effects. Given our central finding of a positive association between investment and TFP, we might expect industries with more dispersed investment to also have more dispersed TFP. We test whether this is the case.

5.46 We also look at the impact on overall industry TFP of this dispersion in investment. More dispersed investment could be bad for overall TFP, if it shows that many firms are not adopting technology that could boost both TFP for them and in aggregate. Alternatively, if a handful of highly productive firms can drive overall productivity growth, we might see a positive relationship between industry investment dispersion and industry TFP levels.

5.47 Figure 5-9 shows the positive association between an industry's investment dispersion and its TFP dispersion, contemporaneously and five years later. For example, a 10% increase in an industry's capital expenditure dispersion, meaning investment among firms becomes more spread out, is associated with almost a 0.7% increase in that industry's productivity dispersion in the current year and it is also associated approximately an 0.8% increase in that industry's productivity dispersion five years later. This positive correlation aligns with the intuition that investment is important for productivity. When there is a wider gap between firm investment levels, this leads to bigger productivity differences within the same industry over time.

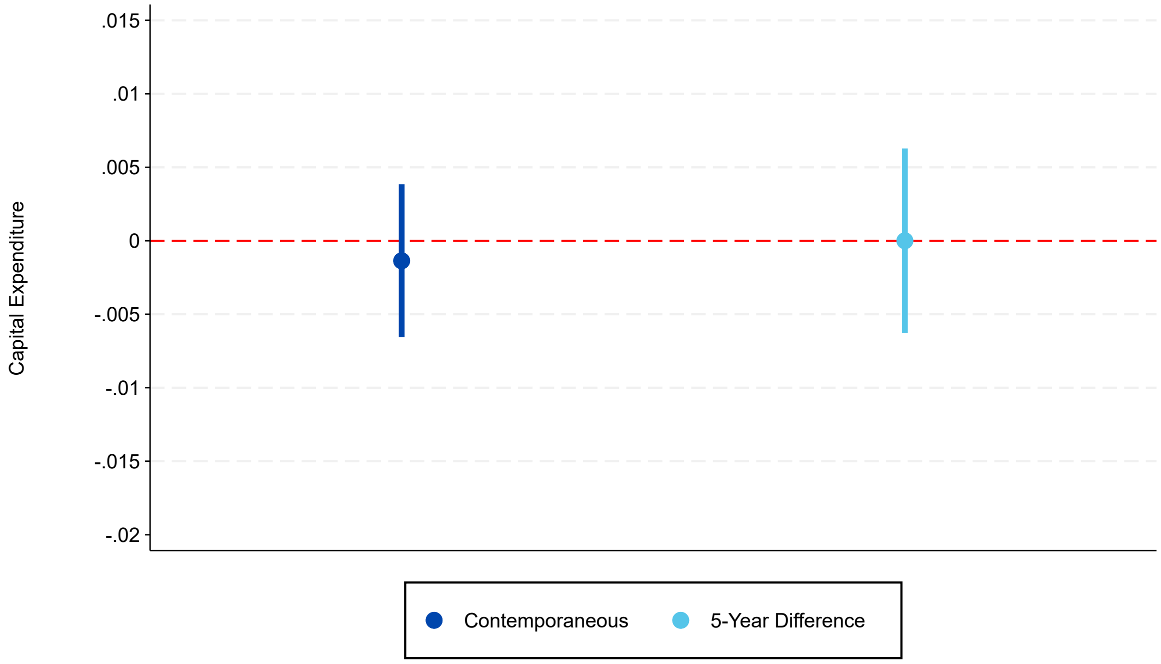
Figure 5-9 Industries with increased capital investment dispersion have more TFP dispersion in the same year and five years later



Coefficients from regressions of an industry's employment-weighted capital expenditure dispersion, against employment-weighted TFP dispersion in the same year (left) and five years later (right). Dispersion is measured using a P90/P10 ratio, from ARDx/ABS and BERD. Lines represent 95% confidence intervals around estimated coefficient.

5.48 We do not find statistically significant evidence that more investment dispersion has a positive or negative association with productivity in an industry as a whole. Figure 5-10 shows the correlation between an industry's investment dispersion and its weighted average TFP growth, in the same year. It also shows the association between changes in investment dispersion and TFP levels over a five-year period – where we do not find a significant correlation.

Figure 5-10 Industry capital investment dispersion does not appear to have a significant impact on productivity outcomes



Coefficients from regressions of an industry's employment-weighted capital expenditure dispersion, against employment-weighted average TFP level in the same year (left) and for the respective differences over five years (right). Dispersion is measured using a P90/P10 ratio, from ARDx/ABS and BERD.

6. How does competition affect the relationship between investment in technology, and productivity?

6.1 The level of competition a firm faces or the level of market power it holds may affect both whether a firm invests in a given technology, and the productivity returns on this investment. Competition may create stronger incentives to adopt technology and make effective use of it as firms seek to escape competition and gain or protect market share. Alternatively, a high level of competition may dampen these incentives if it limits expected future profits from adopting new technologies – this is the hypothesised “inverted-U” pattern linking competition and innovation (Aghion et al., 2005).

6.2 We explore the impact that differences in firms’ market power – measured principally by whether a firm has a markup above the median for their sector – has on the TFP gains from investment. We also look at this relationship for firms in specific sectors of the economy. We examine the equivalent relationship for industry-average markups, investment and TFP, to understand whether investment in technology has a larger effect on productivity in more competitive industries.

6.3 We find a consistent positive effect of competition on the TFP gains firms realise when they invest. Firms with less market power, or in more competitive industries, gain larger TFP benefits from investment.

The positive association between capital expenditure and TFP is generally stronger at lower markups, both across and within firms

6.4 We approximate firms’ market power using markups, which are used in our State of UK Competition Report (2024) as the central indicator of competition. Markups are defined as the difference between the price a firm charges and its marginal cost of production, and we estimate these using the same production function approach as in State of Competition (see Annex B for more details on out methodology).

6.5 One possible explanation for increased markups is market power – representing the ability to sustain prices above marginal cost. However, markups can also be influenced by other factors unrelated to market power, such as changes in firm cost structures and the relative importance of fixed costs (which could include greater use of intangible capital).

6.6 As described in Section 4, our main approach to analyse the relationship between investment and TFP is to use fixed-effects regressions to control for unobserved differences between firms, sectoral trends and size differences.

To show the effect of this, we first present results without these controls, and then with subsequent controls added.

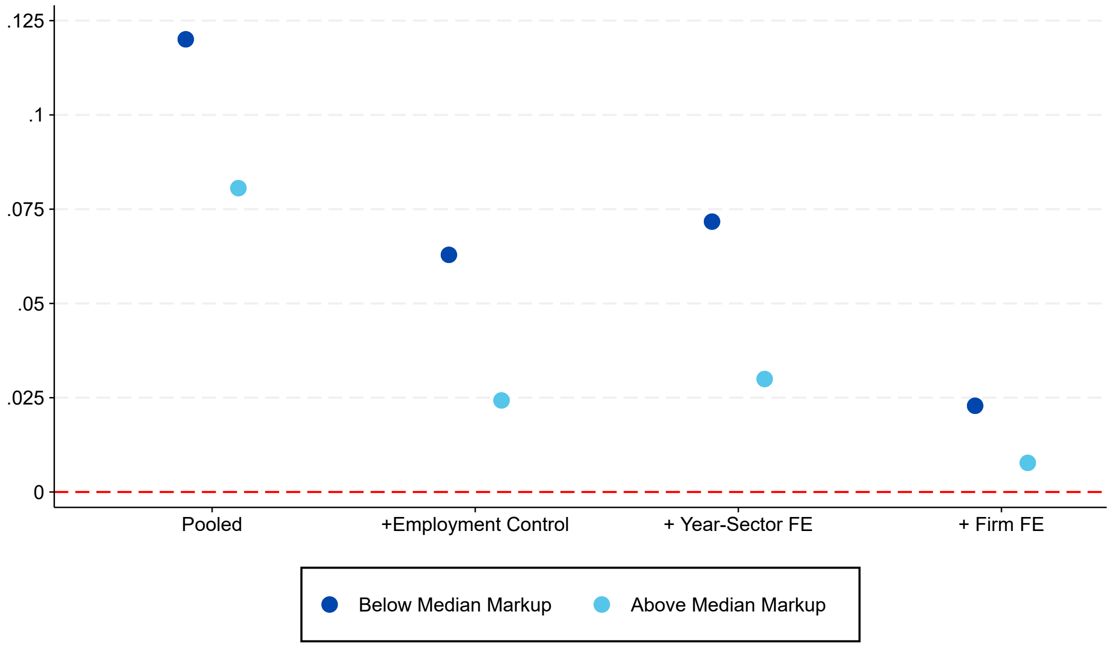
6.7 Figure 6-1 sets out results from a series of regressions of TFP on investment. The points show the estimated coefficient, which can be interpreted as the average increase in a firm's TFP associated with a 1% higher level of capital expenditure, separately for firms with markups above and below their sector median. We compare markups within a sector to reflect that some sectors will have systematically higher markups than others, for example due to differences in the importance of fixed costs.

6.8 This result is presented initially as a pooled OLS regression, showing the average association between investment and TFP across all firms, without controlling for any other factors. Here we find that firms with a markup below the median, which are potentially indicative of lower market power, see a substantially larger positive association between investment and TFP.

6.9 Next, we account for a firm's number of employees, as a measure of their size. We then also control for sector-level trends, through sector-year fixed effects, to remove impacts that are due to changes over time affecting all firms in a sector. In these specifications we continue to see that the relationship between TFP and capital expenditure remains higher for firms with a markup below their industry median, even as the magnitude of the association declines.

6.10 Finally, our main specification also includes firm fixed effects, which means we are now focussing on how investment and TFP change within a given firm, removing effects caused by unobserved differences between firms which do not vary over time. This shows that when a firm increases its investment, they see a stronger association between TFP and capital investment if their markup is below the industry median, though the magnitude of this effect is smaller now we control for other factors. Annex C shows the equivalent charts for other investment variables.

Figure 6-1 The relationship between total capital expenditure and TFP is stronger for low markup firms, and diminishes in magnitude as more controls are included



*Coefficients from regressions of TFP on total capital expenditure (1997-2021) split by whether firm has a markup above or below the median for their sector in a given year, from ARDx/ABS. Coefficient shows the percentage impact on TFP levels of a 1% increase in investment. Lines represent 95% confidence intervals around estimated coefficient. Pooled represents no controls and fixed effects in the regression specification, then we add employment controls, then time * SIC sector fixed effects, then firm level fixed effects.*

6.11 As discussed in Section 4, we focus on firm fixed effects because there are a range of firm-specific factors that influence TFP which may also be correlated with investment levels and markups. When we control for these unobserved differences between firms, the remaining effect of markups on the relationship between investment and TFP diminishes. Nevertheless, this difference in impacts is statistically significant, and the use of controls gives us greater confidence that we have isolated the association between competition, investment and TFP. However, the nature of this relationship means we are only able to describe associations and cannot determine a causal effect.

6.12 Firms may have lower markups because they face more competitive conditions, have different cost structures or are not as sophisticated or productive as the higher-productivity and higher-markup firms in their sector. This result shows these firms with lower markups get a bigger TFP gain from the same level of investment, which could suggest that in more competitive conditions firms make better use of their investments. One possible mechanism for this is improved management practices. Other research has found that competition increases management quality, and improved management quality boosts productivity (Van Reenen 2011, Bloom et al

2014). It is also possible that investment has less impact for high markup firms if they are closer to the productivity frontier and so experience diminishing returns.

Firms with lower markups see higher TFP gains associated with a range of investment types

6.13 We explore the influence of competition on the relationship between investment and TFP for the six different investment variables we examine in Section 5. This allows us to test whether the role of competition is consistent across different types of investment.

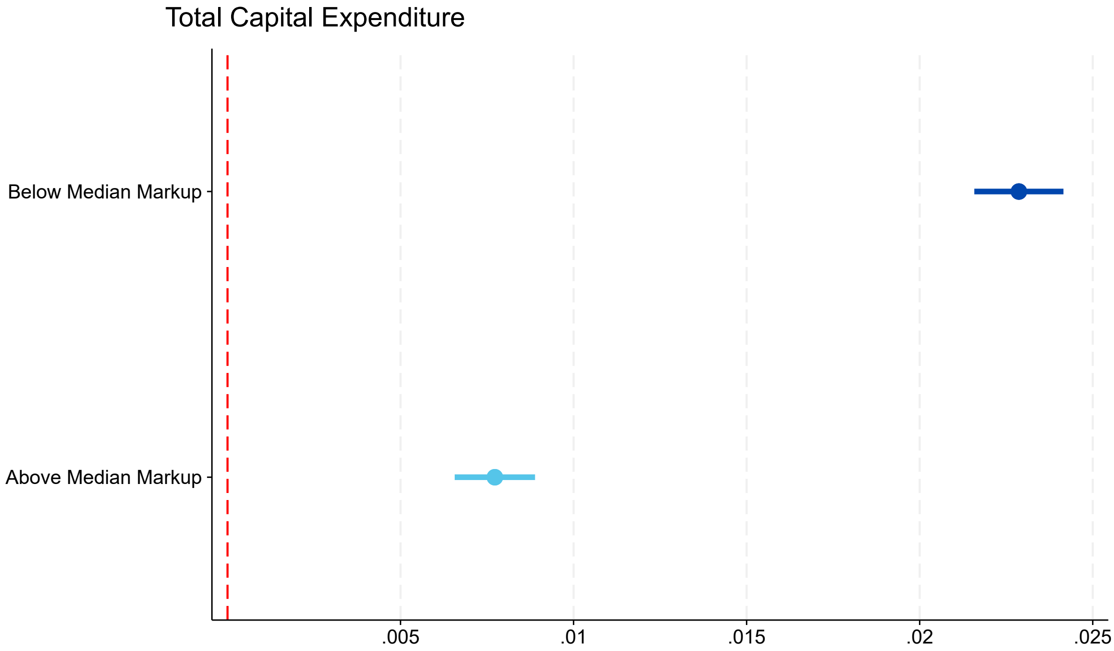
6.14 To give an example, Figure 6-2[12] repeats the result from our main specification. This shows that the positive association between increases in a firm's total capital expenditure and its TFP is three times greater for firms with below median markups compared to those with above median markups. In Annex C, we show that this pattern is repeated for the other 5 measures of investment we use in this analysis. Having a markup below the sector median[13] in a given year also has a strengthening effect on the association between TFP and expenditure on each of machinery, software, patents, internal and external R&D.[14] We also show in Annex C that this relationship is consistent when looking at different broad sectors individually.

[12] We regress firms' TFP on an interaction term including a dummy if the firm's markup is above the industry-median and different technology investment variables. We include controls and fixed effects in our regressions consistent with the regressions in section 5.

[13] We have also replicated these results using median markups defined at the 2- and 4-digit SIC level and find consistent results.

[14] For internal R&D, the relationship between investment and TFP for firms with below median markups is positive but not statistically significant. For patents and external R&D, as the baseline relationship is not significant, we see this pattern manifest as a negative relationship between those investments and TFP for high markup firms.

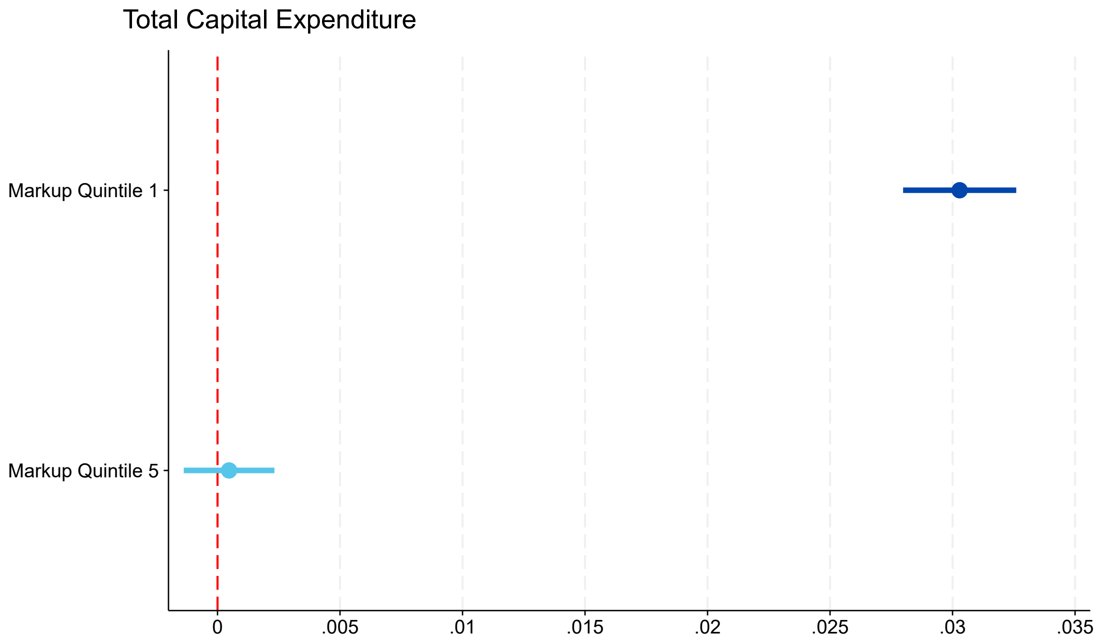
Figure 6-2 Higher markups are associated with lower TFP gains from investment, within a firm



Coefficients from firm-level regressions of TFP on total capital expenditure, split by whether the firm had a markup above or below the median for their sector in a given year (using an interaction dummy variable), 1997-2021, from ARDx/ABS. Coefficient shows the percentage impact on TFP levels of a 1% increase in investment. Lines represent 95% confidence intervals around estimated coefficient.

6.15 To explore this relationship further, we examine how it changes for firms at the top and bottom of the markup distribution. Figure 6-3 shows that firms with markups in the top 20% of the distribution for their sector see no significant correlation between TFP and total investment, compared to all other firms. They also see weaker TFP benefits from sub-categories of investment. In contrast, firms in the bottom 20% of the markup distribution see a substantially bigger TFP gain associated with investment in total, and in software and machinery. This suggests that the dampening effect on TFP gains from investment scales with their relative level of market power. In Annex C, we show similar patterns across our other measures of investment.

Figure 6-3 The negative interaction of markups and investment is stronger towards the top and bottom quintiles, for capital investment



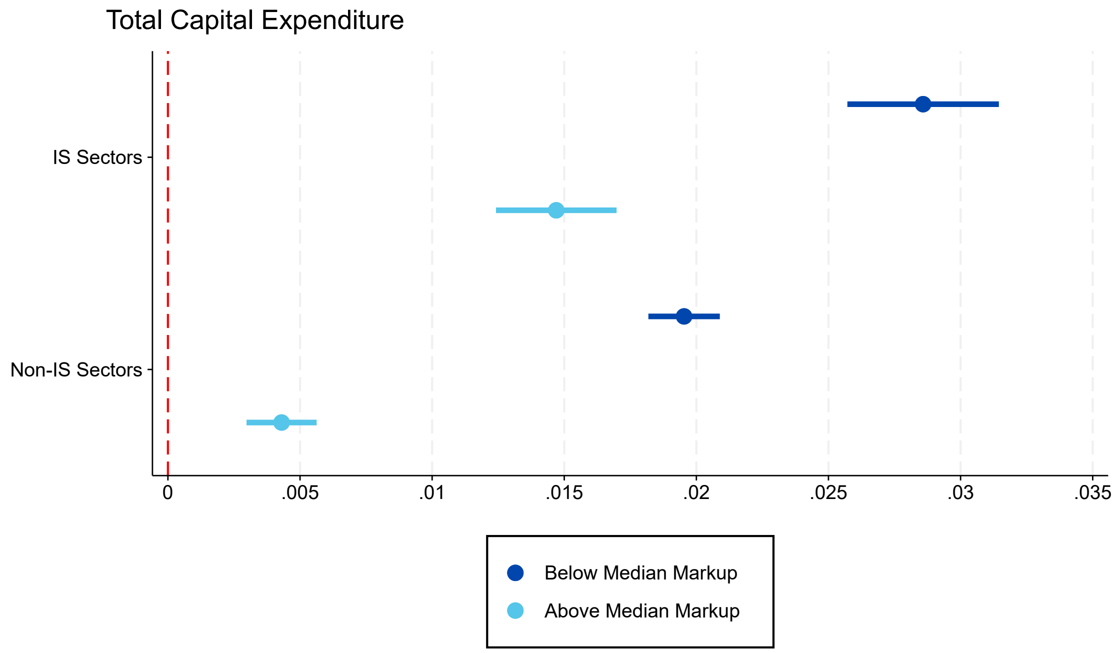
Coefficients from firm-level regressions of TFP on total capital expenditure, for firms with markups in the bottom 20% ("markup quintile 1") or top 20% ("markup quintile 5") for their sector in a given year (using interaction dummy variables), 1997-2021, from ARDx/ABS. Coefficient shows the percentage impact on TFP levels of a 1% increase in investment. Lines represent 95% confidence intervals around estimated coefficient.

Within IS and non-IS sectors, firms with above median markups see lower TFP gains from investment

6.16 To explore differences between sectors in the economy, we again focus on the role of competition in the translation of investment to productivity gains in IS sectors. This allows us to understand whether these effects differ in these high growth potential areas of the economy.

6.17 Figure 6-4 uses total capital investment and shows that when we run the above regressions for firms in IS sectors and all other sectors, the effect of competition appears broadly consistent in the scale of the difference between high and low markup firms. In Annex C, we show consistent results across our other five investment variables.

Figure 6-4 Role of markups in the total investment-TFP relationship in IS sectors and non IS sectors



Coefficients from firm-level regressions of TFP on total capital expenditure split by whether the firm had a markup above or below the median for their sector in a given year (using an interaction dummy variable), separately for firms in IS-8 sectors and in the rest of the economy, 1997-2021, from ARDx/ABS. Coefficient shows the percentage impact on TFP levels of a 1% increase in investment. Lines represent 95% confidence intervals around estimated coefficient.

Industries with high average markups see lower TFP gains associated with investment

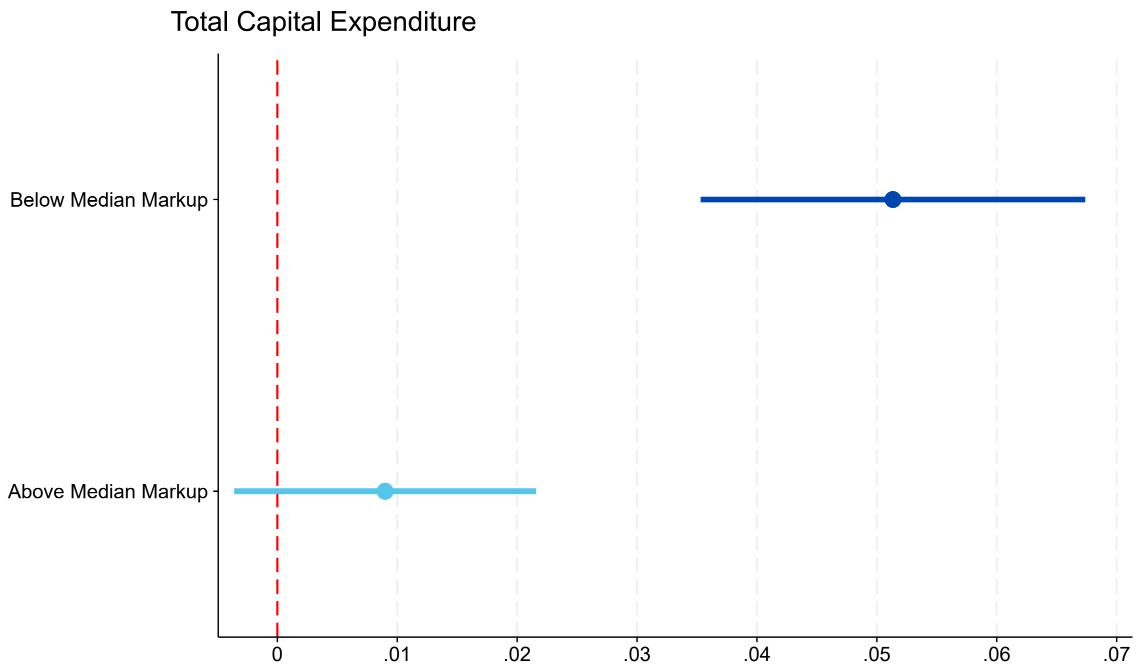
6.18 To explore the impact of the wider competitive environment, we look at the industry level. We examine whether more competitive industries (which we proxy for using average markups) appear to make greater TFP gains from equivalent increases in investment.

