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Staff Working Paper No. 798
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Abstract

In this paper we explore the link between monetary policy and market power. We start by establishing several facts on market power in UK markets using micro data. First, while no clear trend emerges for market concentration, market power measured by markups estimated at the firm level have clearly increased in recent years, with the rise being reasonably broad-based across sectors. Second, we show that the increase is heavily concentrated in the upper tail of the distribution — companies whose mark-ups are in, say, the top quartile. Third, internationally-oriented firms are the driving force behind the rise in markups. Fourth, following Díez *et al* (2018), we find some reduced-form evidence of a non-monotonic relation between markups and investment at the firm level, with high levels of markups being associated with lower investment. Having established these facts, we show that the Phillips curve becomes steeper in the textbook New Keynesian model when firms tend to have more market power, reducing the sacrifice ratio for monetary policy. As inflation becomes less costly in an economy with high market power, however, the optimal targeting rule for monetary policy also changes. A rise in both the trend and volatility of mark-ups may lead to a significant rise in inflation variability. But a secular rise in mark-ups by itself improves monetary policy's ability to stabilise inflation without inducing large movements in output.

Key words: Markups, market power, secular trends, monetary policy, DSGE.

JEL classification: D2, D4, E52, E31.

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1 Introduction

The relationship between *labour markets* and monetary policy has rightly received a lot of attention in recent years (for example, Yellen (2014) and Constâncio (2017)). The relationship between monetary policy and *product* markets has, by comparison, been the road less travelled.[1,2,3]

Yet, over the same period, structural shifts in the product market have been no less profound. They include the emergence of highly-integrated global supply chains, increasing the degree of specialisation of product markets (Baldwin (2016)); the blossoming of companies benefitting from global network economies of scale and scope, who acquire "superstar" status (Autor *et al* (2017)); and the rapid emergence of e-commerce and price-comparison technology (Cavallo (2017)).

The associated shifts in market power, too, might plausibly have altered some of the key macro-economic relationships in the economy (De Loecker and Eeckhout (2017)). They may have influenced the pricing and provision of goods and services in the economy and hence the Phillips curve. And they may have influenced the amount of investment and innovation undertaken by firms and hence the aggregate demand curve (Aghion *et al* (2005)). They, too, might thus have a bearing on the setting of monetary policy.

These structural shifts in product and labour markets may, in some cases, have had common cause. For example, network economies of scale and scope could have increased some companies' market power both over their labour inputs (through monopsony effects) and product outputs (through monopoly effects). This could show up in both a *falling* labour and a *rising* profit share, with potential macro-economic implications for activity, costs and prices (Autor *et al* (2017), Barkai (2017)).

In this paper we explore some of these issues using micro data for the United Kingdom. We first look at market power through the evolution of sector-level market concentration and firm-level markups. To estimate markups, we follow De Loecker and Eeckhout (2017) and thus measure variable inputs using "Cost of Goods Sold" (COGS). Others, like Traina (2018) and Karabarbounis and Neiman (2018), suggest to use "Selling, General & Administrative Expense" (SG&A), arguing that the increase in markups found by De Loecker and Eeckhout (2017) is entirely offset by the increase in overhead costs (measured by SG&A). Nevertheless, De Loecker et al (2018) also show that though there is an increase in overhead costs of US firms, this is more than offset by the increase in markups.[4]

Leaving this debate to further research, we establish several facts. First, while no clear trend emerges for market concentration, market power measured by markups estimated at the firm level have clearly increased in recent years, with the rise being reasonably broad-based across sectors. Second, we show that the increase is heavily concentrated in the upper tail of the distribution – companies whose mark-ups are in, say, the top quartile. Third, strongly internationally-oriented firms are the driving force behind the rise in markups. Fourth, following Díez et al (2018), we find some reduced-form evidence of a non-monotonic relation between mark-ups and investment at the firm level.

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[1] As Blanchard (2008) said, "How mark-ups move, in response to what, and why, is however nearly terra incognita for macro."

[2] Some notable papers that discuss the impact of product market developments on the macro-economy include Cacciatore and Fiori (2016) and Eggertsson, Ferrero and Raffo (2014).

[3] Labour markets have been subject to big structural shifts over recent years, including the secular fall in the degree of worker unionisation in a number of industries (for example, Schnabel (2013)), the emergence of the so-called "gig economy" (for example, Taylor (2017) and Katz and Krueger (2017)) and secular rise in the degree of globalisation and automation in the workplace (for example, Brynjolfsson and McAfee (2014) and Acemoglu and Restrepo (2018)). Each of these shifts has led to a change in employment patterns and tenures and in workers' bargaining power.These structural shifts have been used to help explain the secular fall in labour's share of national income and the recent weakness of wage growth across a number of advanced economies (for example, Dao *et al* (2017) and Abdih and Danninger (2017)). They have also been used to justify potential shifts in the position and/or the slope of the Phillips curve (for example, Blanchard (2016) and Kuttner and Robinson (2010)). Each of these potentially has a bearing on the setting of monetary policy.

[3] Importantly, De Loecker et al (2018) also show that the rise of market power is not restricted to listed firms (as in De Loecker and Eeckhout (2017)) and extends to universe of firms.