6.19 When looking at outcomes for a given industry, rather than firm, we find similar results to our firm-level analysis. Figure 6-5 shows that industries with a markup below the economy median also have a stronger association between industry average TFP and total investment. We find the same effects when looking at sub-categories of investment (see Annex C). These results control for unobserved differences between industries, and between sectors over time.

6.20 This industry-level analysis allows us to examine effects of the wider competitive environment. It also accounts for spillovers between firms that are unaccounted for in firm-level analysis. For example, investment among firms can lead to productivity spillovers as firms learn from each other.

6.21 Similar to points discussed above, whilst higher average markups can be an indicator of weaker competition, this is not the only potential driver. Differences in cost structures, particularly if activities within industries have a greater or increasing share of fixed costs, can also be reflected in differences in average markups.

Figure 6-5 Industries with lower markups have a stronger association between investment and TFP



Coefficients from industry-level regressions of TFP on total capital expenditure split by whether the industry had an average markup above or below the median for their sector in a given year (using an interaction dummy variable), 1997-2021, from ARDx/ABS. Coefficient shows the percentage impact on TFP levels of a 1% increase in investment. Lines represent 95% confidence intervals around estimated coefficient.

7. Conclusion

7.1 We have found evidence that competition plays a role in how effectively investment by a firm translates into technology-related productivity gains. Firms facing more competitive pressure appear to make stronger TFP gains when they invest. Firms with high markups may still see positive TFP gains associated with investment, but these are substantially smaller. Our results suggest that competition drives firms to make better use of investments, and this could include where they are adopting technology. Competition provides greater pressure to realise efficiency and productivity gains to outcompete rivals and eventually escape these competitive pressures.

7.2 Underlying this, we find a significant positive association between firms' investment levels – which we use as a proxy for technology adoption – and their TFP – which can be a broad measure of the results of technology use for firms. This suggests that investment tends to be productivity enhancing on average by improving the technology available to firms, although lots of other factors can influence firm productivity. A 10% increase in capital investment by a firm is associated with an average 0.2% increase in their TFP in the same year, with additional increases in subsequent years. Whilst the magnitude of this effect may seem relatively small, in the context of average annual TFP growth of less than 1% across our sample changes in TFP levels of the scale suggested by our results are meaningful. Investment will typically increase the capital intensity of a given firm. When this is driven by the introduction of a more advanced technology firms also become more efficient, which is reflected in higher TFP.

7.3 We have explored different types of investment and find that investment in machinery and software is most likely to yield TFP gains. We find that the correlation of investment and TFP is also significant in the years following investment, suggesting an extended process where investment in technology is incorporated into business processes over time. We also find indications of a possible positive relationship between internal R&D expenditure and TFP, though this is not statistically significant on our baseline specification controlling for differences between firms. We do not find evidence of an association between patents (intellectual property), or external research and development (R&D) investment and TFP. This likely reflects the uncertain nature of R&D activities and the often-extended timespan between R&D investment and implementation of these innovations in ways that affect that firm's estimated productivity.

7.4 We have also explored the distribution of TFP. We find that differences in TFP across firms have increased. We use firm-level estimates of TFP and find that the gap between firms at the top of the TFP distribution and the rest has increased. This is true both across the economy as a whole, and within the majority of sectors. These findings may help identify particular opportunities to improve overall productivity, including through more effective adoption of technology by a wider range of firms in a given industry.

A. Acknowledgements

A.1 This report was written by James Banner, Oliver Borrows, Samir Doshi, Yannis Papadakis and Tom Farmer on behalf of the CMA Microeconomics Unit.

A.2 The authors would like to thank Diane Coyle, Jonathan Haskel, Richard Kneller, Joel Stiebale and many CMA and government colleagues for their feedback at various stages of the project.

A.3 This work was undertaken in the Office for National Statistics Secure Research Service using data from ONS and other owners and does not imply the endorsement of the ONS or other data owners. We are grateful to the ONS for providing access to these datasets

B. Data, variables and empirical strategies

Data and variables

B.1 The main source of capital investment is the Annual Respondents Database (ARDx). ARDx combines information from the Annual Business Inquiry (ABI) for 1998–2008 and the Annual Business Survey (ABS) from 2009-2020, supplemented with employment data from the Business Register and Employment Survey (BRES) after 2009. We add data from the 2021 ABS.

B.2 We perform a firm level analysis of investment measures and bring into this analysis markup and TFP estimates from our most recent State of Competition publication, as well as external and internal R&D expenditure from the BERD.

B.3 We use the following ARDx/ABS variables as measures of investment:

(a) Value of total capital expenditure (capex) acquisitions,

(b) Investment in purchased computer software,

(c) Investment in machinery and equipment, and

(d) Acquisitions of patents and other intellectual property assets.

B.4 These variables allow us to distinguish between tangible and intangible investments, and to identify technology-related expenditures such as machinery, software and intellectual property.

B.5 A key component of intangible capital investment is Research and Development (R&D) expenditures. We source variables on R&D expenditures from the Business Expenditure on Research and Development (BERD) Survey which started in 1994. BERD is the main source of official R&D expenditure estimates and is based on a sample of approximately 3,500 to 26,000 businesses each year, drawn from the Inter-Departmental Business Register (IDBR).

B.6 Given that both the ARDx/ABS and BERD include IDBR employment and turnover information, which are considered reliable because businesses are legally required to report them to HMRC and they are stored in administrative data sources (PAYE and VAT) without the reporting errors often found in surveys, we use these variables as controls and outcomes whenever possible.

B.7 One limitation of the ARDx is that while it provides extended longitudinal coverage, by harmonizing the ABI and ABS may have introduced additional noise into the resulting dataset. Also, the ARDx measures do not capture any internally developed technology. To address these limitations, we use two alternative measures of investment and innovation: internal and external R&D. We source the variable from the BERD, which distinguishes between in-house (intramural) R&D and purchased (extramural) R&D. One limitation of this dataset is that R&D information for businesses with lower R&D values may be less accurate because of the imputation methods and sampling techniques used in the survey for these businesses.

B.8 We supplement our analysis with two additional surveys that include technology-related variables: the UK E-Commerce Survey and the UK Innovation Survey (UKIS). Both surveys draw their samples from the IDBR, cover a wide range of sectors.

TFP and Markup Estimates

B.9 TFP and markup estimates are sourced from analysis carried out for our most recent State of Competition publication (2024). By studying changes in turnover while controlling for firm size (employment), we can analyse how investment is linked to productivity. However, it is possible that increased turnover results from firms increasing their capital stock by investing in capital assets. To separate efficiency changes from changes in production factors, we need to control for capital stock, which allows us to calculate Total Factor Productivity as a residual. In this analysis, we use focus on a Translog production function for greater flexibility in deriving TFP, and check robustness using the alternative of a Cobb Douglas function. Thus, evidence of TFP dispersion could be interpreted as suggesting uneven technology adoption and diffusion. This is because if all firms had equal access to and adopted the same technologies, productivity differences would not be present. This estimate of TFP is revenue based, and so also captures pricing heterogeneity in addition to efficiency.

B.10 Specifically, starting from the cost minimisation problem of the firm, we can derive the firm's optimality conditions which show that the markup is equal to ratio between the output elasticity of each variable input (in short output elasticity), and the input's share of revenue. Estimates of the output elasticities are obtained by estimating a parametric production function such - Cobb-Douglas or more general Translog function. The input's share of revenue is measured directly from the data. Therefore, the markup μ is defined as

$$\mu = \frac{\theta_m}{s_m}$$

where θ is the output elasticity and s is the share of revenue for that input.

B.11 In this report, we estimate markups using an OLS estimator and a Translog production function at the SIC 2-digit level. The data sources for our analysis are ARDx (covering 1997-2020) and the ABS (2021). We use intermediate consumption (materials) as the variable input in the production function. This method is consistent with the baseline markup estimation approach used in the CMA State of UK Competition 2024 report (SoC, 2024), which also implemented and compared alternative methods. During the estimation process, we calculate firm-level total factor productivity (TFP) as the residual output after accounting for capital and labour contributions.

B.12 Before estimation, we clean the firm-level data by trimming the top and bottom 1% of observations for capital share, labour share, and intermediate consumption share. We also remove the observations that – once converted to logarithms – have negative values for capital, employment, turnover, value added, intermediate consumption, labour cost, or investment.

Empirical Strategy

B.13 We estimate the relationship (β) between investment (X) and TFP (Y). Our identification relies on within-firm variation over time. By augmenting the specification with a firm level employment control variable, firm fixed effects (α) that absorb unobserved, time-invariant characteristics (C), and sector-year fixed effects (δ) that absorb common shocks and trends at the industry level, we mitigate the impact of confounding factors and isolate the relationship of interest. The estimating equation has the following form:

$$Y_{it} = \beta X_{it} + \gamma C_{it} + a_i + \delta_{jt} + \varepsilon_{it}$$

where *i* denotes firms (RUREFs) and *j* denotes sectors (SIC sections). After including markups (M) and their interaction with investment, the estimating equation, in compact matrix notation, becomes:

$$Y_{it} = \beta X_{it} + C_{it}\gamma + \kappa\,(X_{it} \times M_{it}) + a_i + \delta_{jt} + \varepsilon_{it}$$

where C now is a vector of control variables (employment and markups).

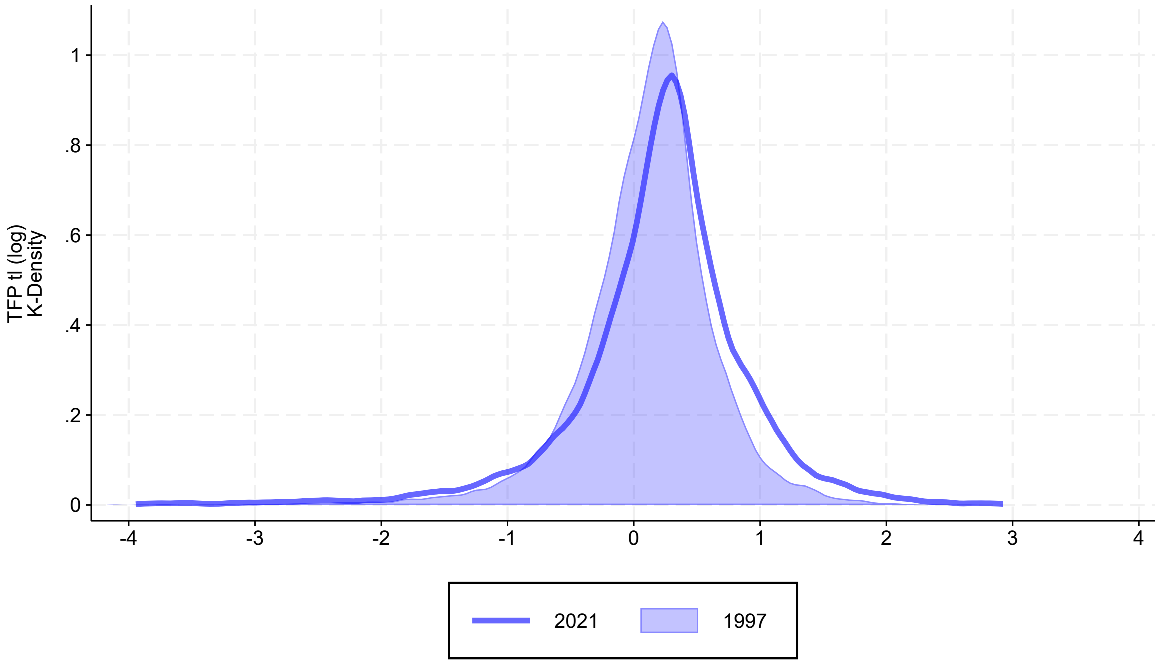
C. Supplementary charts

TFP dispersion has increased over time

C.1 In Section 3 we describe the increasing dispersion of firm-level TFP based on the gap between the top and bottom of the distribution. Here we present charts showing alternative measures of TFP dispersion.

C.2 Figure 7-1 shows the TFP distribution for all firms in our ARDx/ABS sample in 1997 and 2021. We can see the distribution has widened over time.

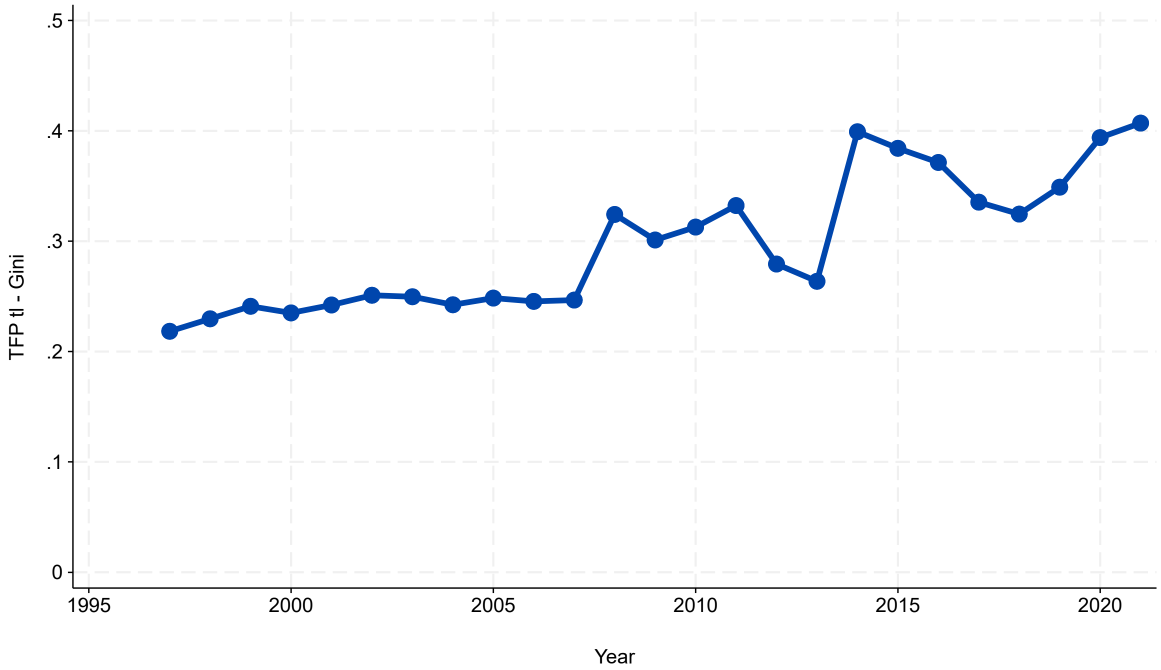
Figure 7-1 TFP distribution has widened over time



Kernel density of the log of TFP in 1997 and 2021, from ARDx/ABS

C.3 Figure 7-2 shows the Gini coefficient of all firms in our sample over time. It’s rise indicates more unequal TFP levels amongst those firms.

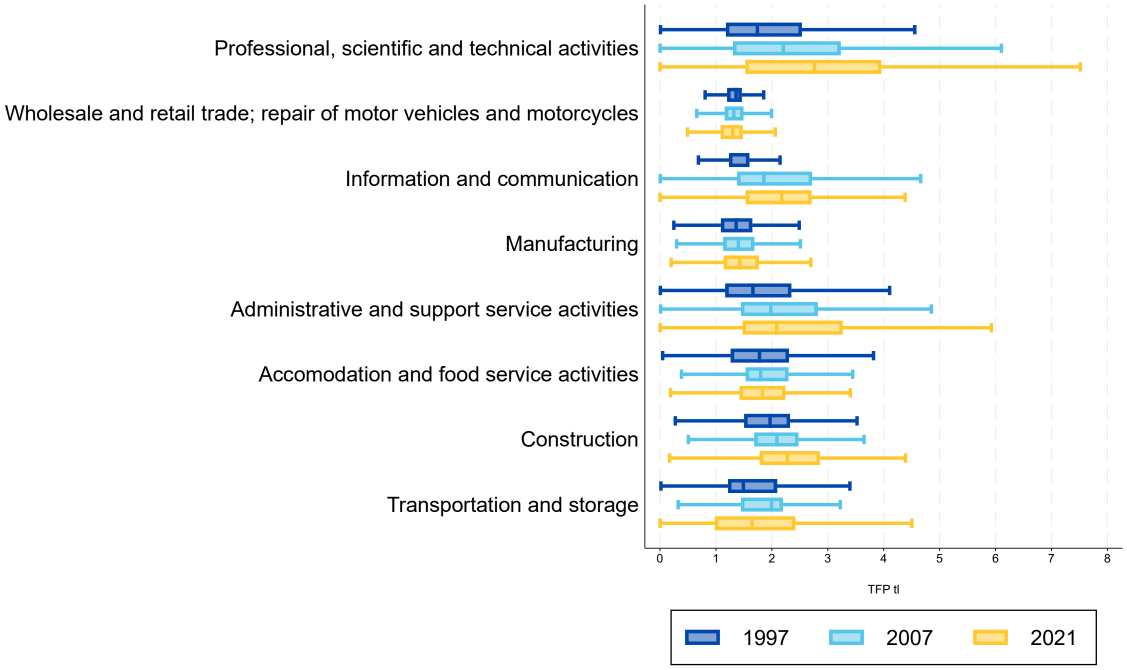
Figure 7-2 Rising Gini coefficient for TFP points to more dispersion



Gini coefficient TFP for GB firms, 1997 to 2021, from ARDx/ABS

C.4 We find that our results on within-sector TFP dispersion from 1997 to 2019 (see Figure 4-3) are consistent with extending the time period of analysis to 2021, considering the Covid-19 pandemic overlapping with the longer time-period. Figure 7-3 shows boxplots of TFP amongst firms within sectors, highlighting the quartiles of the TFP distribution (the box) and outlying values (the tails), in 1997, 2007, and 2021.

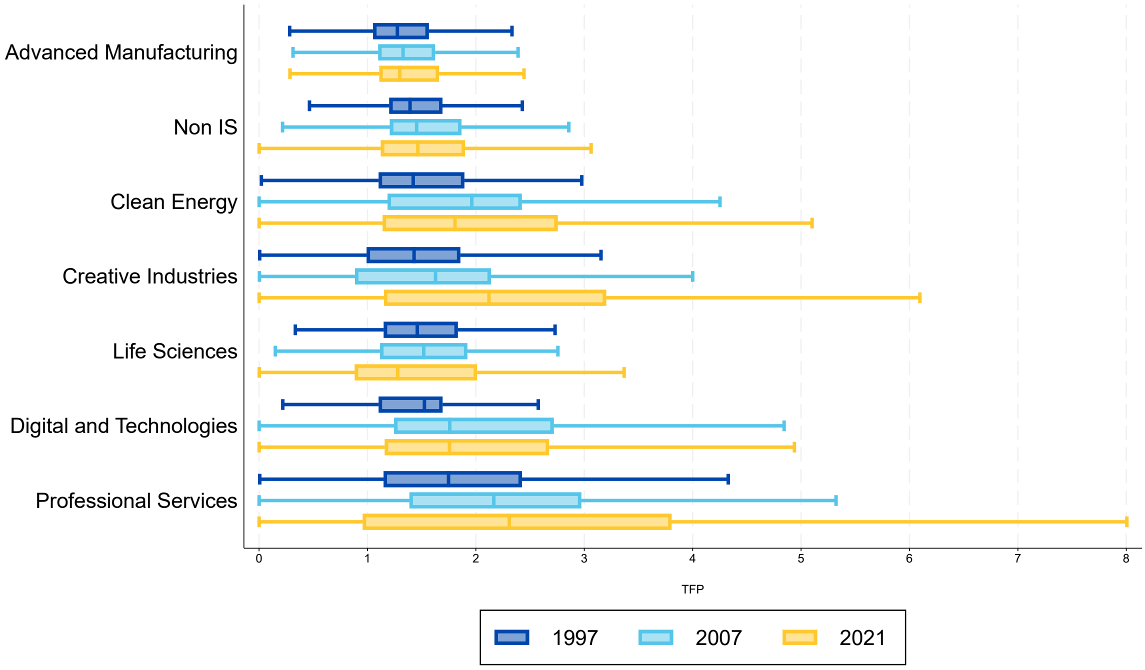
Figure 7-3 TFP dispersion among firms has increased within most sectors



Firm-level TFP boxplots within SIC sectors, boxes show quartiles and median, tails show extreme values 1.5x the inter-quartile range, for years 1997, 2007 and 2021, from ARDx/ABS

C.5 We find that our results on widening within-IS-sector TFP dispersion from 1997 to 2019 (see Figure 4-4) are consistent with extending the time period of analysis to 2021, considering the Covid-19 pandemic overlapping with the longer time-period. Figure 7-4 shows boxplots of TFP amongst firms within IS sectors and across all non-IS sectors, highlighting the quartiles of the TFP distribution (the box) and outlying values (the tails), in 1997, 2007, and 2021.

Figure 7-4 Some IS sectors have experienced large increases in TFP dispersion over time



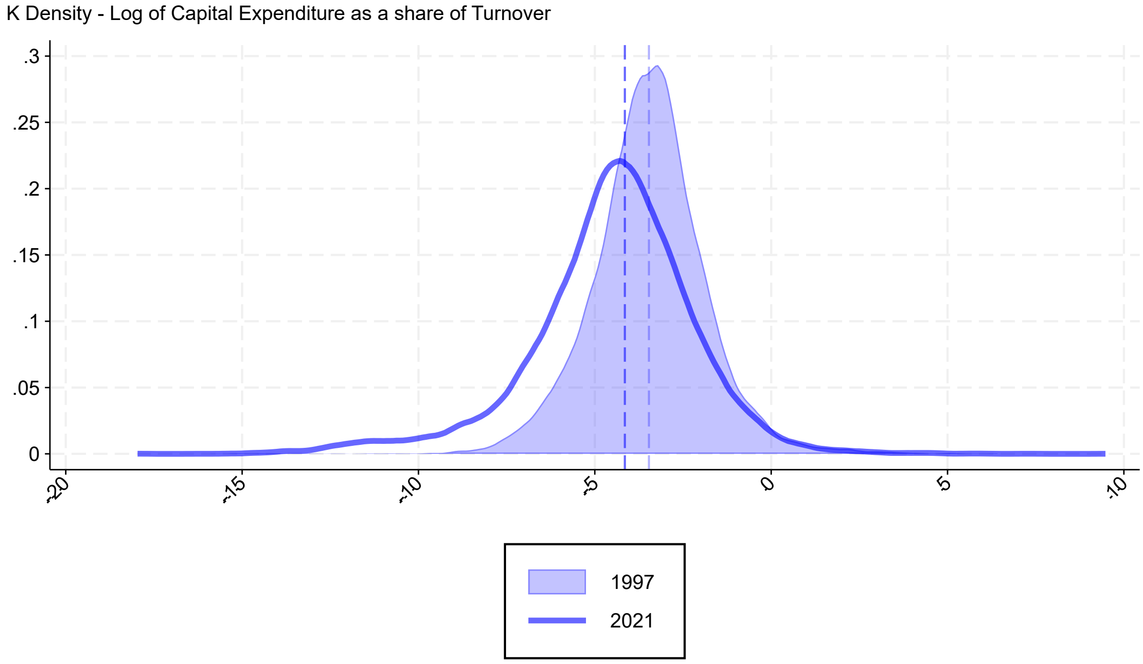
Firm-level TFP boxplots within each of the IS sectors and the rest of the economy, 1997, 2007, 2021, from ARDx/ABS

Investment dispersion has increased over time

C.6 Across various technology measures, investment dispersion has increased over time.

C.7 Figure 7-5 shows the allocation of capital investment among firms throughout the economy. This differences in capital spending between firms have widened in 2020 compared to 1997, suggesting more uneven investment taking place across firms. A substantial amount of firms report little to no investment in these years, potentially suggesting uneven technology adoption between firms. We explore below whether these differences in investment levels can be associated with differences in firms' TFP performance.

Figure 7-5 The distribution of capital expenditure across firms has widened between 1997 and 2021

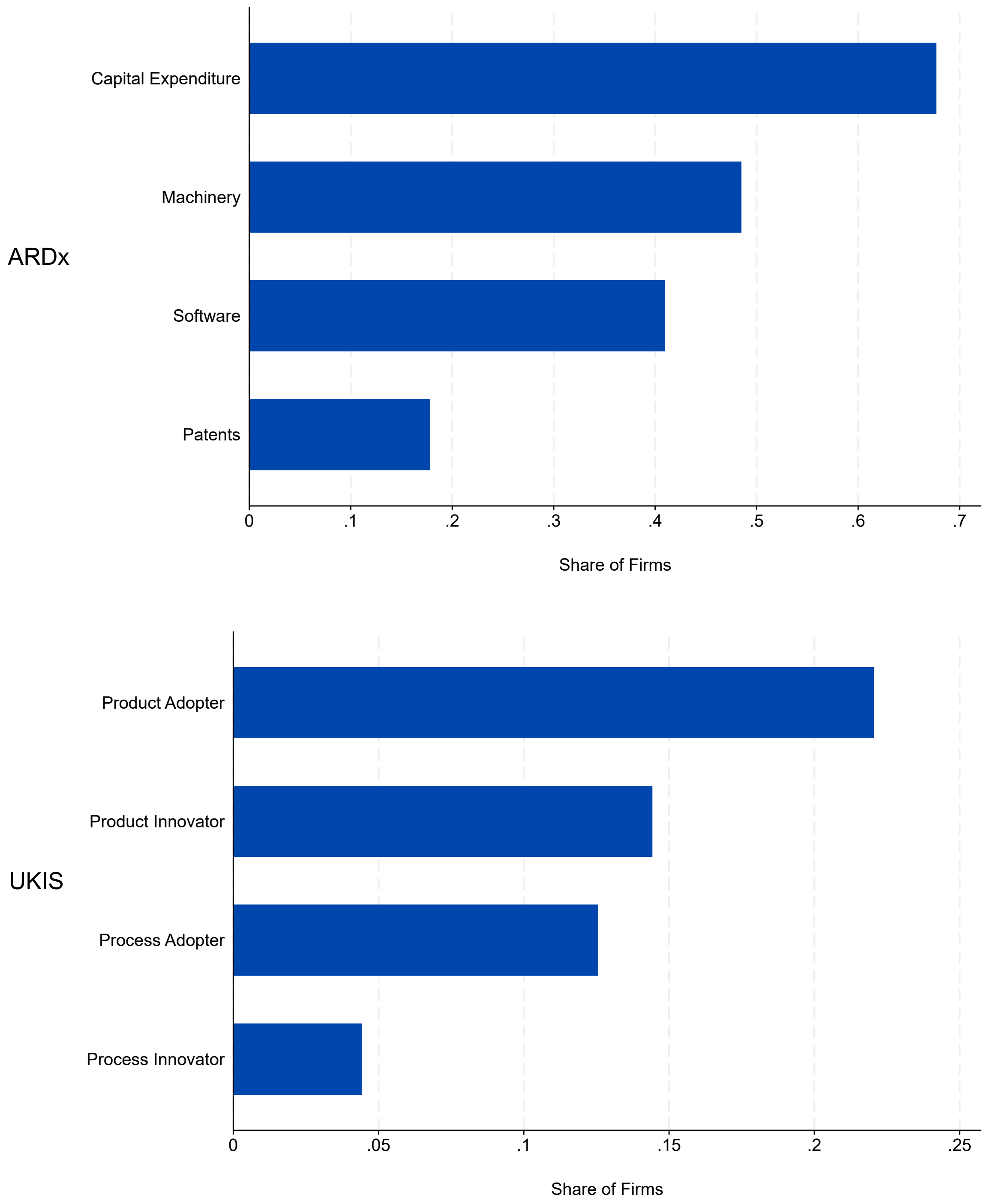


K-density of capital investment, as a proportion of turnover across all firms in our sample, 2000 and 2021, from ARDx

Investment or varies by type

C.8 Figure 7-6 presents the proportion of firms submitting a non-zero value for technology investments and find that 60-70% of firms invest in capital expenditure of one form. Just under half of our firms invest in machinery. A smaller, but substantial, proportion of firms invest in software and patents – at least 15% of firms in our sample. It is also clear that more firms engage in internal R&D compared to external R&D.

Figure 7-6 Not all firms invest in capital, machinery, software, and patents

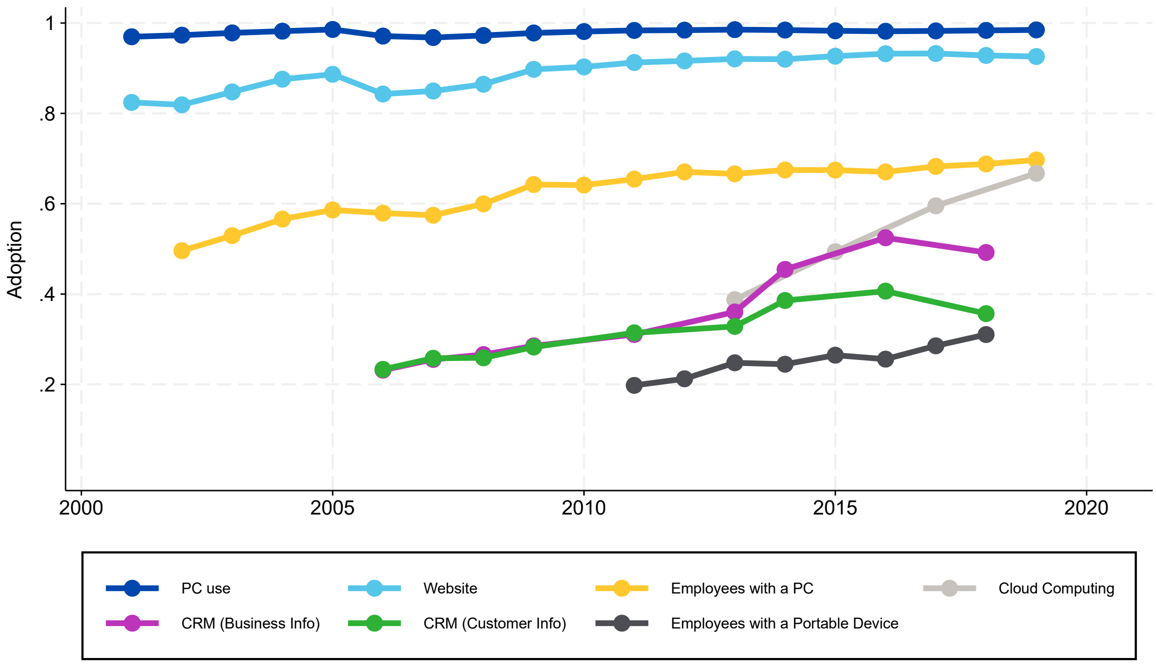


Proportion of firms adopting each technology, on average across the years they were asked about them, 1997-2021, from ARDx/ABS BERD, E-commerce, and UKIS

Adoption levels have grown for certain technologies

C.9 Adoption of some technologies has increased over recent years. Figure 7-7 uses survey data on the use of specific technologies from the e-commerce survey. This shows technology usage rates have increased, more notably for newer technologies such as CRM software, cloud computing and portable devices. Note that many surveys ask firms about technologies once they have gained prevalence in the economy, so these results do not capture early-stage uptake of specific technologies.

Figure 7-7 Specific technology usage rates have grown in recent years



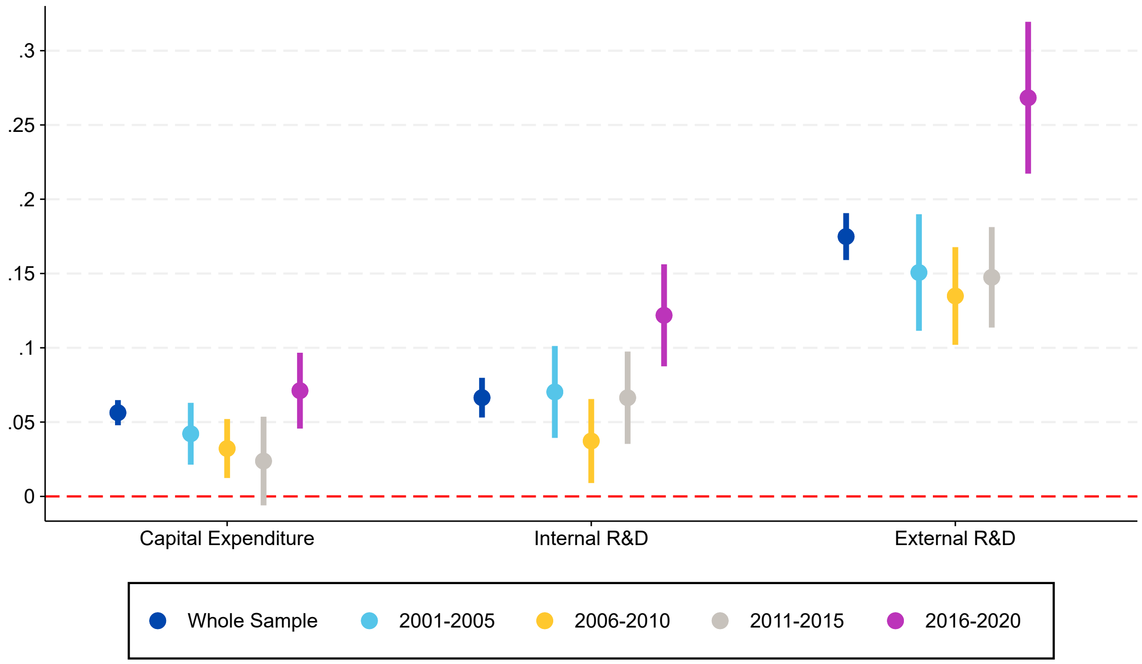
Proportion of firms claiming to adopt various types of technologies, 2001 and 2019, from E-commerce

A firm invests more when other firms within their industry increase that type of investment

C.10 When firms are making decisions to invest, one factor they might take into account is the behaviour of others in their industry (some of whom are likely to be competitors). We find that a firm's investment is correlated with similar investment for other firms within their industry.

C.11 Figure 7-8 shows that, generally in most time periods and across different types of investment, when the average investment of other firms within a (narrowly defined four digit) industry increases, this is associated with a firm increasing its own investment. This suggests that firms mirror investments done within their industry – one possible explanation is that this reflects their effort to outperform or keep up with their competitors.

Figure 7-8 Across time, and within subperiods, a firm's own investment is generally positively correlated with investment in their industry

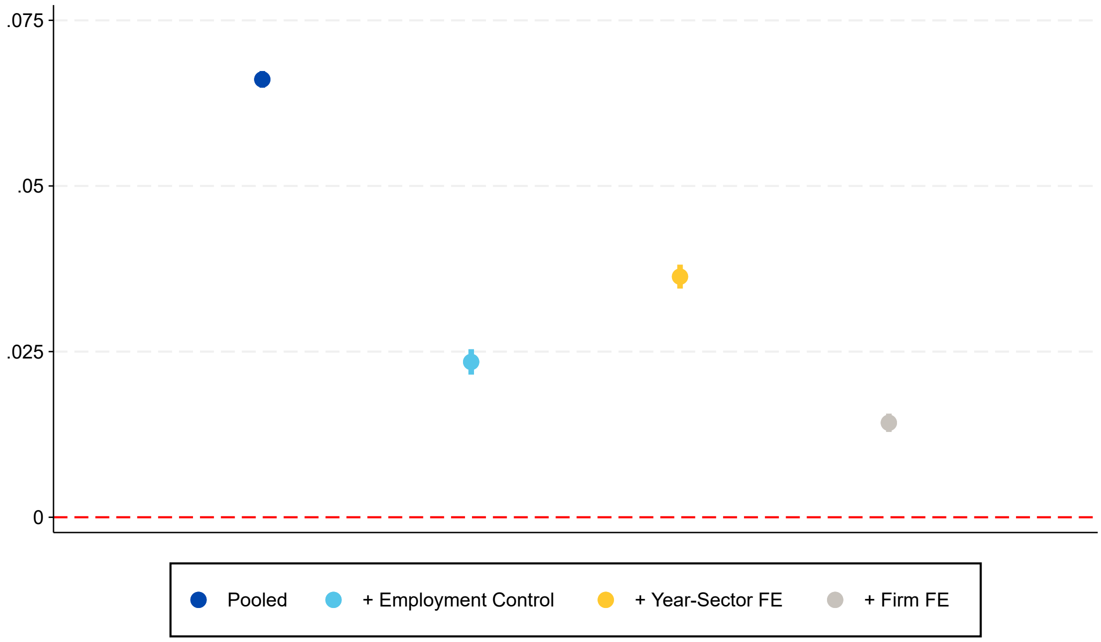


Coefficients obtained from regressing a firms' own investment against the industry average for the same type of investment (excluding the investment of that particular firm), for the whole sample and in different time subperiods, 2001 and 2020, from ARDx/ABS and BERD

The addition of controls generally diminishes the strength of the relationship between TFP and types of investment

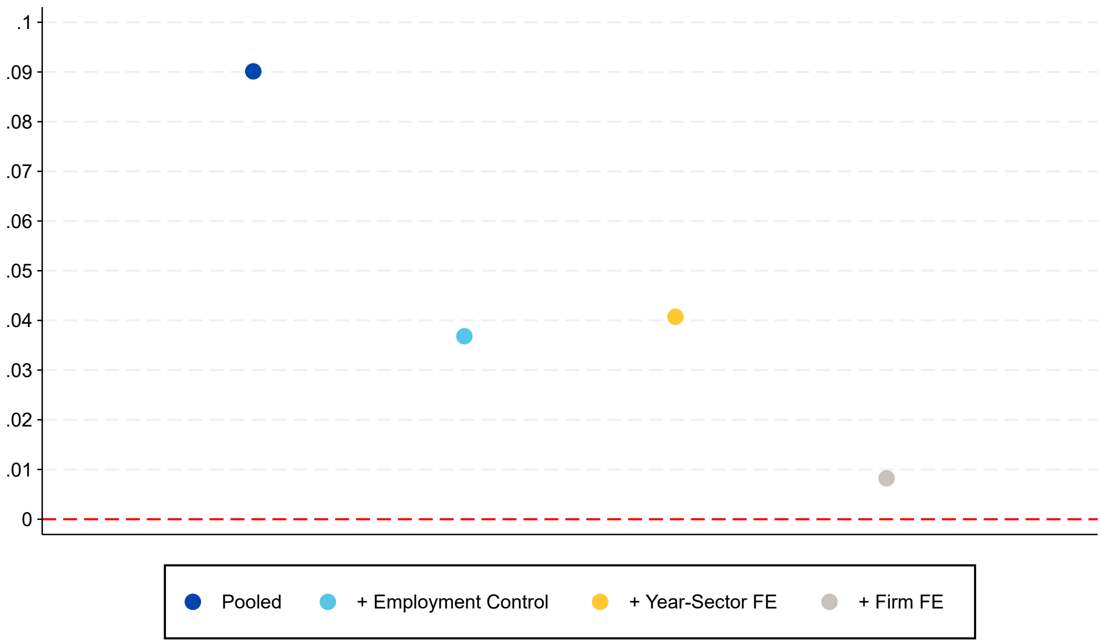
C.12 Figure 7-9, Figure 7-10, Figure 7-11, Figure 7-12 and Figure 7-13 show the coefficients when regressing TFP on investment in machinery, software, patents, internal R&D and external R&D. The first coefficient is a regression specification without controls or fixed effects (Pooled), then we control for employment at the firm, then we include fixed effects for the SIC sector interacted with each year, then we add firm level fixed effects to present changes within a firm. We present these results to show the validity of our main regressions, when altering econometric approaches.

Figure 7-9 Associations between TFP and machinery investment, incrementally adding controls and fixed effects



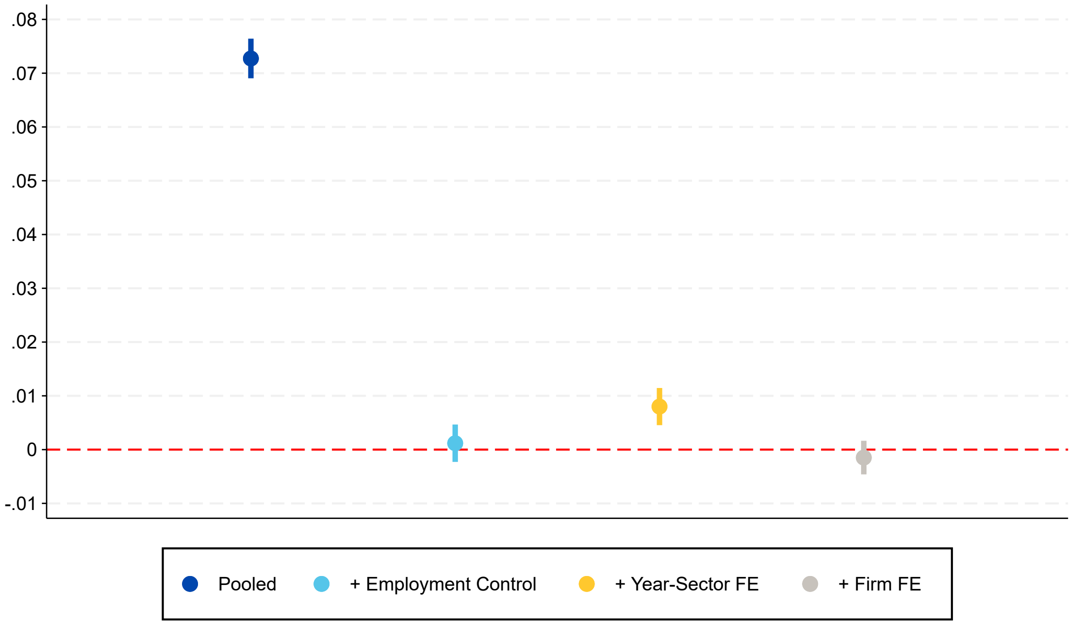
*Coefficients from firm-level regressions of TFP on machinery investment (2000-2021), from ARDx/ABS. Lines represent 95% confidence intervals around estimated coefficient. Pooled represents no controls and fixed effects in the regression specification, then we add employment controls, then time * SIC sector fixed effects, then firm level fixed effects.*

Figure 7-10 Associations between TFP and software investment, incrementally adding controls and fixed effects



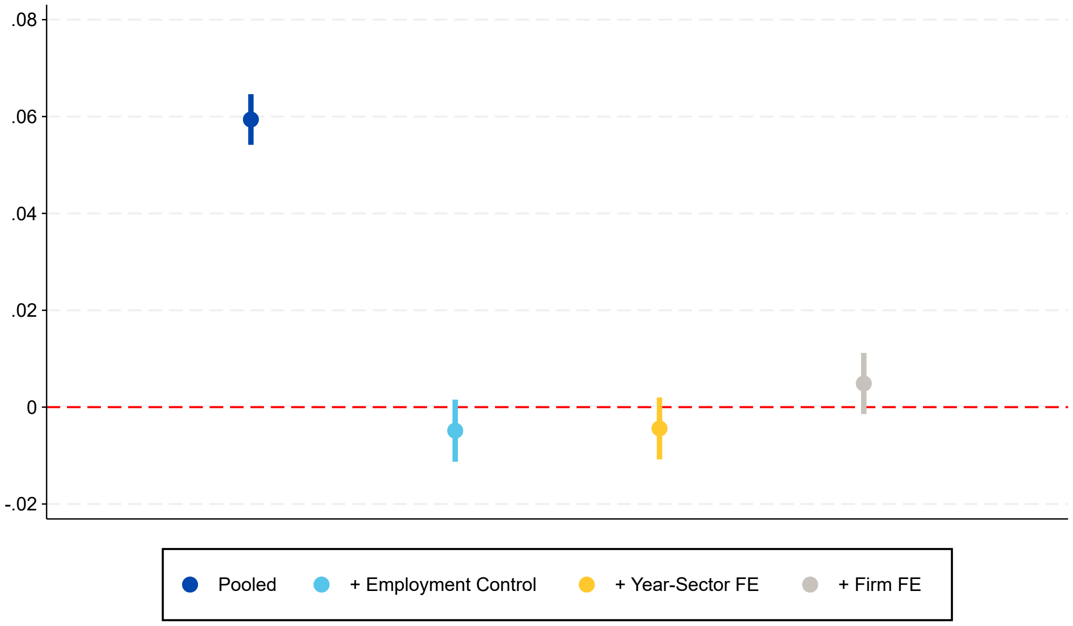
*Coefficients from firm-level regressions of TFP on software investment (2000-2021), from ARDx/ABS. Lines represent 95% confidence intervals around estimated coefficient. Pooled represents no controls and fixed effects in the regression specification, then we add employment controls, then time * SIC sector fixed effects, then firm level fixed effects.*

Figure 7-11 Associations between TFP and patent investment, incrementally adding controls and fixed effects



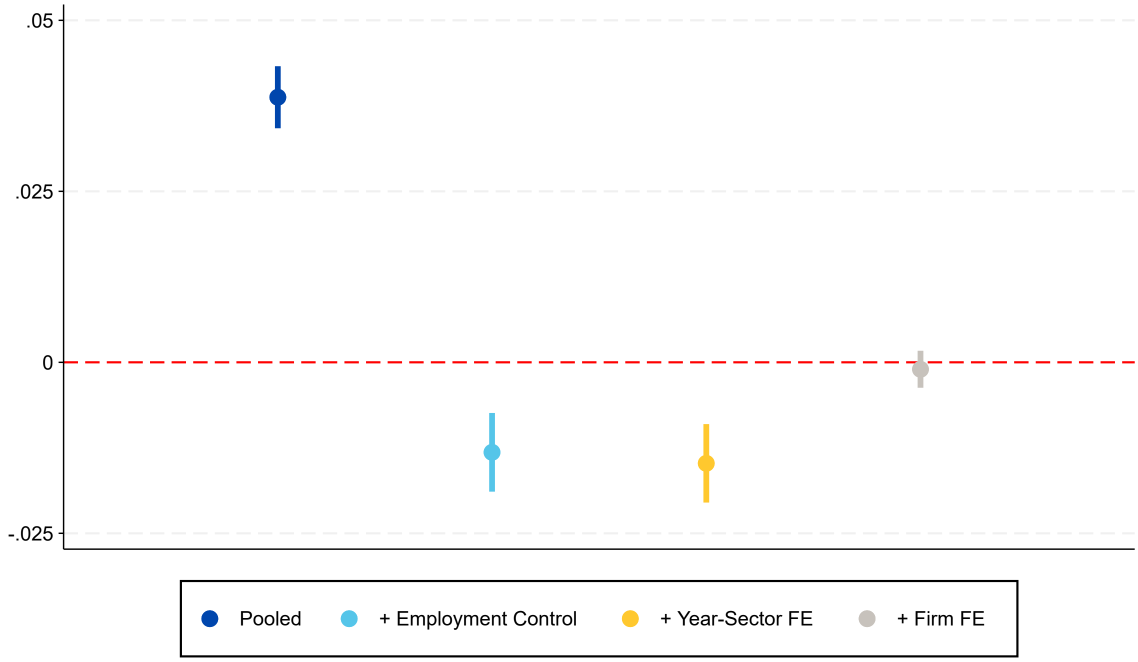
*Coefficients from firm-level regressions of TFP on patent investment (2000-2013), from ARDx/ABS. Lines represent 95% confidence intervals around estimated coefficient. Pooled represents no controls and fixed effects in the regression specification, then we add employment controls, then time * SIC sector fixed effects, then firm level fixed effects.*

Figure 7-12 Associations between TFP and internal R&D investment, incrementally adding controls and fixed effects



*Coefficients from firm-level regressions of TFP on internal R&D investment (2000-2021), from ARDx/ABS and BERD. Lines represent 95% confidence intervals around estimated coefficient. Pooled represents no controls and fixed effects in the regression specification, then we add employment controls, then time * SIC sector fixed effects, then firm level fixed effects.*

Figure 7-13 Associations between TFP and external R&D investment, incrementally adding controls and fixed effects



*Coefficients from firm-level regressions of TFP on external R&D investment (2000-2021), from ARDx/ABS and BERD. Lines represent 95% confidence intervals around estimated coefficient. Pooled represents no controls and fixed effects in the regression specification, then we add employment controls, then time * SIC sector fixed effects, then firm level fixed effects.*

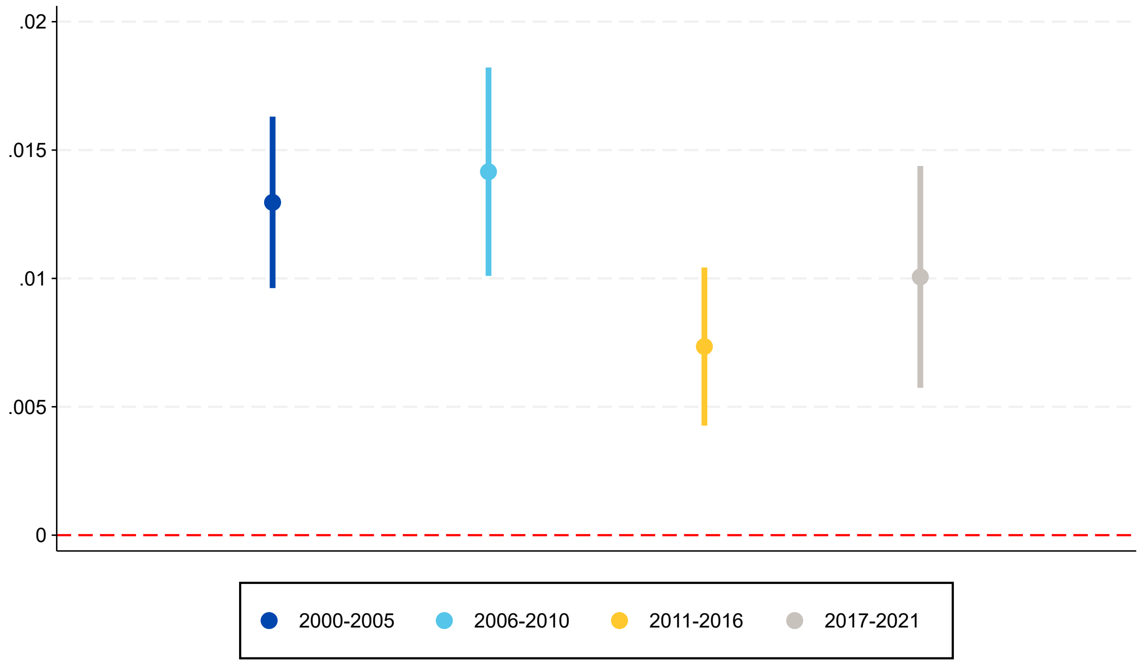
The positive association between investment and TFP is robust to different approaches

Sub-period analysis

C.13 Increases in a firm's capital expenditure are associated with productivity improvements, across different time subperiods in our sample.

C.14 Figure 7-14 shows the increase in a firm's TFP associated with a 1% increase in capital expenditure, in time subperiods 2000-2005, 2006-2010, 2011-2016, 2017-2021, using our sample of firms in ARDx/ABS. The effect is positive for all subperiods, although slightly reduced after 2010, indicating that the association between TFP and capital expenditure has persisted throughout the years covered in our sample.

Figure 7-14 TFP is positively associated with capital expenditure in each of the time subperiods



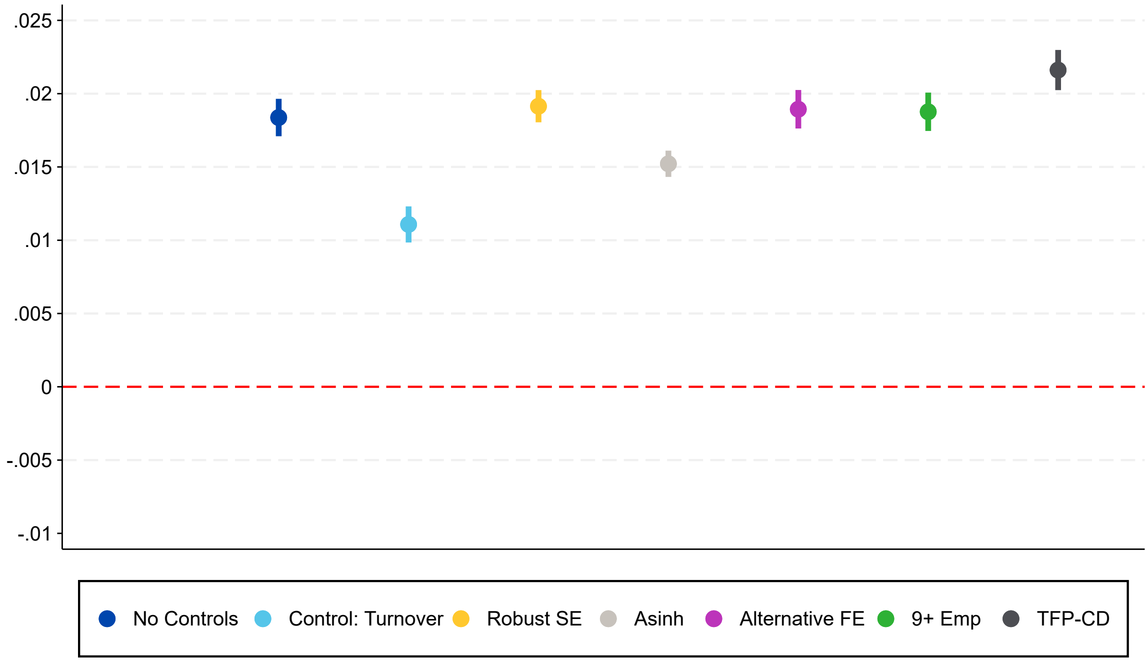
Coefficients from firm-level regressions of TFP on capital expenditure (2000-2021), within different time periods, from ARDx/ABS. Lines represent 95% confidence intervals around estimated coefficient.

Alternative specifications

C.15 The main regressions include applying log transformations to our variables, which excludes firms with no investment. We apply asinh transformations to include those firms and find that the relationship holds. Meaning that increases in a firm's capital expenditure are associated with productivity improvements, accounting for firms with no investment.

C.16 This is presented in Figure 7-15. The first specification does not apply robust standard errors, controls, asinh, or fixed effects. The second controls for turnover. The third includes robust standard errors, as a method to potentially deal with heteroscedastic errors. The fourth applies the asinh formation to include observations with no investment. The fifth applies fixed effects separately for the SIC sector and year, rather than interacting them. The sixth includes only firms with more than nine employees. And the seventh specification uses TFP estimated through assuming a Cobb-Douglas production function instead of the Translog function. All these changes are cumulative, except the asinh transformation which applies only to the fifth specification.

Figure 7-15 TFP is positively associated with capital expenditure for alternative specifications

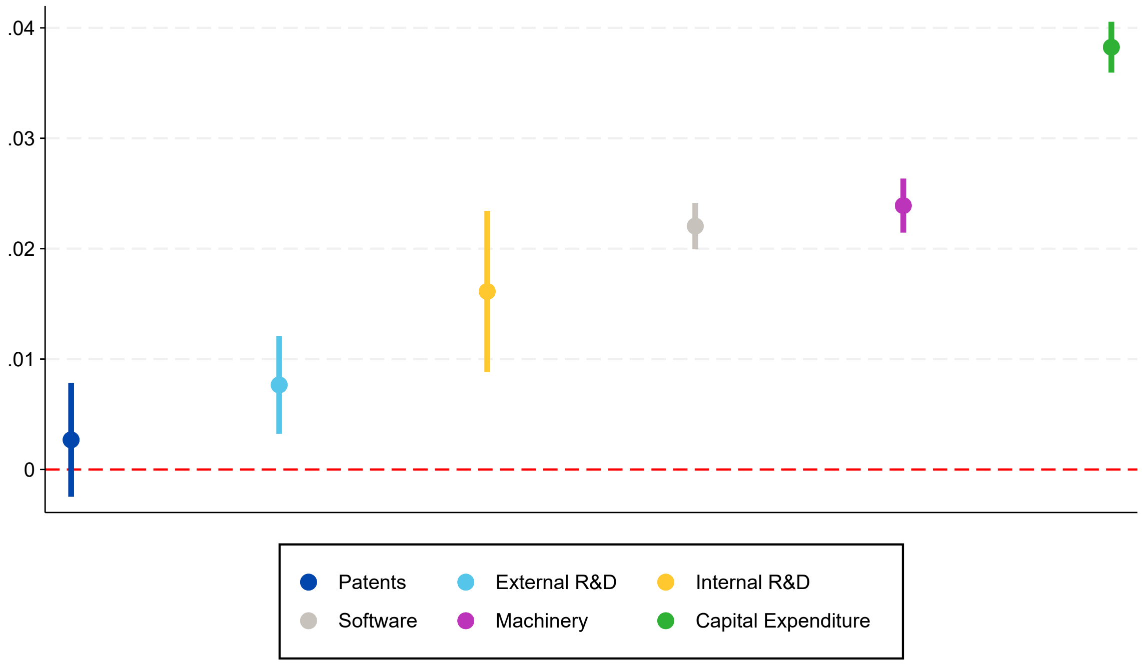


Coefficients from firm-level regressions of TFP on capital expenditure (2000-2021), from ARDX/ABS. The first regressions cumulatively add controls, standard errors, fixed effects, and then separately changing specification to apply the Asinh transformation, fixed effects separately for SIC sector and year, for firms with more than 9 employees, and using the Cobb-Douglas production function to estimate TFP. Lines represent 95% confidence intervals around estimated coefficient.

Technology and R&D investments are generally positively associated with labour productivity gains

C.17 Another robustness check includes estimate coefficients of regressing turnover, instead of TFP, on our investment measures in Figure 7-16. By controlling for employment, our estimated effect measures the associated impact of investment following a 1% increase in turnover for a given level of employment, and therefore can be interpreted as a proxy for labour productivity.

Figure 7-16 Labour productivity is positively associated with capital expenditure and other investment measures except patents



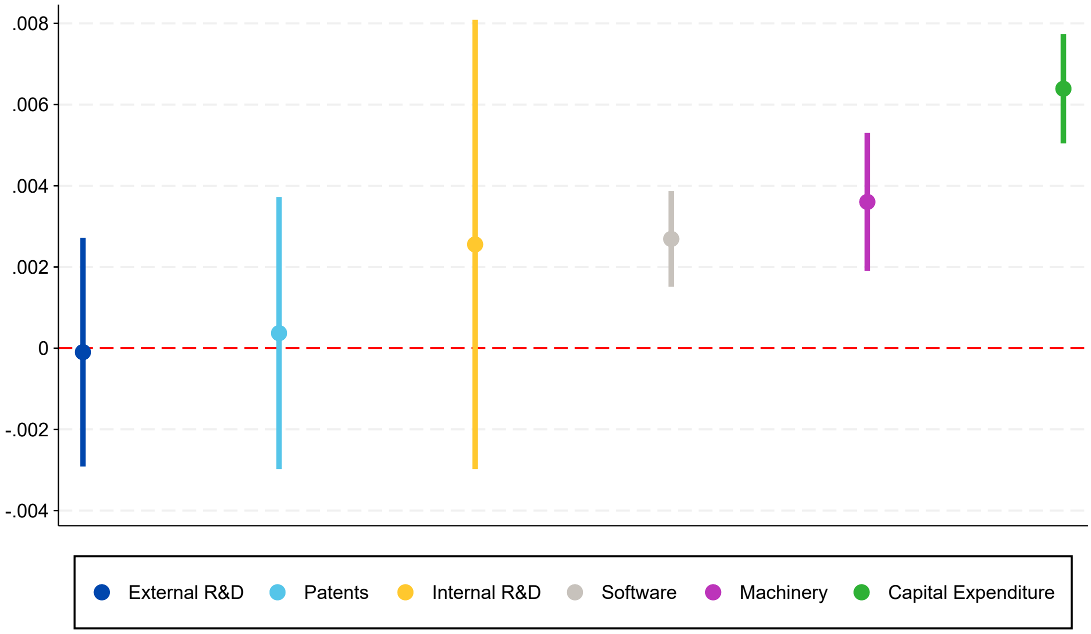
Coefficients from firm-level regressions of turnover (controlling for employment) on capital expenditure (1997-2021), patents (2000-2013), software investment (2000-2021), machinery (2000-2021), internal and external R&D (2000-2021), from ARDx/ABS and BERD. Lines represent 95% confidence intervals around estimated coefficient.

Relationship between current TFP and investment in previous years

C.18 Previously, we found that increases in a firm's capital, software, and machinery expenditure were associated with TFP increases in the same year.

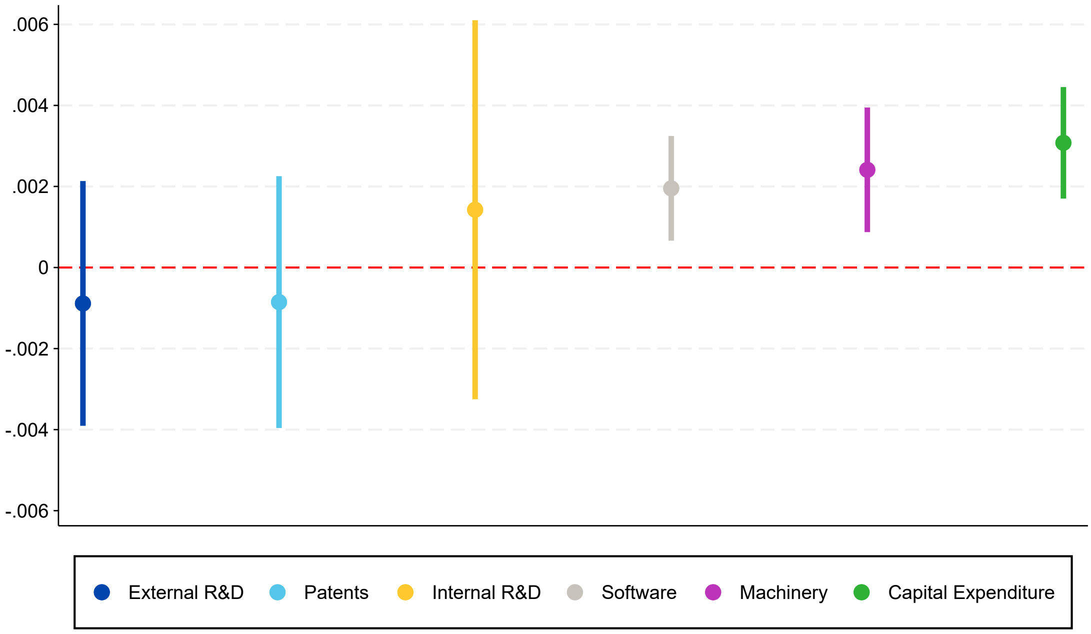
C.19 Figure 7-17, Figure 7-18, and Figure 7-19 show the increase in a firm's TFP associated, one, two, and three years, respectively, following a 1% increase in various types of investment for the firm. These increases are smaller than those observed when comparing investment increases to TFP increases in the current year, see Figure 5-4. Nevertheless, we see that TFP increases are associated with increases in a firm's capital and software investment, one year, two years, and three years before. TFP increases are positively associated with machinery investments made one or two, but not three, years earlier.

Figure 7-17 Capital, software, and machinery expenditure increases are associated with smaller positive TFP returns after one year following the investment



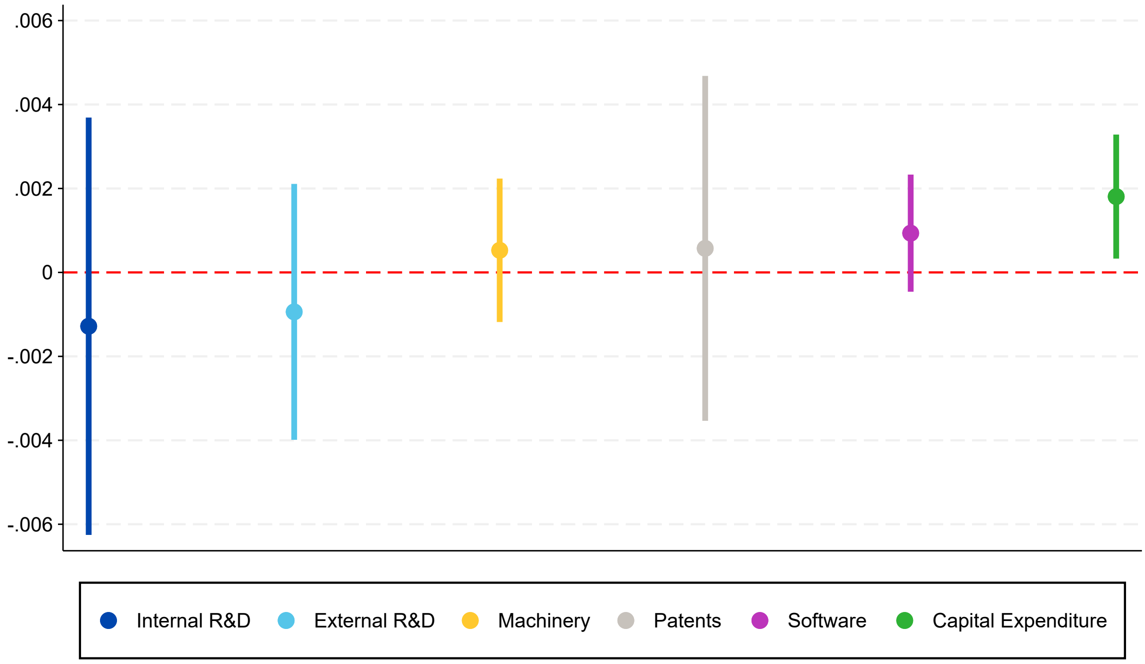
Coefficients from firm-level regressions of TFP, with a one-year lag, on capital expenditure (1997-2021), patents (2000-2013), software investment (2000-2021), machinery (2000-2021), internal and external R&D (2000-2021), from ARDx/ABS and BERD. Lines represent 95% confidence intervals around estimated coefficient.

Figure 7-18 Capital, software, and machinery expenditure increases are associated with smaller positive TFP returns after two years following the investment



Coefficients from firm-level regressions of TFP, with a two-year lag, on capital expenditure (1997-2021), patents (2000-2013), software investment (2000-2021), machinery (2000-2021), internal and external R&D (2000-2021), from ARDx/ABS and BERD. Lines represent 95% confidence intervals around estimated coefficient.

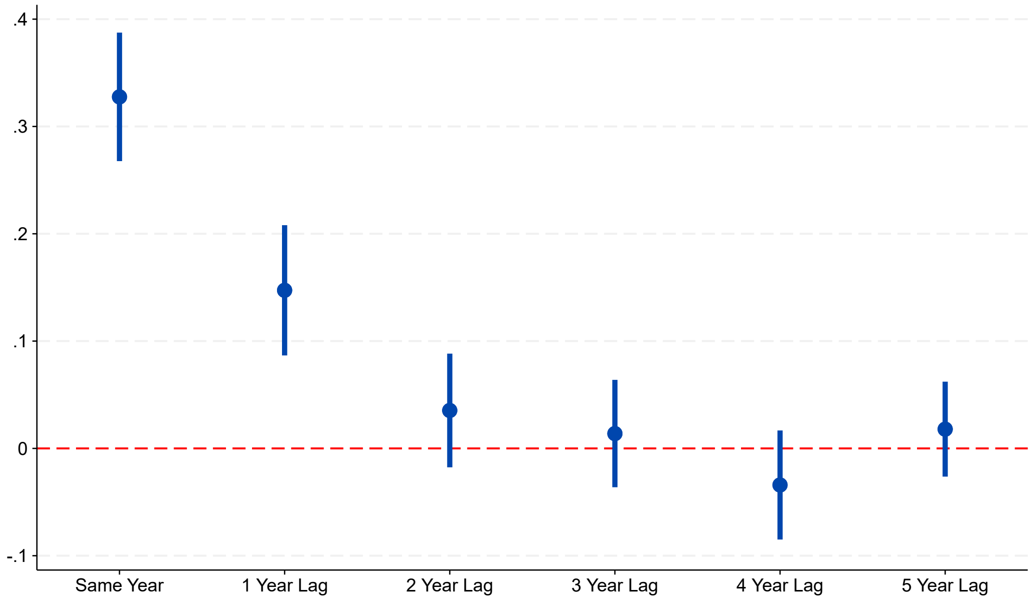
Figure 7-19 Capital and software expenditure increases are associated with smaller positive TFP returns after three years following the investment



Coefficients from firm-level regressions of TFP, with a three-year lag, on capital expenditure (1997-2021), patents (2000-2013), software investment (2000-2021), machinery (2000-2021), internal and external R&D (2000-2021), from ARDx/ABS and BERD. Lines represent 95% confidence intervals around estimated coefficient.

C.20 We find that the level of capital expenditure in a given year is positively associated with TFP increases in that year the prior year in that year, and in the prior 3 years. This shows that TFP has immediate impacts on current and short-term future investment. Figure 7-20 shows the effect of an increase in a firm's TFP on capital expenditure, for the set of firms where we can track this effect over at least a five-year period. We find that for a given firm, in a given year, current capital expenditure is positively associated with TFP in the same year and the previous year. Each lagged TFP term reflects the additional contribution of investment made to current capital expenditure. The cumulative impact on capital investment in any given year represents the sum of individual impacts from TFP increases in the current and previous years.

Figure 7-20 TFP increases are associated with positive capital expenditure in the current and following year

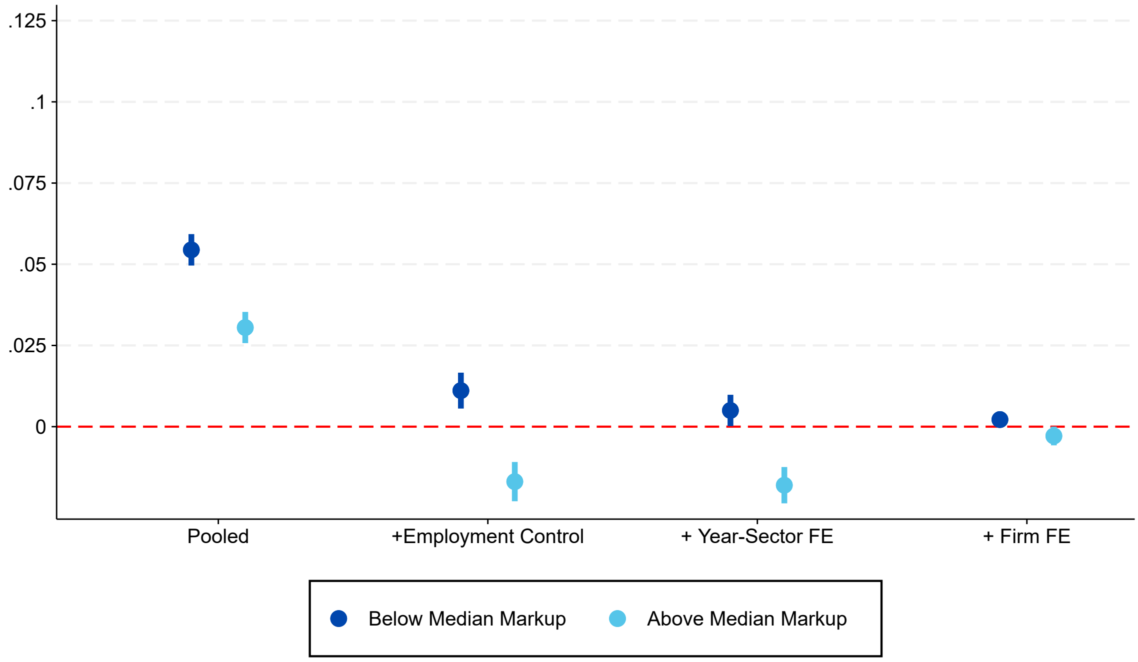


Coefficients from regressions of a firm's capital expenditure in the current year and its TFP in the current year and previous years, 1997-2021, from ARDx/ABS and BERD. Coefficient shows the percentage impact on capital expenditure levels of a 1% increase in TFP. Lines represent 95% confidence intervals around estimated coefficient.

Adding controls weakens the impact of competition on the investment-TFP relationship, but it remains significant

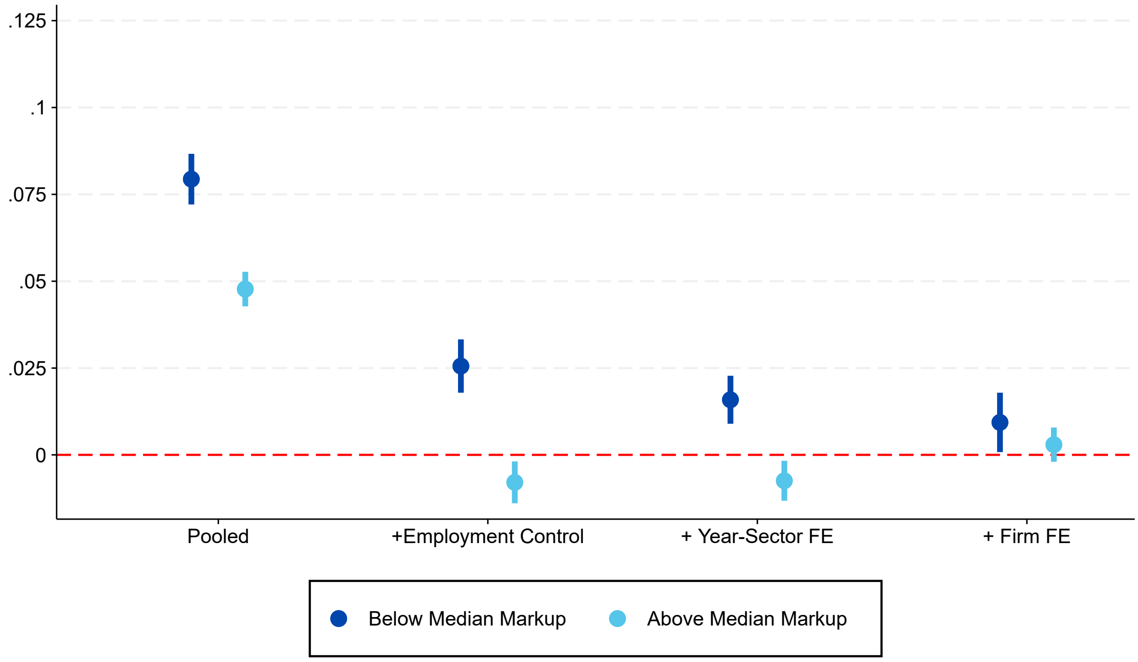
C.21 Figure 7-21, Figure 7-22, Figure 7-23, Figure 7-24, and Figure 7-25 show the coefficients when regressing TFP on internal and external R&D, machinery, software, and patent investment for firms above and below the median markup within their SIC sector. The first coefficient is a regression specification without controls or fixed effects (Pooled), then we control for employment at the firm, then we include fixed effects for the SIC sector interacted with each year, then we add firm level fixed effects to present changes within a firm. We present these results to show the validity of our main regressions, when altering econometric approaches.

Figure 7-21 Associations between TFP and external R&D, for firms with markups above and below their SIC-sector median, incrementally adding controls and fixed effects



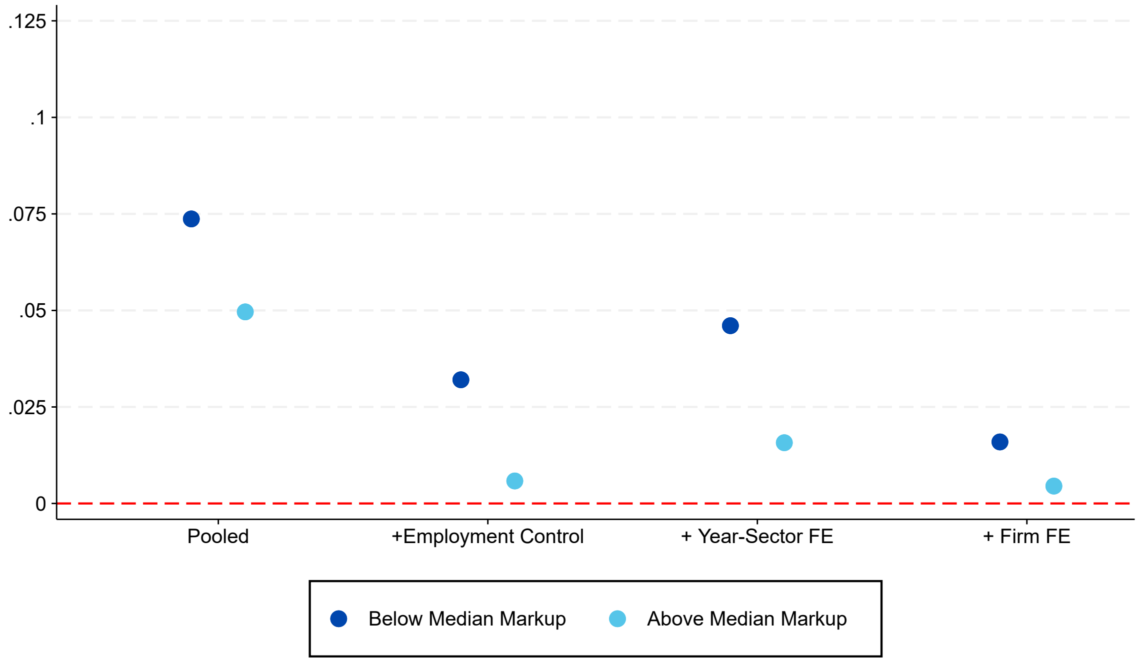
*Coefficients from firm-level regressions of TFP on external R&D investment (2000-2021), for firms with markups above and below their SIC-sector median, from ARDx/ABS and BERD. Lines represent 95% confidence intervals around estimated coefficient. Pooled represents no controls and fixed effects in the regression specification, then we add employment controls, then time * SIC sector fixed effects, then firm level fixed effects.*

Figure 7-22 Associations between TFP and internal R&D, for firms with markups above and below their SIC sector median, incrementally adding controls and fixed effects



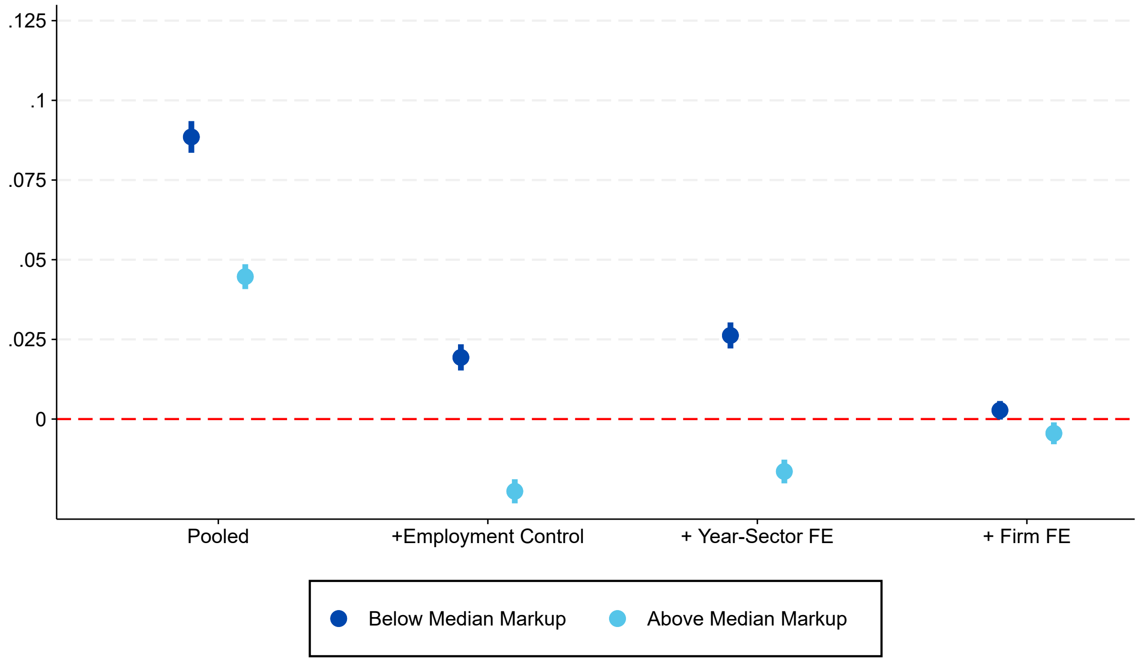
*Coefficients from firm-level regressions of TFP on internal R&D investment (2000-2021), for firms with markups above and below their SIC-sector median, from ARDx/ABS and BERD. Lines represent 95% confidence intervals around estimated coefficient. Pooled represents no controls and fixed effects in the regression specification, then we add employment controls, then time * SIC sector fixed effects, then firm level fixed effects.*

Figure 7-23 Associations between TFP and machinery investment, for firms with markups above and below their SIC sector median, incrementally adding controls and fixed effects



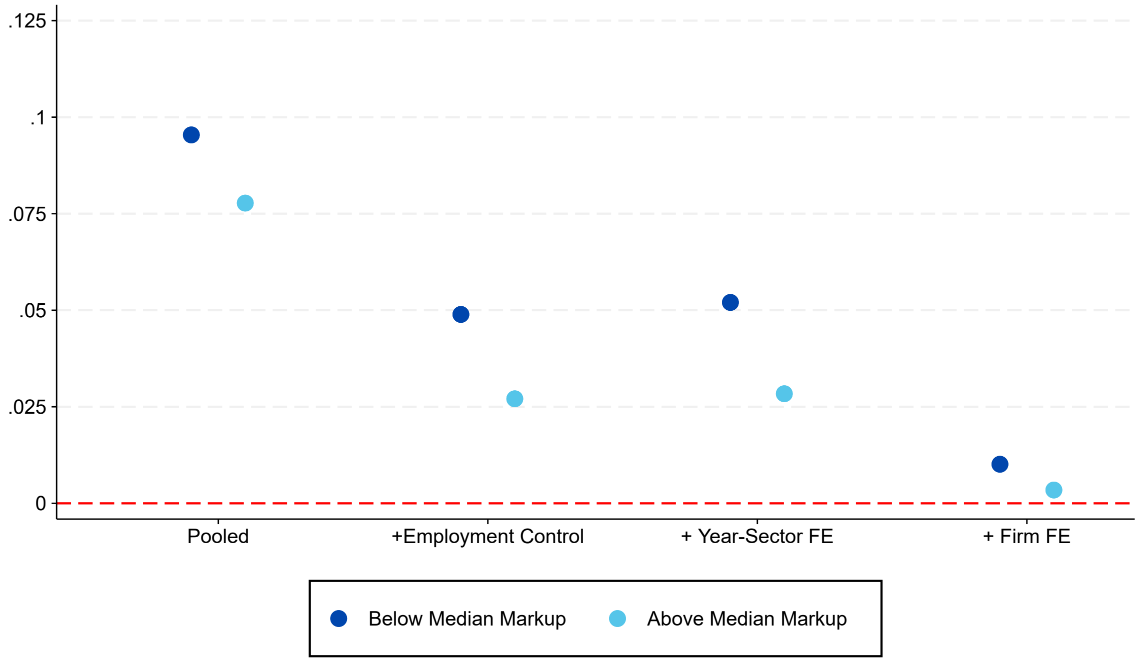
*Coefficients from firm-level regressions of TFP on machinery investment (2000-2021), for firms with markups above and below their SIC-sector median, from ARDx/ABS. Lines represent 95% confidence intervals around estimated coefficient. Pooled represents no controls and fixed effects in the regression specification, then we add employment controls, then time * SIC sector fixed effects, then firm level fixed effects.*

Figure 7-24 Associations between TFP and patent investment, for firms with markups above and below their SIC sector median, incrementally adding controls and fixed effects



*Coefficients from firm-level regressions of TFP on machinery investment (2000-2013), for firms with markups above and below their SIC-sector median, from ARDx/ABS. Lines represent 95% confidence intervals around estimated coefficient. Pooled represents no controls and fixed effects in the regression specification, then we add employment controls, then time * SIC sector fixed effects, then firm level fixed effects.*

Figure 7-25 Associations between TFP and software investment, for firms with markups above and below their SIC-sector median, incrementally adding controls and fixed effects



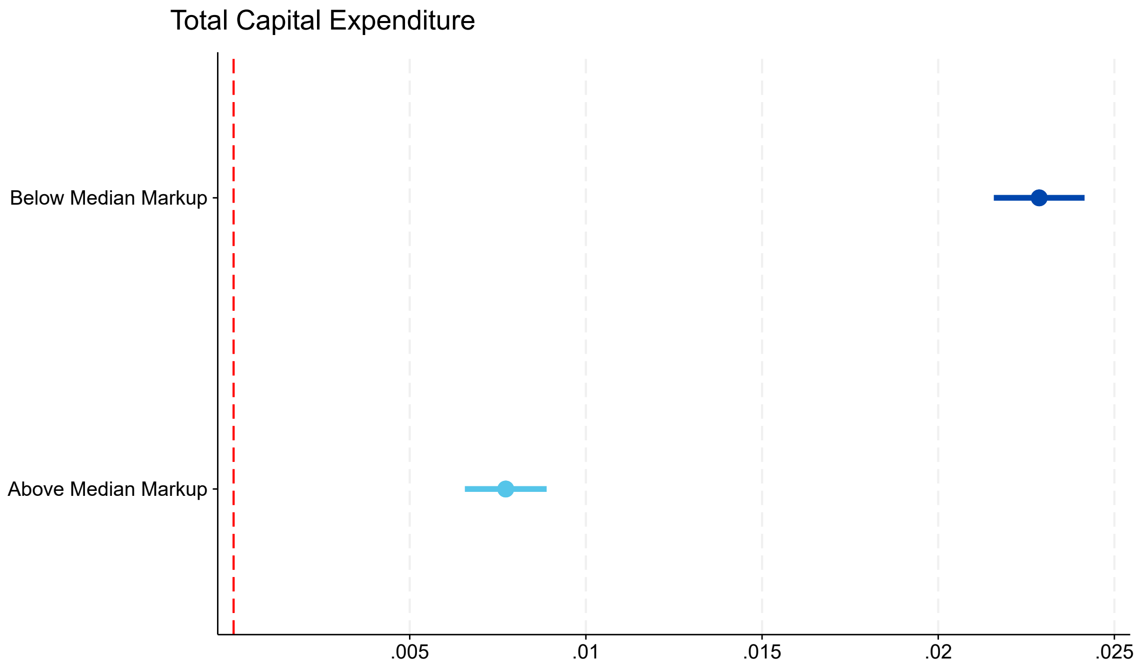
Coefficients from firm-level regressions of TFP on software investment (2000-2021), for firms with markups above and below their SIC-sector median, from ARDx/ABS. Lines represent 95% confidence *intervals around estimated coefficient. Pooled represents no controls and fixed effects in the regression specification, then we add employment controls, then time * SIC sector fixed effects, then firm level fixed effects.*

Firms with lower markups have a stronger association between investment and TFP, across a range of investment types

Results using above/below median sector markup

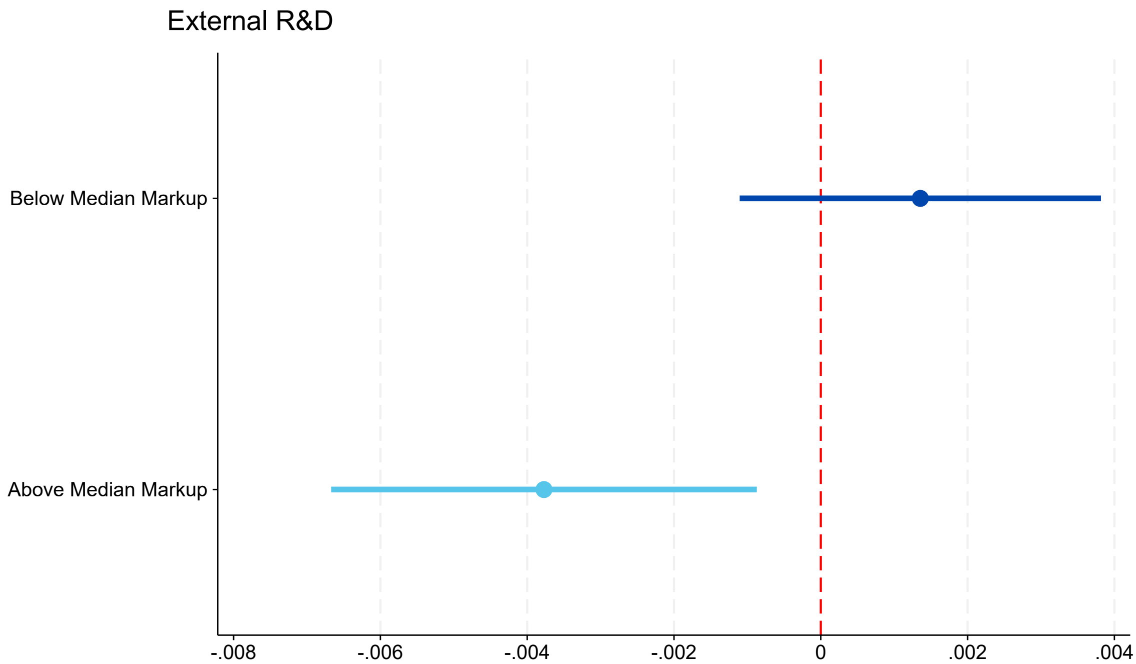
C.22 Figure 7-26, Figure 7-27, Figure 7-28, Figure 7-29, Figure 7-30, and Figure 7-31 show the coefficients when regressing TFP on total capital expenditure, internal and external R&D investment, machinery, software, and patent investment for firms above and below the median markup within their SIC sector.

Figure 7-26 Associations between TFP and total capital expenditure, for firms with markups above and below their SIC sector median



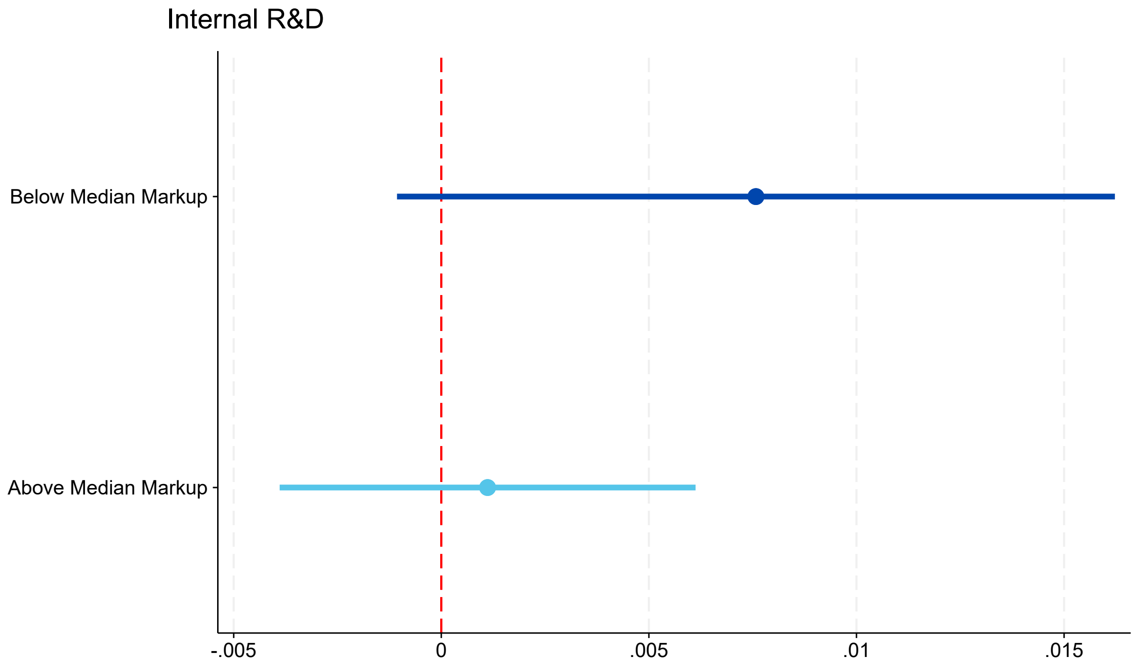
Coefficients from firm-level regressions of TFP on capital expenditure (1997-2021), for firms with markups above and below their SIC-sector median, from ARDx/ABS. Lines represent 95% confidence intervals around estimated coefficient.

Figure 7-27 Associations between TFP and external R&D investment, for firms with markups above and below their SIC sector median



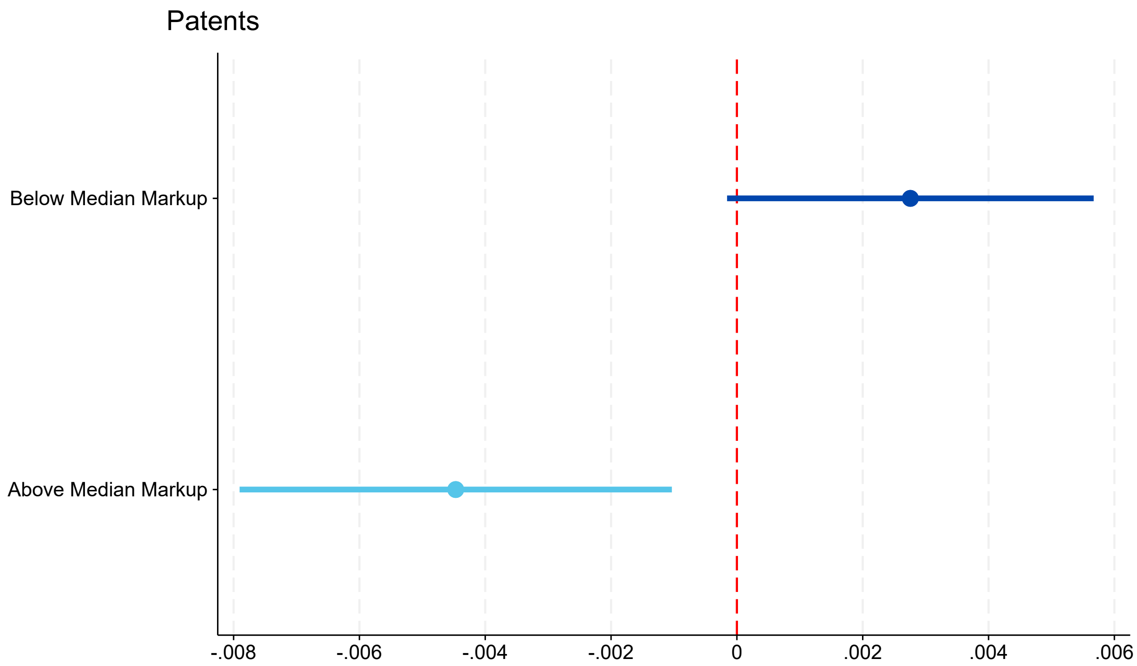
Coefficients from firm-level regressions of TFP on external R&D investment (2000-2021), for firms with markups above and below their SIC-sector median, from ARDx/ABS and BERD. Lines represent 95% confidence intervals around estimated coefficient.

Figure 7-28 Associations between TFP and internal R&D investment, for firms with markups above and below their SIC sector median



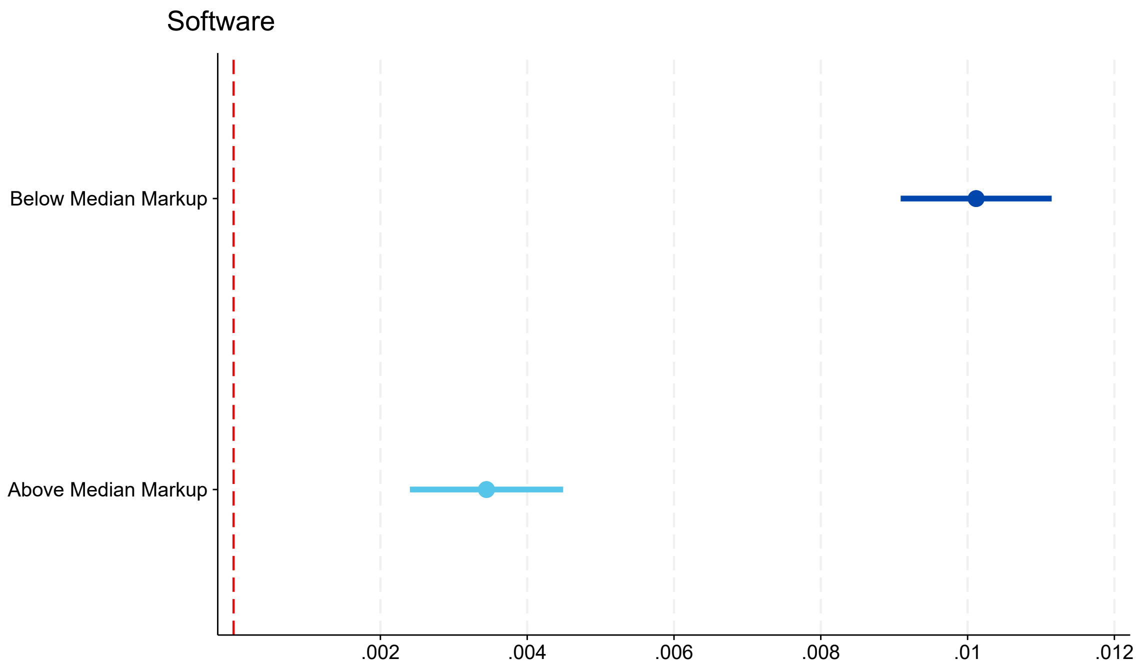
Coefficients from firm-level regressions of TFP on internal R&D investment (2000-2021), for firms with markups above and below their SIC-sector median, from ARDx/ABS and BERD. Lines represent 95% confidence intervals around estimated coefficient.

Figure 7-29 Associations between TFP and patent investment, for firms with markups above and below their SIC sector median



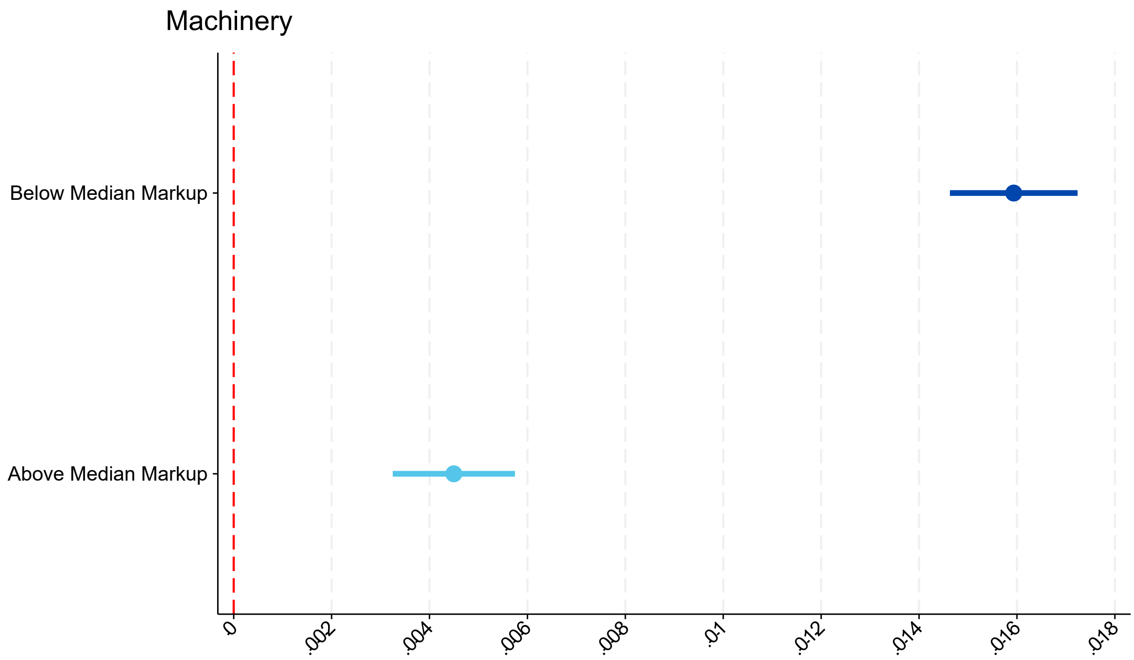
Coefficients from firm-level regressions of TFP on internal R&D investment (2000-2013), for firms with markups above and below their SIC-sector median, from ARDx/ABS. Lines represent 95% confidence intervals around estimated coefficient.

Figure 7-30 Associations between TFP and software investment, for firms with markups above and below their SIC sector median



Coefficients from firm-level regressions of TFP on software investment (2000-2021), for firms with markups above and below their SIC-sector median, from ARDx/ABS. Lines represent 95% confidence intervals around estimated coefficient.

Figure 7-31 Associations between TFP and machinery investment, for firms with markups above and below their SIC sector median

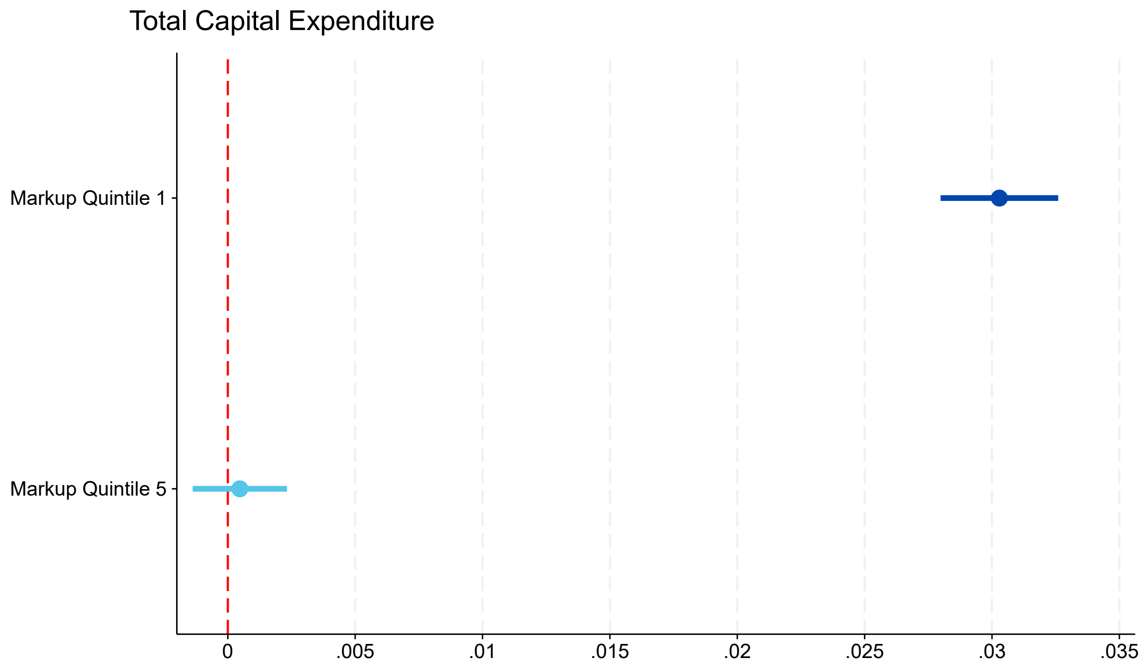


Coefficients from firm-level regressions of TFP on machinery investment (2000-2021), for firms with markups above and below their SIC-sector median, from ARDx/ABS. Lines represent 95% confidence intervals around estimated coefficient.

Results using top and bottom quintiles of markup distribution

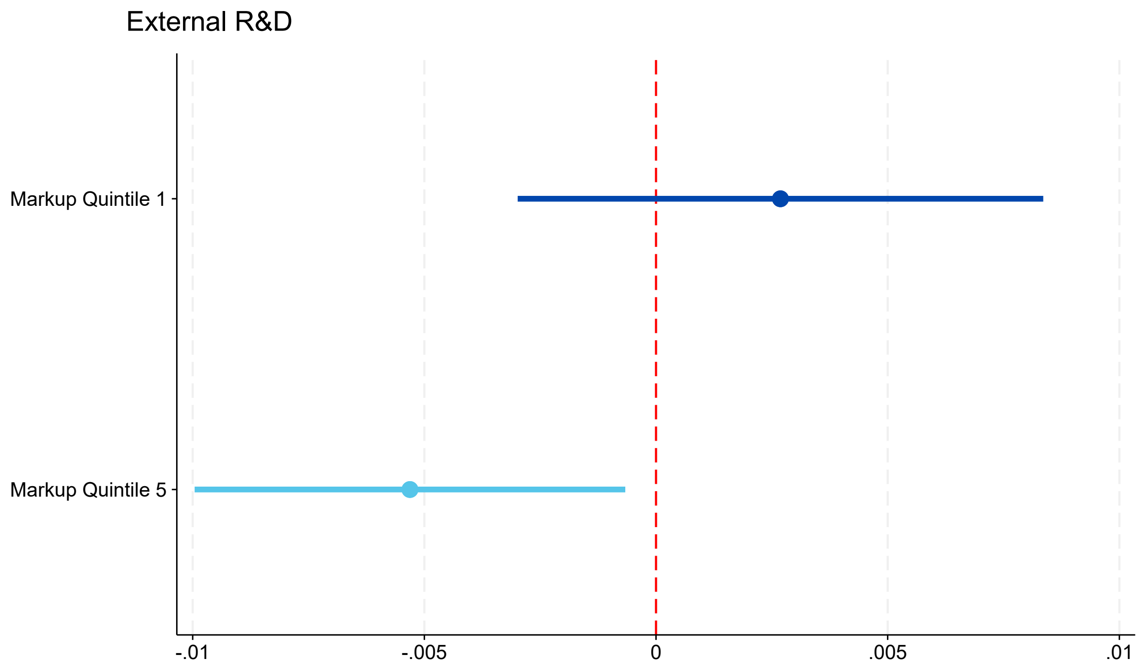
C.23 Figure 7-32, Figure 7-33, Figure 7-34, Figure 7-35, Figure 7-36, and Figure 7-37 show the coefficients when regressing TFP on total capital expenditure, internal and external R&D investment, machinery, software, and patent investment for firms in the first and fifth quintiles of the markup distribution within their SIC sector. We present these results to show the validity of our main regressions, at different aspects of the markup distribution.

Figure 7-32 Associations between TFP and total capital expenditure, for firms in the first and fifth quintile of the markup distribution within their SIC sector



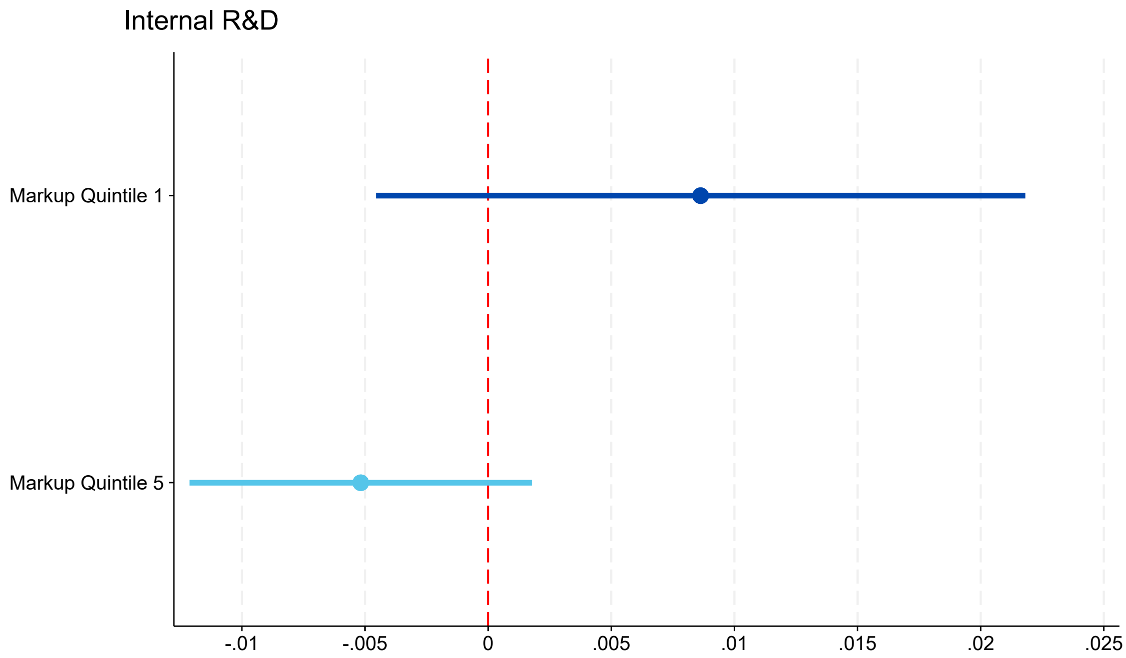
Coefficients from firm-level regressions of TFP on capital expenditure (1997-2021), for firms in the first and fifth quintiles of the markup distribution, from ARDx/ABS. Lines represent 95% confidence intervals around estimated coefficient.

Figure 7-33 Associations between TFP and external R&D expenditure, for firms in the first and fifth quintile of the markup distribution within their SIC sector



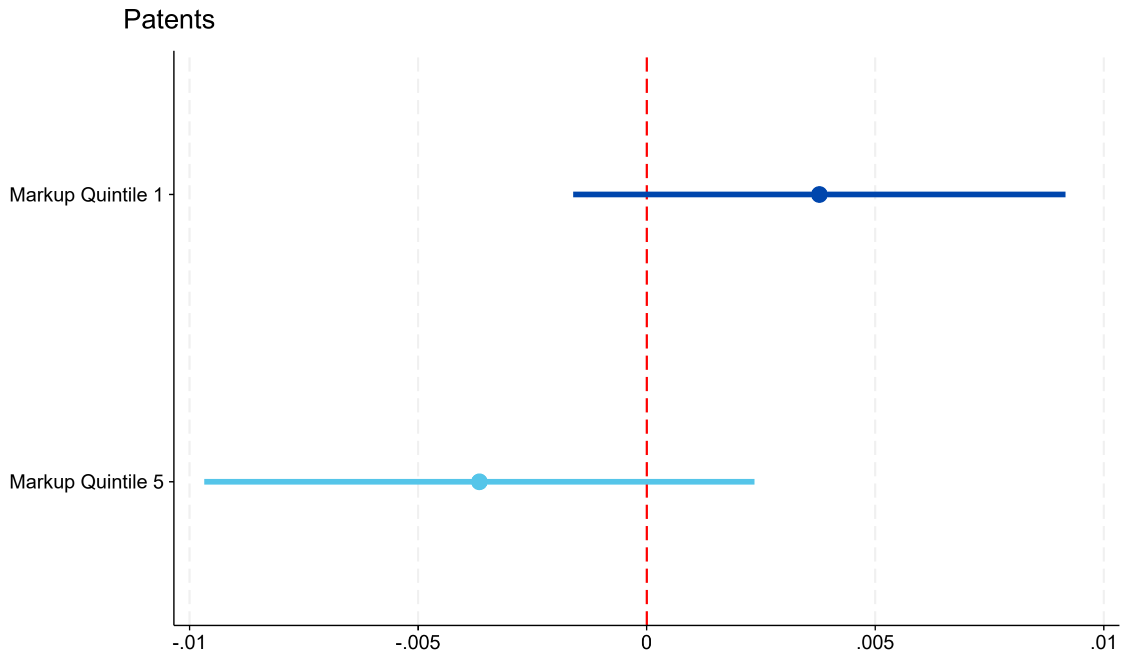
Coefficients from firm-level regressions of TFP on external R&D investment (1999-2021), for firms in the first and fifth quintiles of the markup distribution, from ARDx/ABS and BERD. Lines represent 95% confidence intervals around estimated coefficient.

Figure 7-34 Associations between TFP and internal R&D expenditure, for firms in the first and fifth quintile of the markup distribution within their SIC sector



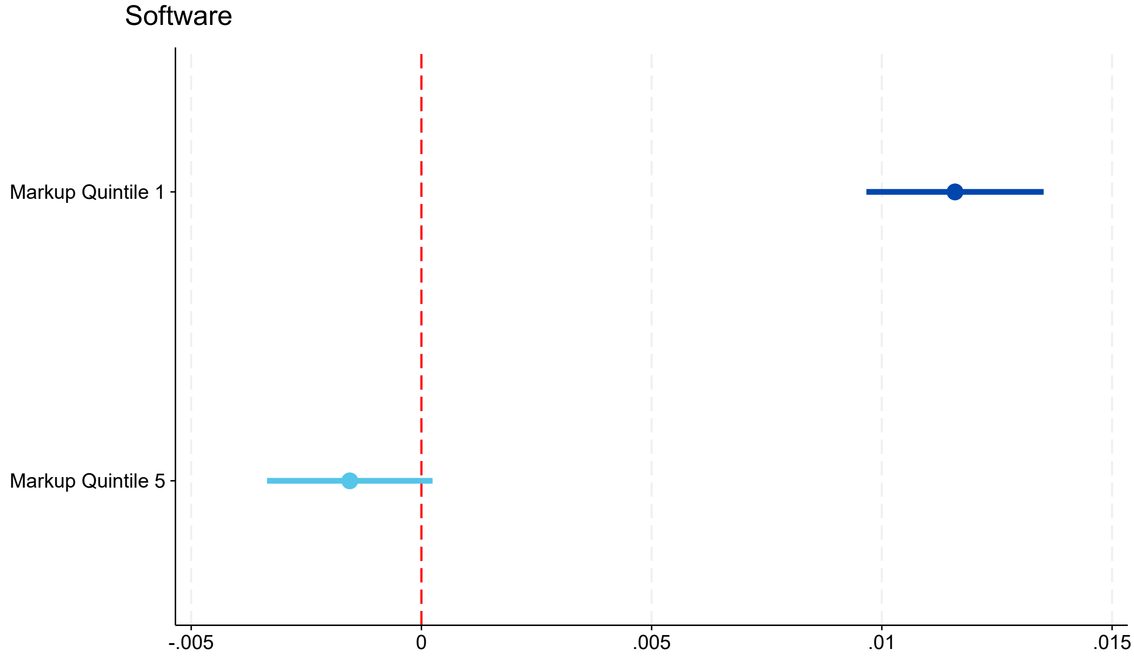
Coefficients from firm-level regressions of TFP on internal R&D investment (1999-2021), for firms in the first and fifth quintiles of the markup distribution, from ARDx/ABS and BERD. Lines represent 95% confidence intervals around estimated coefficient.

Figure 7-35 Associations between TFP and patent investment, for firms in the first and fifth quintile of the markup distribution within their SIC sector



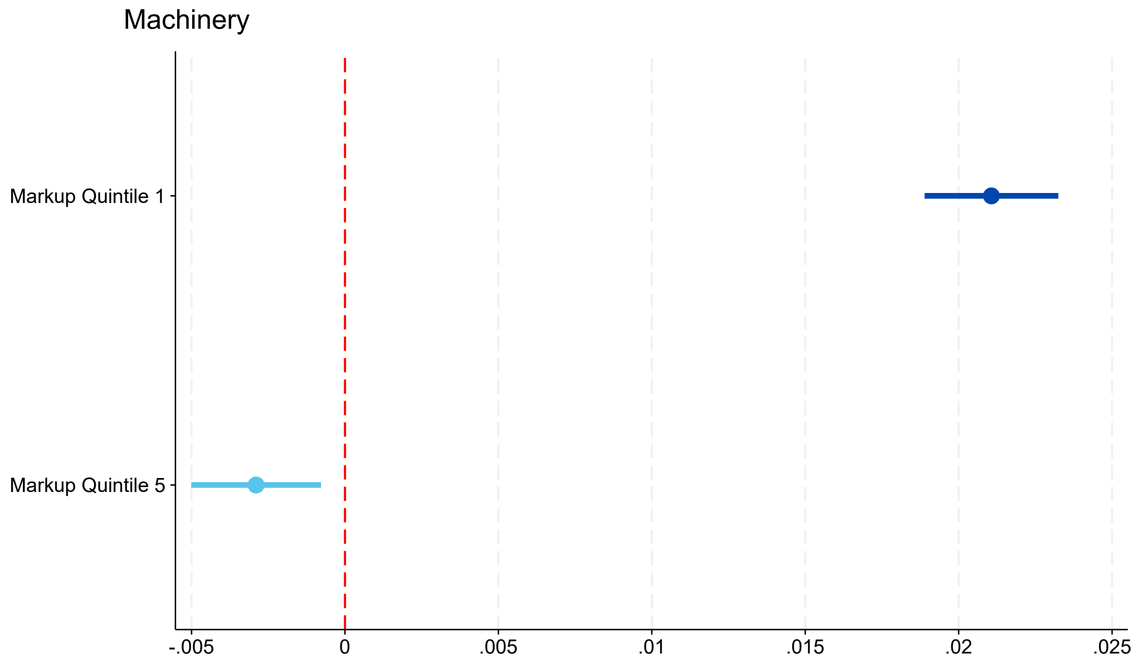
Coefficients from firm-level regressions of TFP on patent investment (2000-2013), for firms in the first and fifth quintiles of the markup distribution, from ARDx/ABS. Lines represent 95% confidence intervals around estimated coefficient.

Figure 7-36 Associations between TFP and software investment, for firms in the first and fifth quintile of the markup distribution within their SIC sector



Coefficients from firm-level regressions of TFP on software investment (2000-2021), for firms in the first and fifth quintiles of the markup distribution, from ARDx/ABS. Lines represent 95% confidence intervals around estimated coefficient.

Figure 7-37 Associations between TFP and machinery investment, for firms in the first and fifth quintile of the markup distribution within their SIC sector



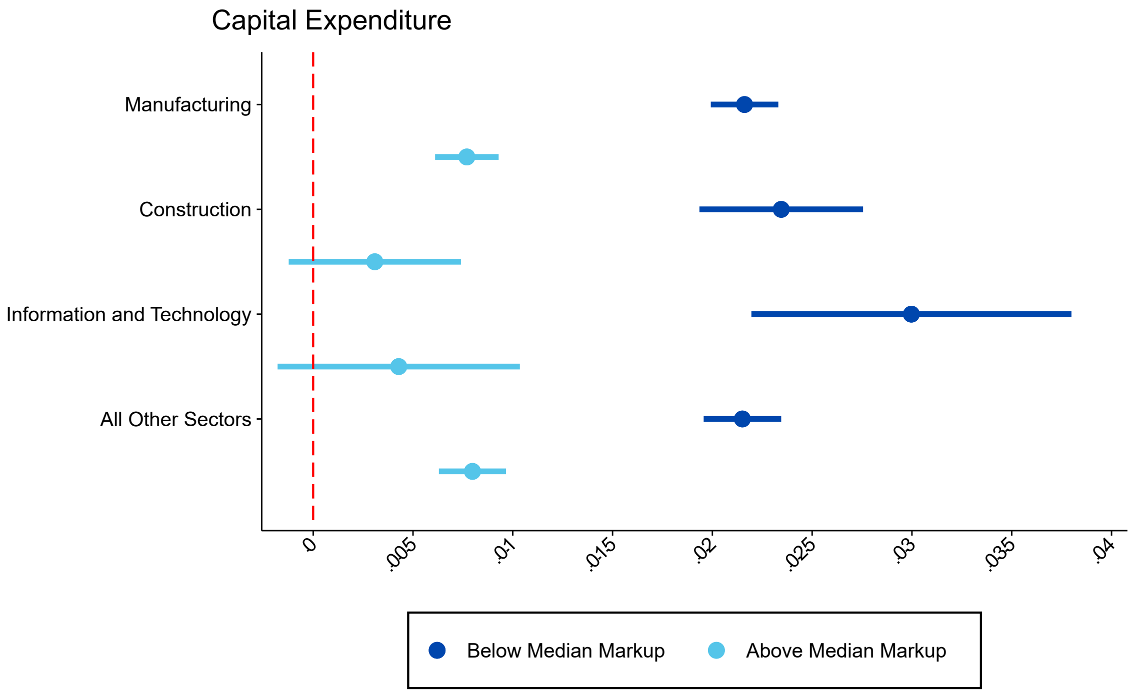
Coefficients from firm-level regressions of TFP on machinery investment (2000-2021), for firms in the first and fifth quintiles of the markup distribution, from ARDx/ABS. Lines represent 95% confidence intervals around estimated coefficient.

Within sectors, firms with below median markups see higher TFP gains from investment

C.24 We test whether this aggregate dampening effect of markups on capital investment and productivity is consistent across sectors or driven by firms in a certain industry.

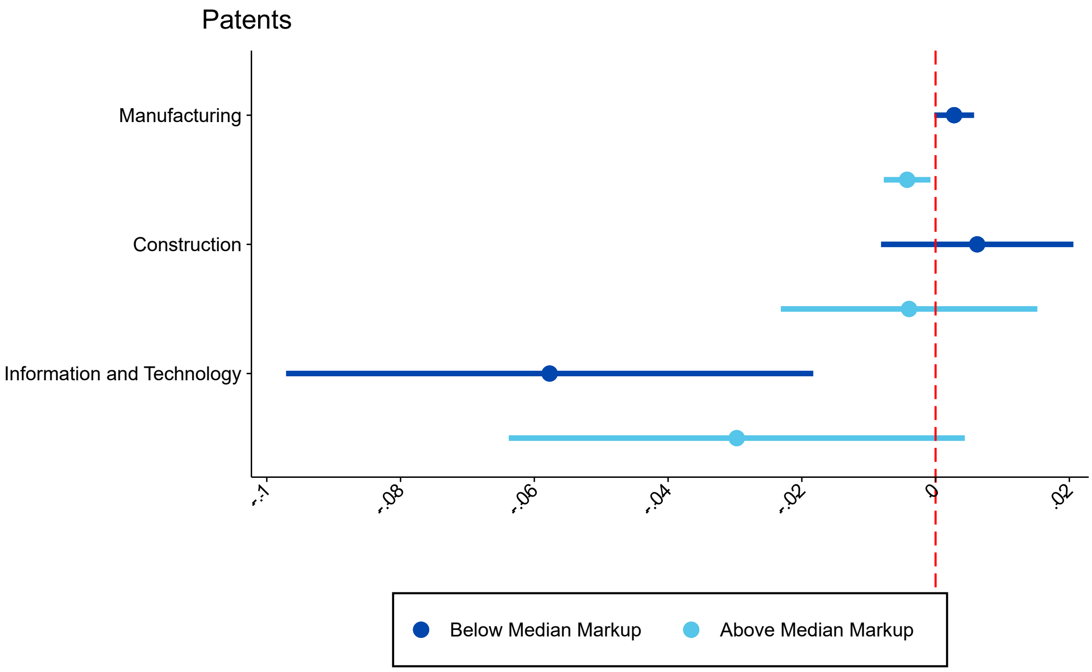
C.25 Figure 7-38, Figure 7-39, Figure 7-40, Figure 7-41, Figure 7-41, and Figure 7-43 show the coefficients when regressing TFP on total capital expenditure, internal and external R&D investment, machinery, software, and patent investment for firms above and below the median markup within their SIC sector, separately for firms in construction, manufacturing, information and communication, and all other sectors together.

Figure 7-38 Associations between TFP and capital expenditure, for firms with markups above and below their SIC sector median, by sector



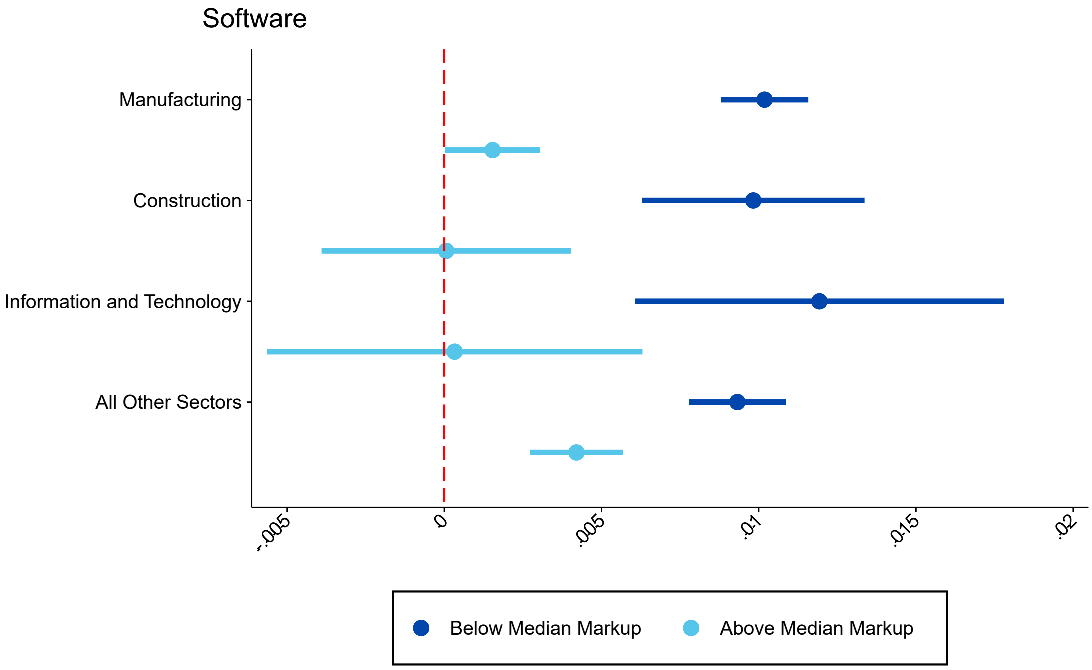
Notes: Coefficients from regressions of TFP on interaction of a dummy for whether the firm was above the median markup and the following investment measures: capital expenditure (1997-2021), patents (2000-2013), software investment (2000-2021), software capex (2008-2014), hardware capex (2008-2014), machinery (2000-2021), other capex (1997-2021), internal and external R&D (2000-2021), by industry, from ARDx/ABS and BERD

Figure 7-39 Associations between TFP and patent investment, for firms with markups above and below their SIC sector median, by sector



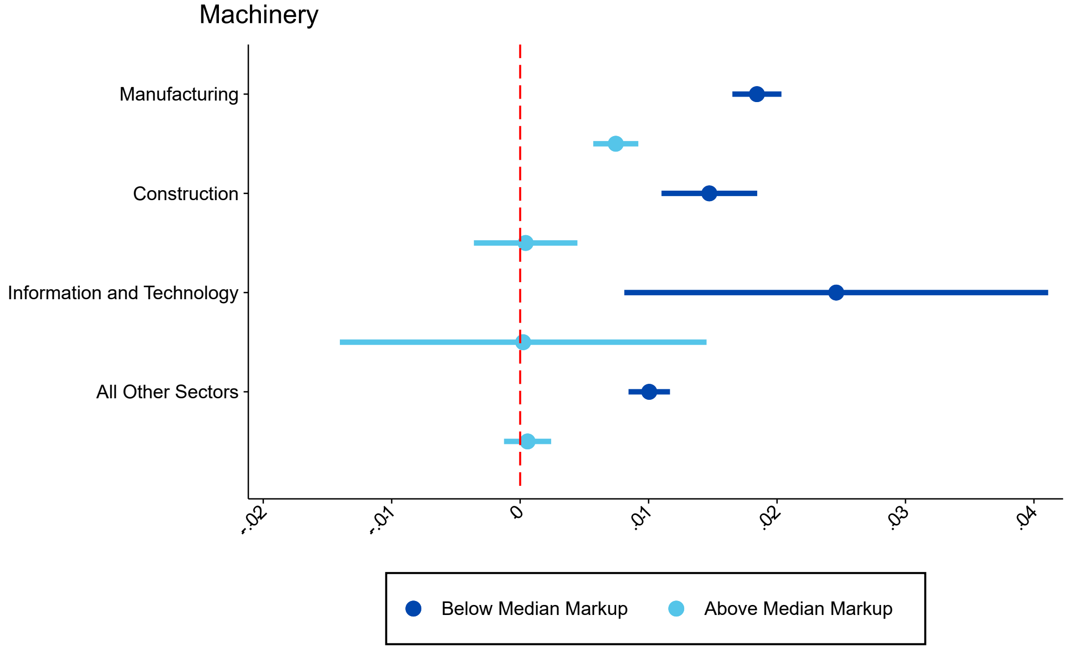
Coefficients from firm-level regressions of TFP on patent investment (2000-2013), for firms with markups above and below their SIC-sector median, separately for firms in manufacturing, construction, and information and technology sectors, from ARDx/ABS. Lines represent 95% confidence intervals around estimated coefficient.

Figure 7-40 Associations between TFP and software investment, for firms with markups above and below their SIC sector median, by sector



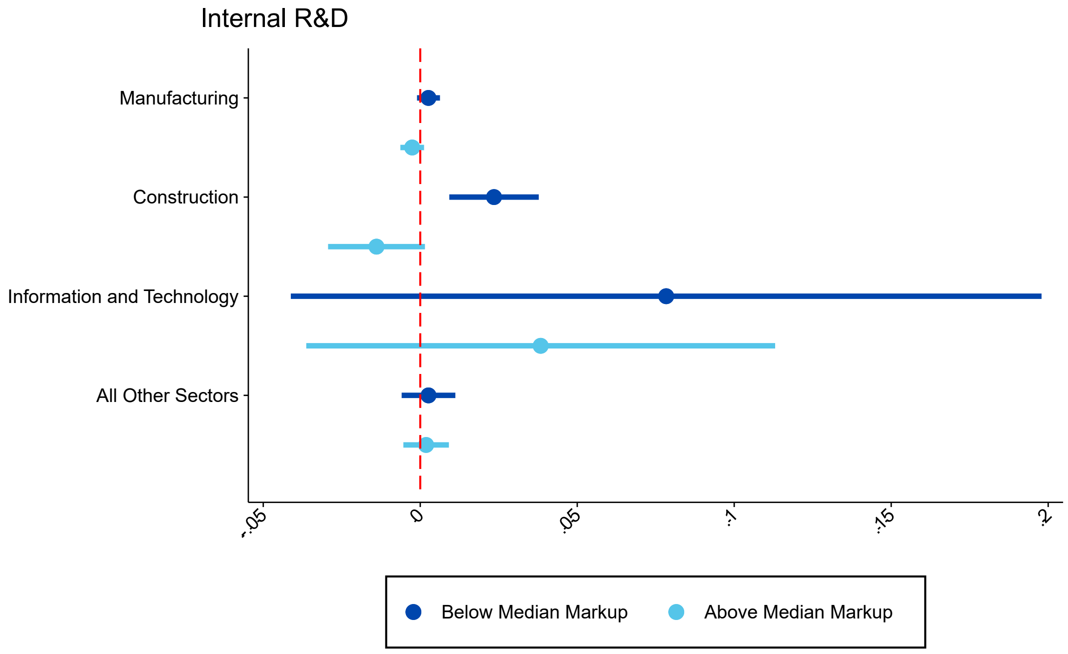
Coefficients from firm-level regressions of TFP on software investment (2000-2021), for firms with markups above and below their SIC-sector median, separately for firms in manufacturing, construction, and information and technology sectors, from ARDx/ABS. Lines represent 95% confidence intervals around estimated coefficient.

Figure 7-41 Associations between TFP and machinery investment, for firms with markups above and below their SIC sector median, by sector



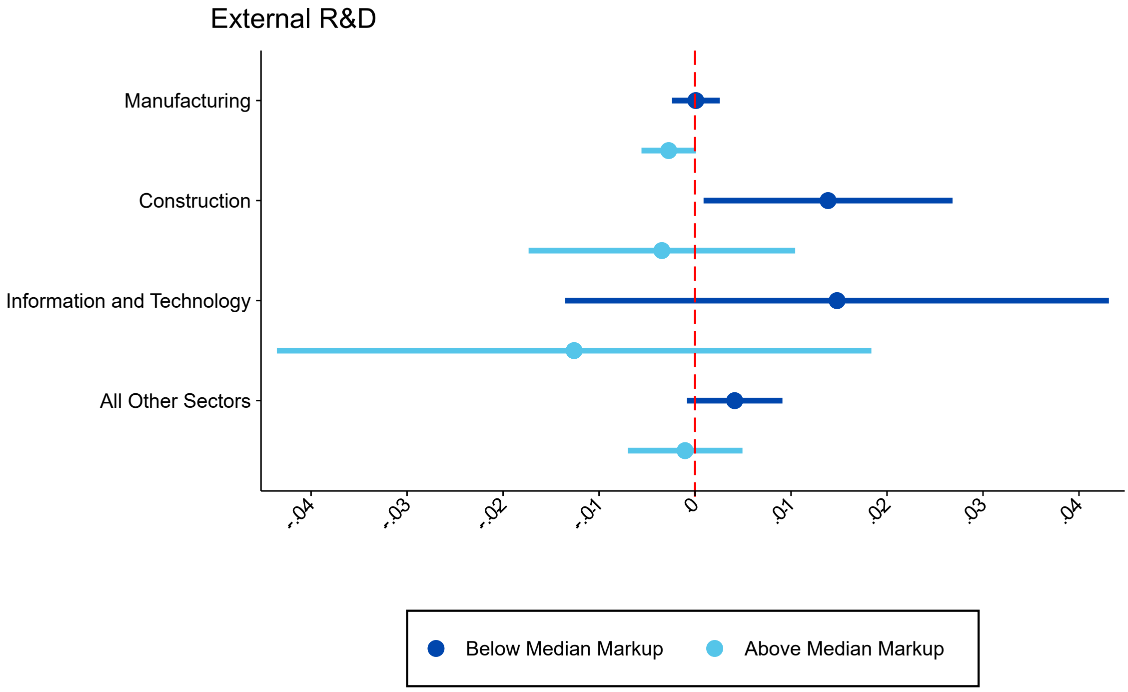
Coefficients from firm-level regressions of TFP on machinery investment (2000-2021), for firms with markups above and below their SIC-sector median, separately for firms in manufacturing, construction, and information and technology sectors, from ARDx/ABS. Lines represent 95% confidence intervals around estimated coefficient.

Figure 7-42 Associations between TFP and internal R&D investment, for firms with markups above and below their SIC sector median, by sector



Coefficients from firm-level regressions of TFP on internal R&D investment (1999-2021), for firms with markups above and below their SIC-sector median, separately for firms in manufacturing, construction, and information and technology sectors, from ARDx/ABS and BERD. Lines represent 95% confidence intervals around estimated coefficient.

Figure 7-43 Associations between TFP and external R&D investment, for firms with markups above and below their SIC sector median, by sector

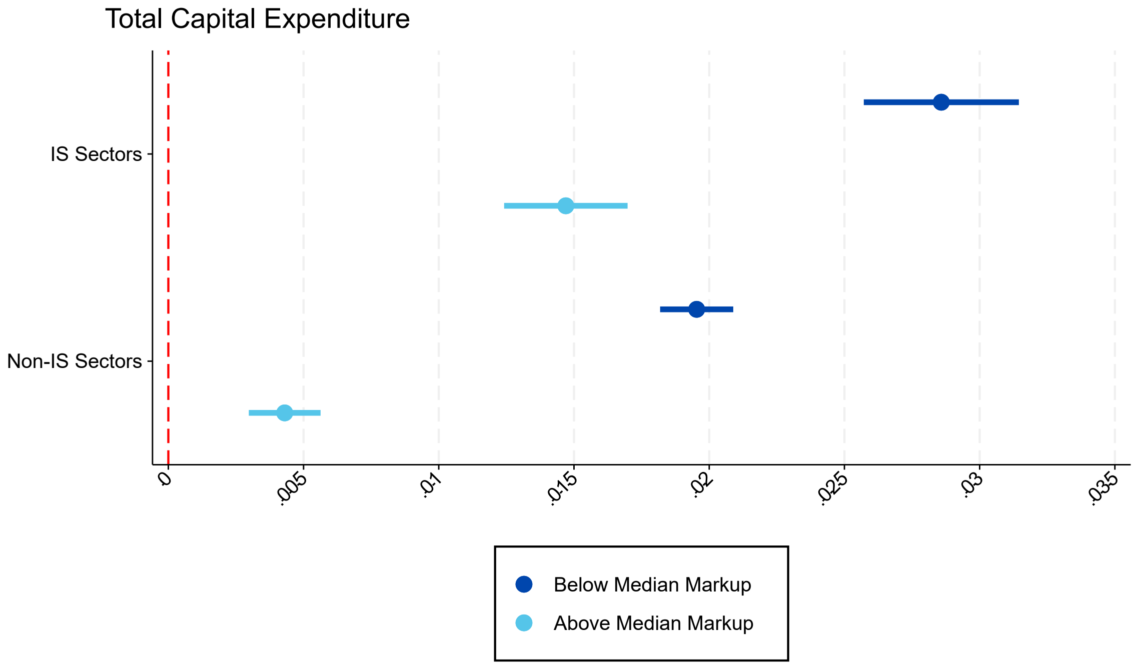


Coefficients from firm-level regressions of TFP on external R&D investment (1999-2021), for firms with markups above and below their SIC-sector median, separately for firms in manufacturing, construction, and information and technology sectors, from ARDx/ABS and BERD. Lines represent 95% confidence intervals around estimated coefficient.

The effect of markups on the relationship between TFP and investment in IS sectors is consistent with the rest of the economy

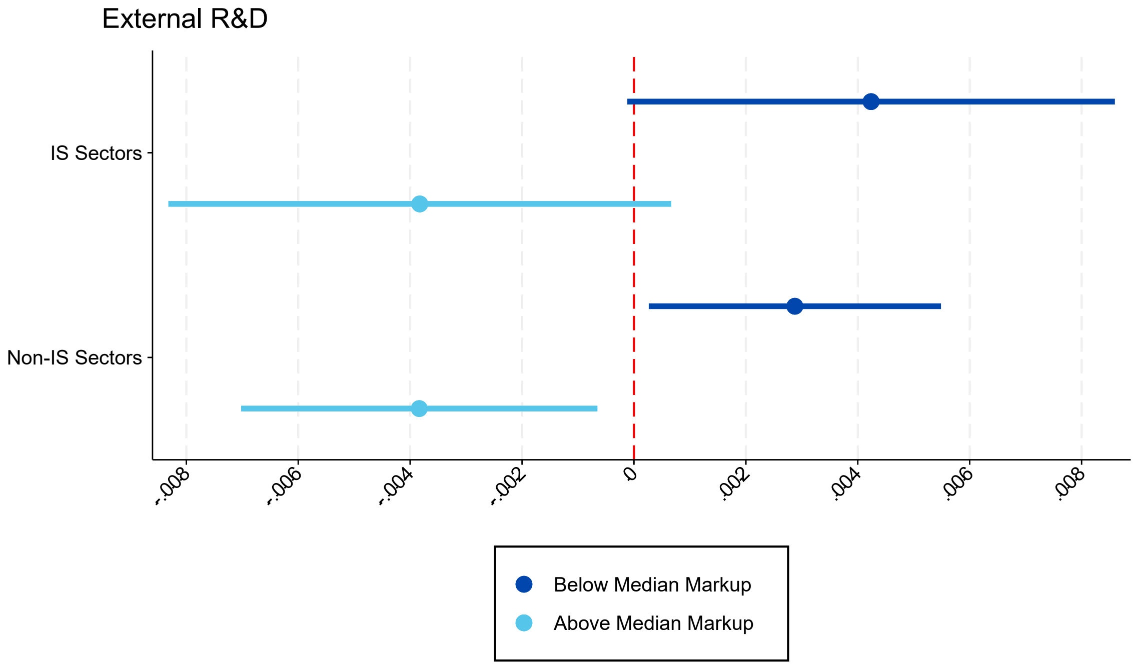
C.26 Figure 7-44, Figure 7-45, Figure 7-46, Figure 7-47, Figure 7-48, and Figure 7-49 show the coefficients when regressing TFP on total capital expenditure, internal and external R&D investment, machinery, software, and patent investment for firms above and below the median markup within their SIC sector, separately for all firms in the IS sectors, and for firms in other sectors.

Figure 7-44 Associations between TFP and capital expenditure, for firms with markups above and below their SIC sector median, separately for firms in IS sectors and those in other sectors



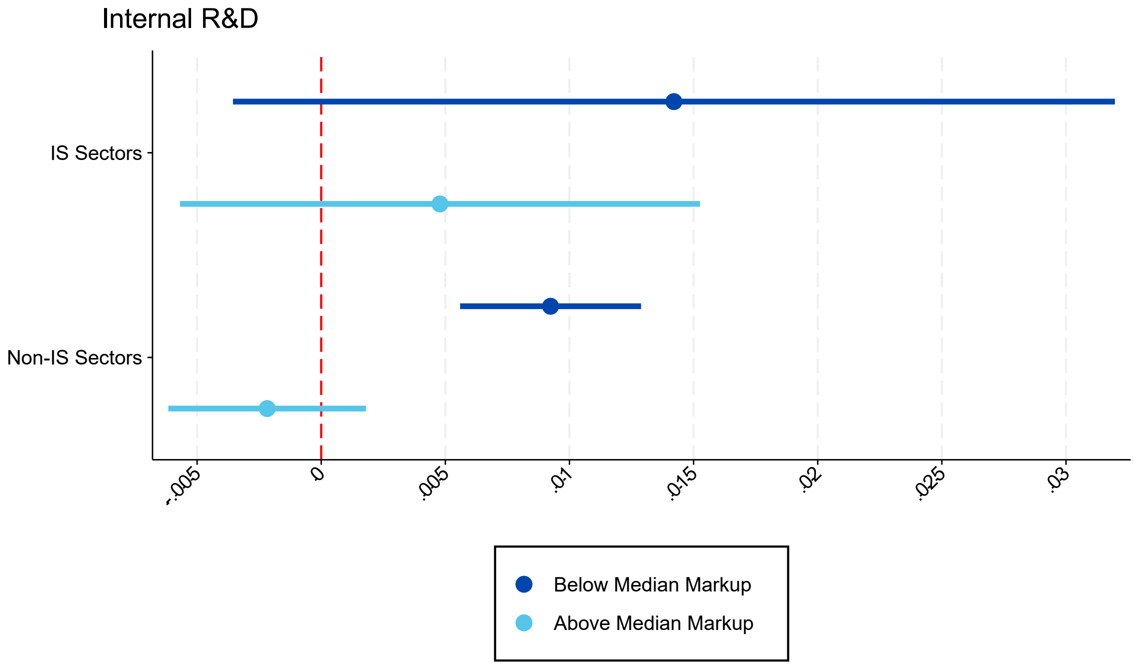
Coefficients from firm-level regressions of TFP on capital expenditure (1997-2021), for firms with markups above and below their SIC-sector median, separately for firms in IS sectors and those in other sectors, from ARDx/ABS. Lines represent 95% confidence intervals around estimated coefficient.

Figure 7-45 Associations between TFP and external R&D investment, for firms with markups above and below their SIC sector median, separately for firms in IS sectors and those in other sectors



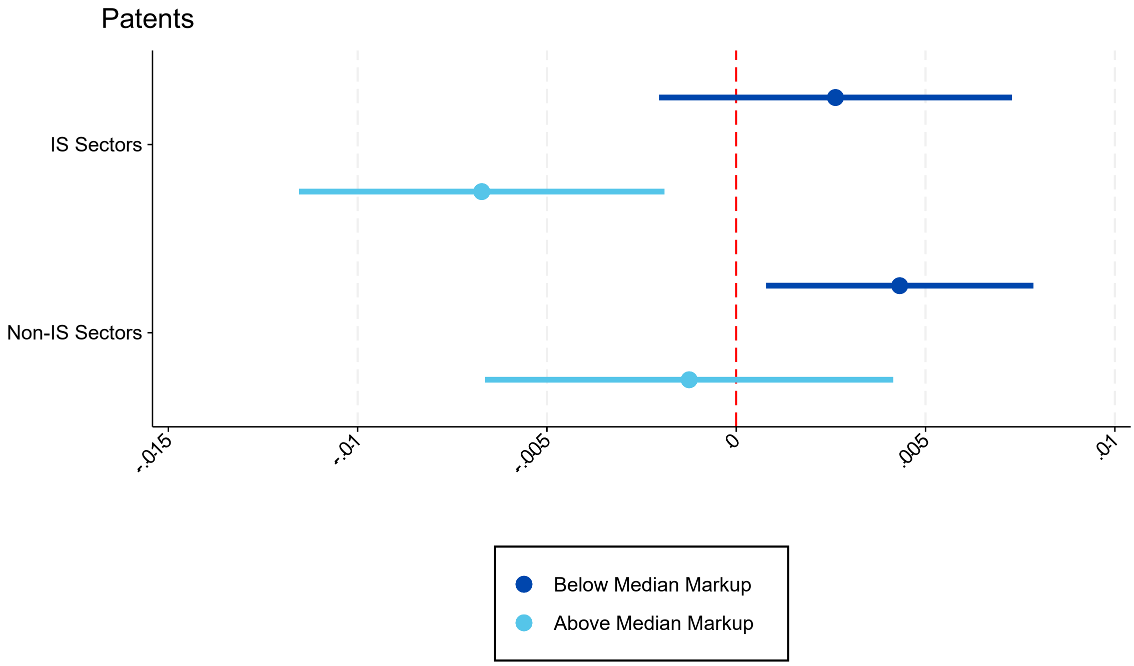
Coefficients from firm-level regressions of TFP on external R&D investment (1999-2021), for firms with markups above and below their SIC-sector median, separately for firms in IS sectors and those in other sectors, from ARDx/ABS and BERD. Lines represent 95% confidence intervals around estimated coefficient.

Figure 7-46 Associations between TFP and internal R&D investment, for firms with markups above and below their SIC sector median, separately for firms in IS sectors and those in other sectors



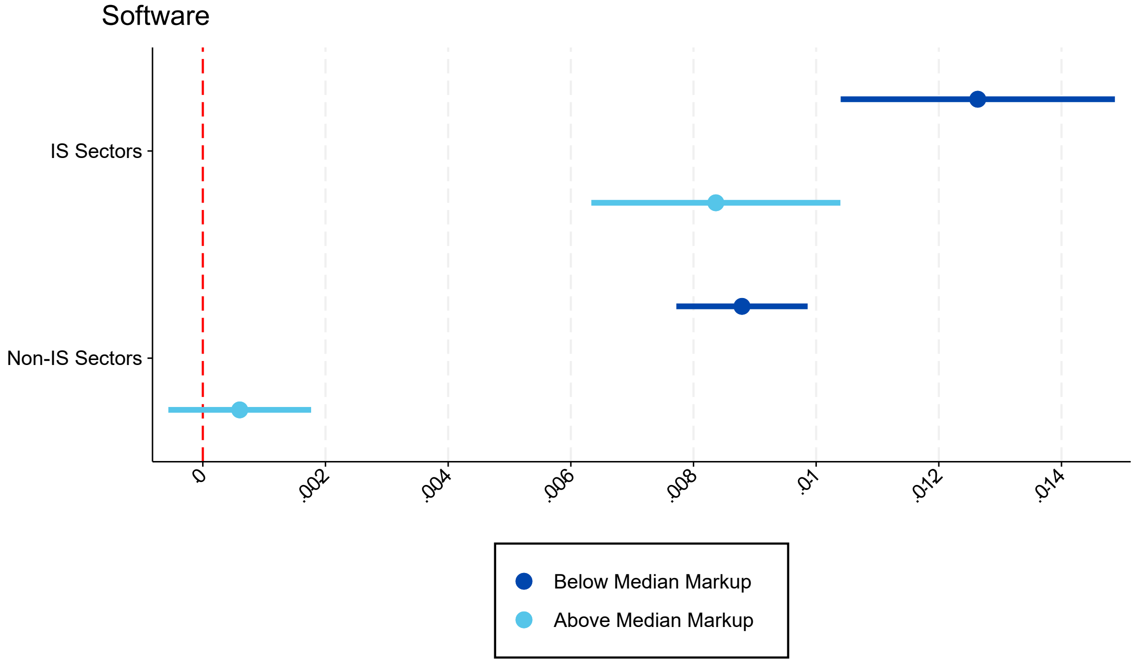
Coefficients from firm-level regressions of TFP on internal R&D investment (1999-2021), for firms with markups above and below their SIC-sector median, separately for firms in IS sectors and those in other sectors, from ARDx/ABS and BERD. Lines represent 95% confidence intervals around estimated coefficient.

Figure 7-47 Associations between TFP and patent investment, for firms with markups above and below their SIC sector median, separately for firms in IS sectors and those in other sectors



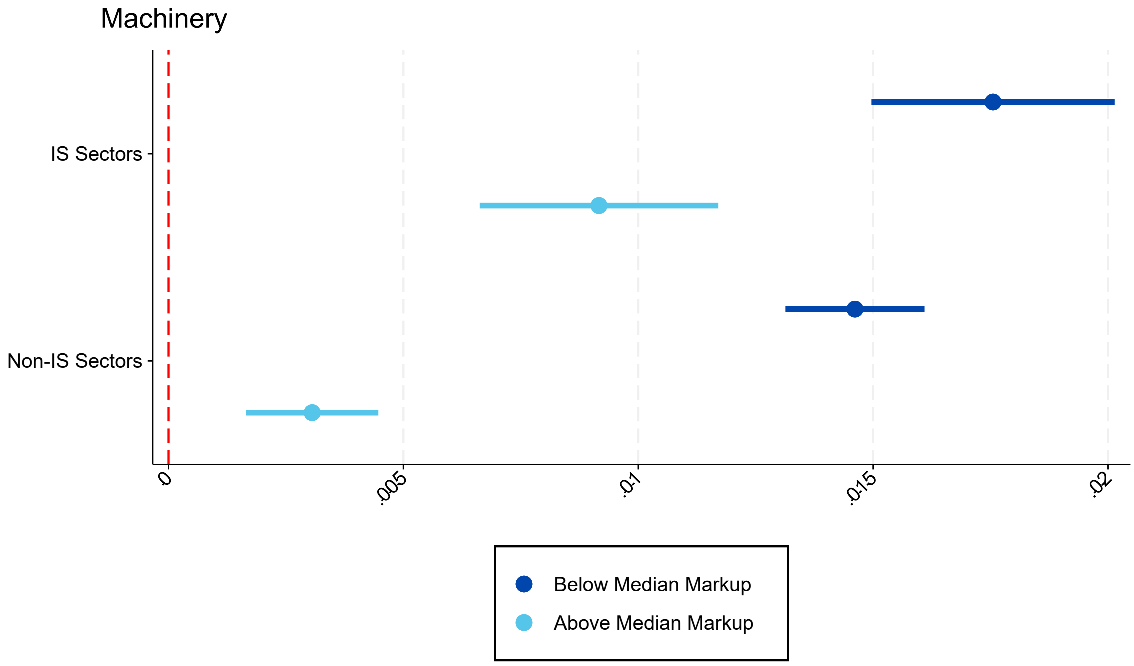
Coefficients from firm-level regressions of TFP on patent investment (2000-2021), for firms with markups above and below their SIC-sector median, separately for firms in IS sectors and those in other sectors, from ARDx/ABS. Lines represent 95% confidence intervals around estimated coefficient.

Figure 7-48 Associations between TFP and software investment, for firms with markups above and below their SIC sector median, separately for firms in IS sectors and those in other sectors



Coefficients from firm-level regressions of TFP on software investment (2000-2021), for firms with markups above and below their SIC-sector median, separately for firms in IS sectors and those in other sectors, from ARDx/ABS. Lines represent 95% confidence intervals around estimated coefficient.

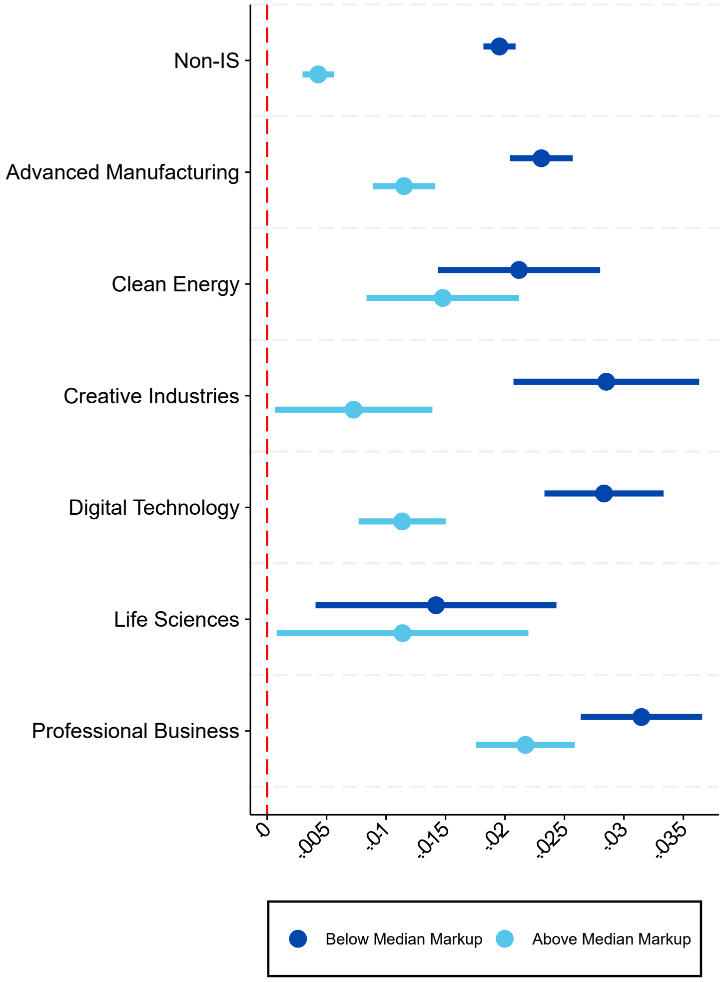
Figure 7-49 Associations between TFP and machinery investment, for firms with markups above and below their SIC sector median, separately for firms in IS sectors and those in other sectors



Coefficients from firm-level regressions of TFP on machinery investment (2000-2021), for firms with markups above and below their SIC-sector median, separately for firms in IS sectors and those in other sectors, from ARDx/ABS. Lines represent 95% confidence intervals around estimated coefficient.

C.27 Figure 7-50 shows the coefficients when regressing TFP on total capital expenditure for firms above and below the median markup within their SIC sector, separately for all firms within each of the IS sectors, and for firms in non-IS sectors.

Figure 7-50 Associations between TFP and capital expenditure, for firms with markups above and below their SIC sector median, separately for firms within each of the IS sectors and those in other sectors

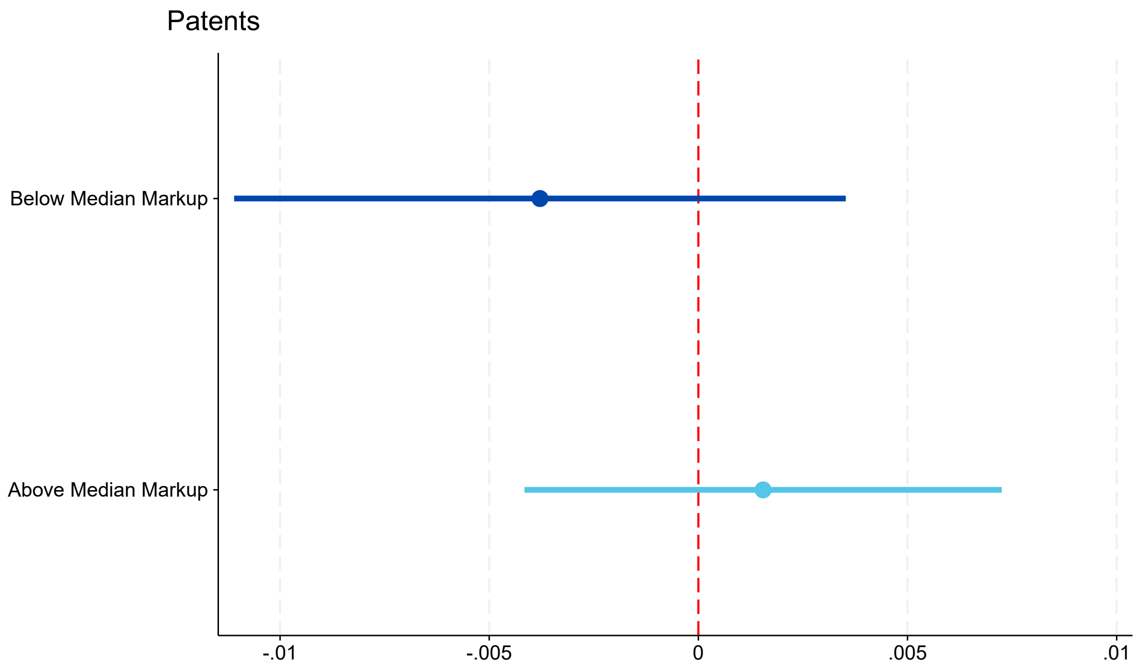


Coefficients from firm-level regressions of TFP on capital expenditure (1997-2021), for firms with markups above and below their SIC-sector median, separately for firms in each of the IS sectors and those in other sectors, from ARDx/ABS and BERD. Lines represent 95% confidence intervals around estimated coefficient.

Industries with higher average markups have a stronger relationship between investment and TFP

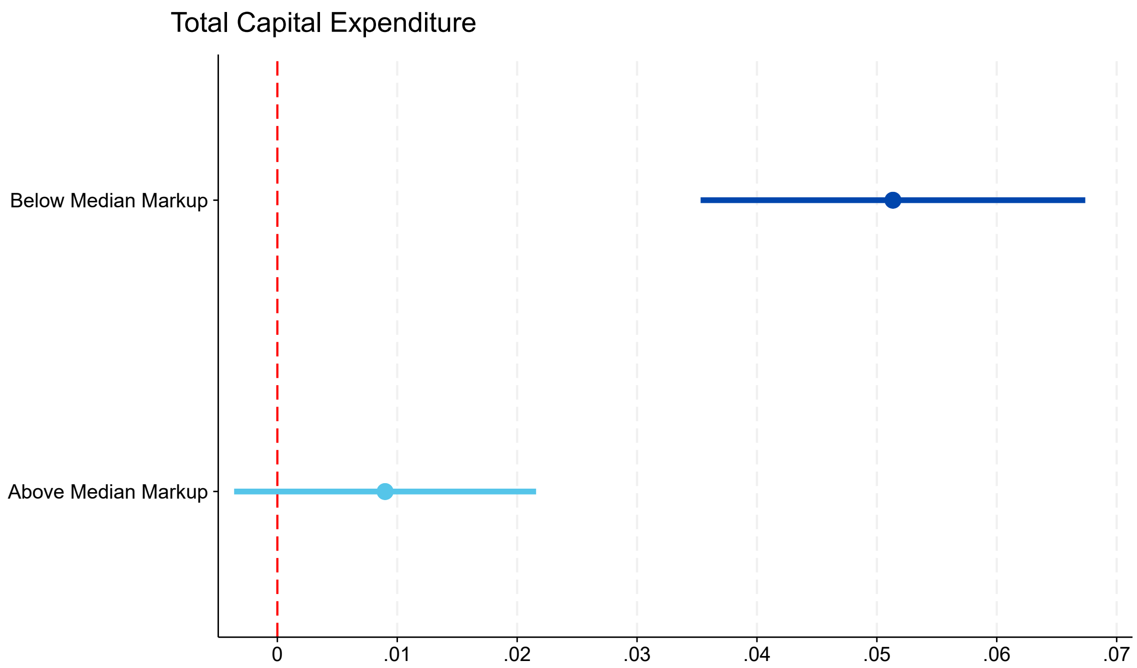
C.28 Figure 7-51, Figure 7-52, Figure 7-53, Figure 7-54, Figure 7-55, and Figure 7-56 show the coefficients when regressing an industry's aggregate TFP on its aggregate total capital expenditure, internal and external R&D investment, machinery, software, and patent investment for firms above and below the median markup within their SIC sector.

Figure 7-51 Associations between an industry's TFP and its patent investment, for firms with markups above and below their SIC sector median



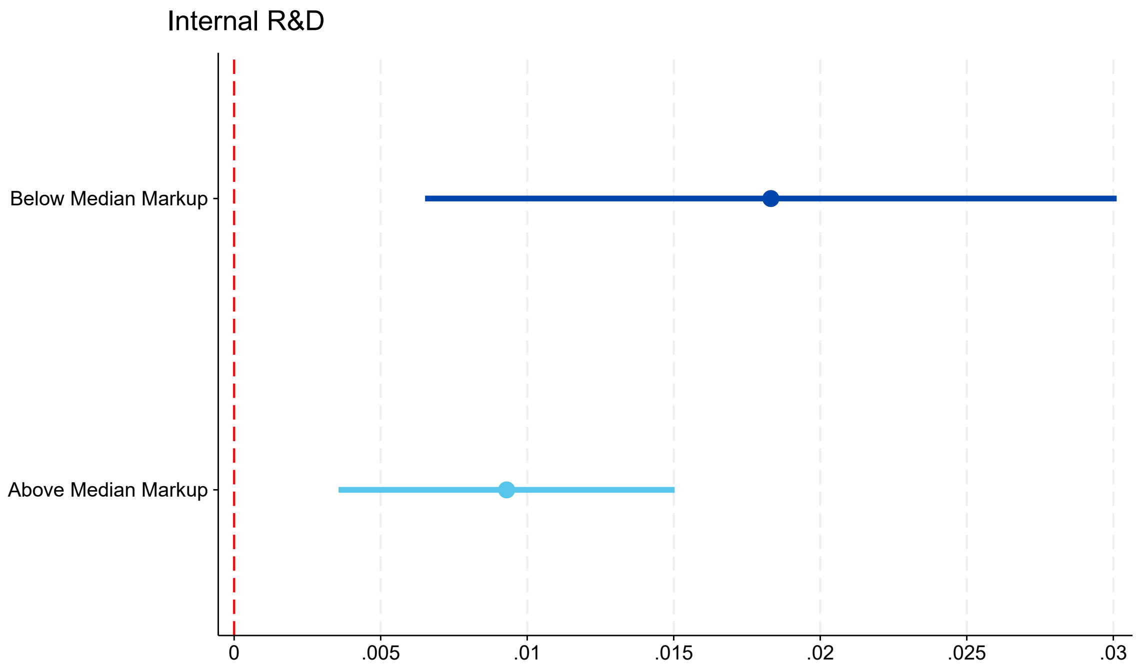
Coefficients from industry-level regressions of TFP on patent investment (2000-2013), for firms with markups above and below their SIC-sector median, from ARDx/ABS. Lines represent 95% confidence intervals around estimated coefficient.

Figure 7-52 Associations between an industry's TFP and its capital expenditure, for firms with markups above and below their SIC sector median



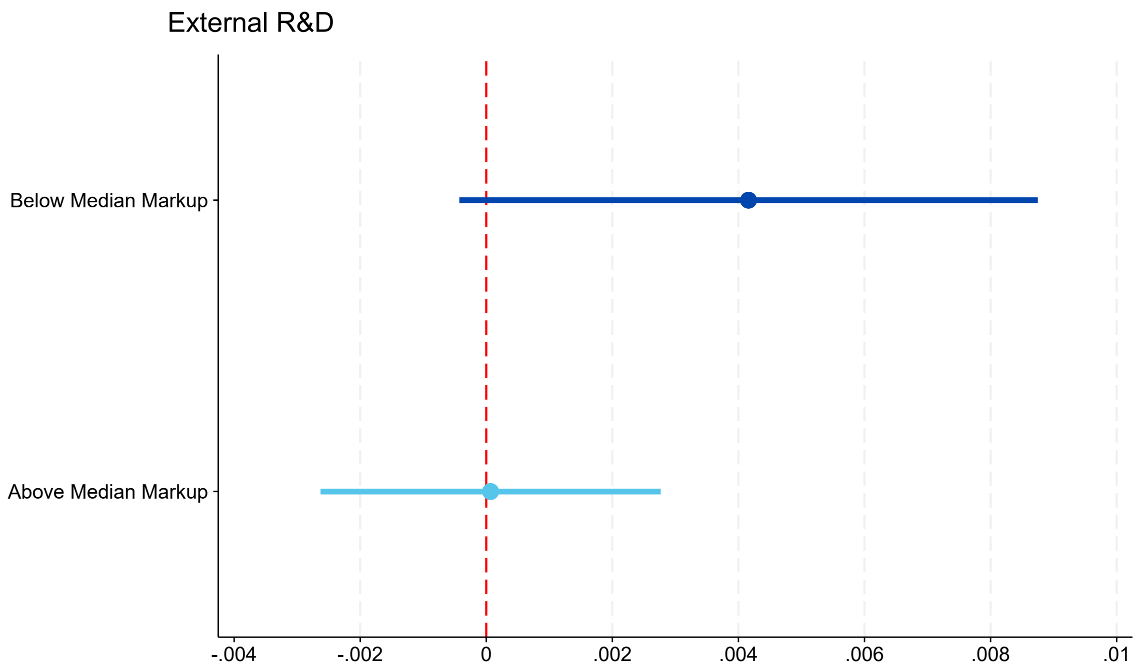
Coefficients from industry-level regressions of TFP on capital expenditure (1997-2021), for firms with markups above and below their SIC-sector median, from ARDx/ABS. Lines represent 95% confidence intervals around estimated coefficient.

Figure 7-53 Associations between an industry's TFP and its internal R&D investment, for firms with markups above and below their SIC sector median



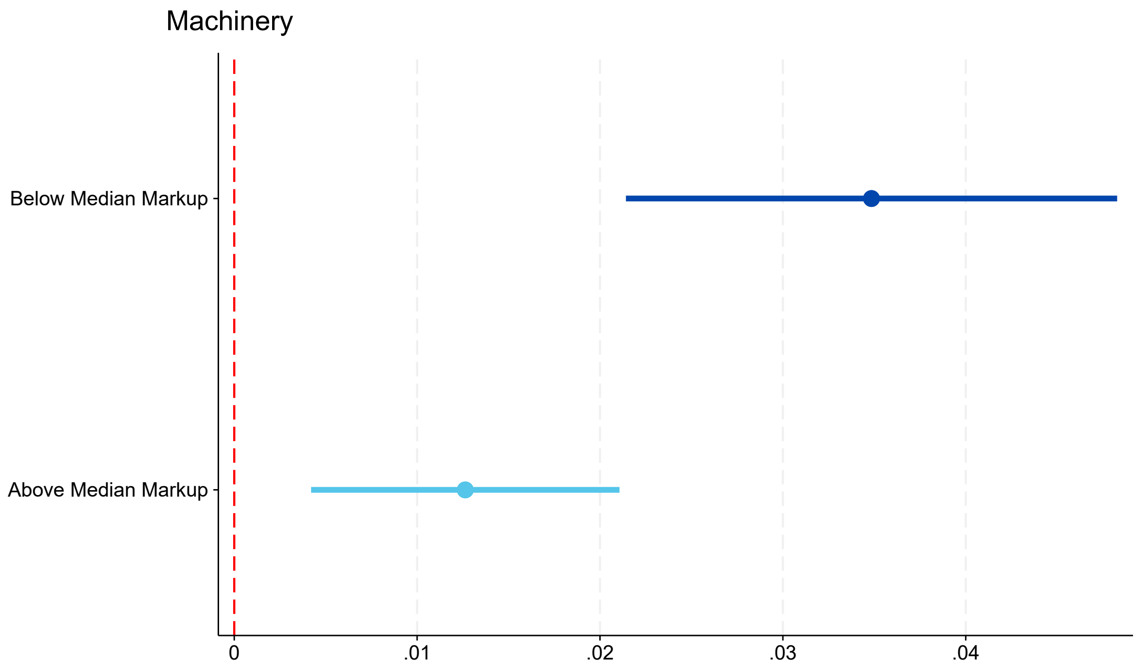
Coefficients from industry-level regressions of TFP on internal R&D investment (1999-2021), for firms with markups above and below their SIC-sector median, from ARDx/ABS and BERD. Lines represent 95% confidence intervals around estimated coefficient.

Figure 7-54 Associations between an industry's TFP and its external R&D investment, for firms with markups above and below their SIC sector median



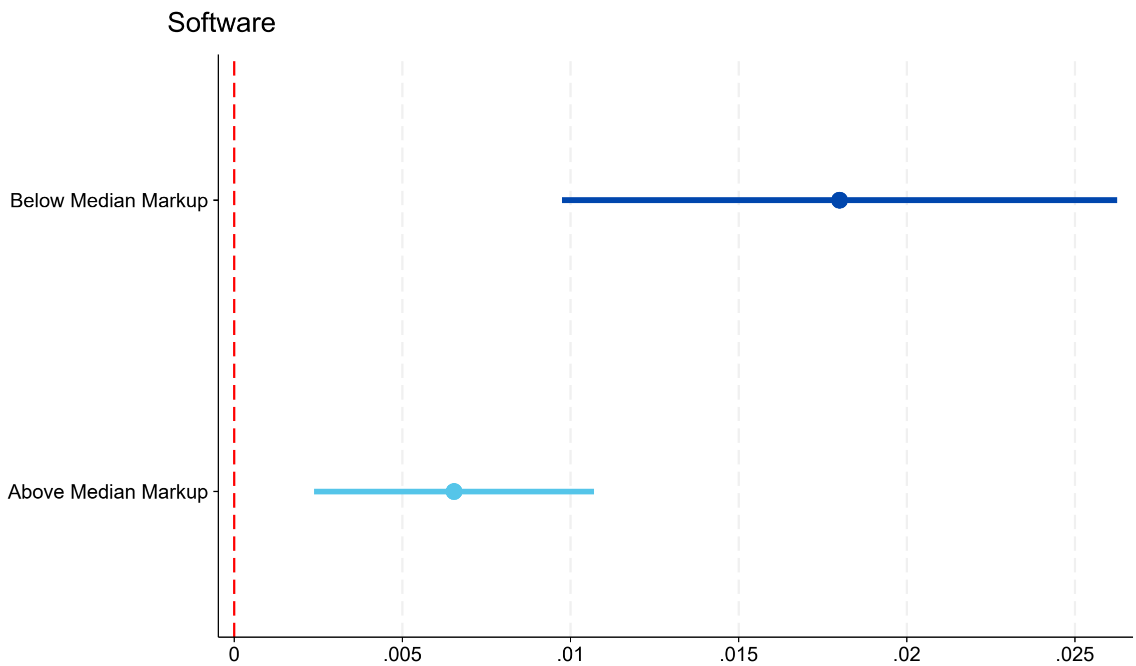
Coefficients from industry-level regressions of TFP on external R&D investment (1999-2021), for firms with markups above and below their SIC-sector median, from ARDx/ABS and BERD. Lines represent 95% confidence intervals around estimated coefficient.

Figure 7-55 Associations between an industry's TFP and its machinery investment, for firms with markups above and below their SIC sector median



Coefficients from industry-level regressions of TFP on machinery investment (2000-2021), for firms with markups above and below their SIC-sector median, from ARDx/ABS. Lines represent 95% confidence intervals around estimated coefficient.

Figure 7-56 Associations between an industry's TFP and its software investment, for firms with markups above and below their SIC sector median



Coefficients from industry-level regressions of TFP on software investment (2000-2021), for firms with markups above and below their SIC-sector median, from ARDx/ABS. Lines represent 95% confidence intervals around estimated coefficient.