Having established these facts, we turn to the implications for monetary policy. The macroeconomic literature has long recognised an important role for mark-up shocks, in particular to explain nominal variables. But the trend level of mark-ups has not played a prominent role. We use the textbook New Keynesian model to derive a set of implications for monetary policy. We show that the Phillips curve becomes steeper when firms tend to have more market power, reducing the sacrifice ratio for monetary policy. But as inflation becomes less costly in an economy with high market power, the optimal targeting rule for monetary policy also steepens. In particular, monetary policy should let inflation absorb more, and the output gap less, of the adjustment after a trade-off inducing disturbance.

Correctly identifying secular changes and cyclical variation in mark-ups is important for monetary policy. Mark-up shocks induce a policy trade-off, as they typically drive inflation and the output gap in opposite directions. In other words, the identification of mark-up shocks and trends is important to locate the monetary policy possibility frontier correctly. An incorrect assessment might lead to a misperception about the outcomes that monetary policy can attain.[5] We show that a rise in both the trend and volatility of mark-ups may lead to a significant rise in inflation variability but relatively less change in output variability. For a given volatility of cost-push disturbances, a secular increase in trend mark-ups reduces the volatilities of both output and inflation.

There are two additional ways in which the path of monetary policy might potentially be affected by increases in market power. When companies have a significant degree of market power, the level of output produced is likely to be below the social optimum, creating an incentive for monetary policy to try to offset that by running the economy hot ("inflation bias"). And if market power lowered companies' investment rates, this could reduce the economy's natural rate of interest. Neither, however, at present has a strong empirical basis. To the extent these channels do operate, they reinforce the institutional case for independent central banks charged with pursuing well-defined inflation targets.

At the same time, actual inflation across advanced economies has been relatively low and stable over recent decades. So while the micro-economic evidence – a secular increase in mark-ups – is striking, it is not easily reconciled with the macro-economic evidence on measured inflation, including on the impact of mark-ups on inflation (for example, Smets and Wouters (2007)). Reconciliation of the two strands of evidence – micro and macro – means that some combination of the following would have to be true.

First, the micro-economic *firm-level* evidence may not accurately describe how *economy-wide* mark-ups have evolved since the 1980s. Second, other macro-economic factors may have more than offset the impact of rising mark-ups on the behaviour of inflation. Third, the theoretical macro-economic framework we use here – a New Keynesian model with monopolistic competition – may not be appropriate to analyse firm-level changes in mark-ups. The apparent puzzle between the micro-economic and macro-economic evidence deserves further research, given its potential impact on inflation dynamics and monetary policy.

The paper is organised as follows. In Section 2, we use micro data to establish some facts on the evolution of market power in the UK over the last three decades. Section 3 presents a comparative static analysis of a rise in market power in the New Keynesian model. Section 4 concludes with an outline for further research.

2 Facts on UK's Market Power: Firms and sectors

There is a rich micro-economic literature that assesses the impact of market power on pricing and other firm decisions (for example, Tirole (1988)). There has been rather less evidence linking the industrial organisation of firms to developments in the wider macro-economy. That has changed recently, with a number of papers exploring

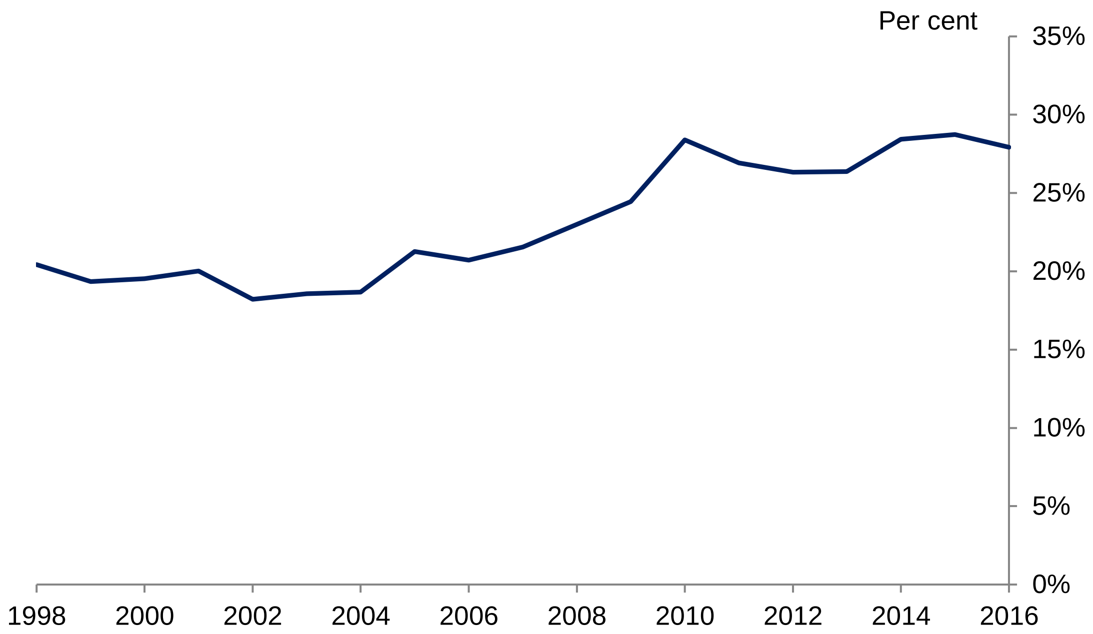
[5] In standard DSGE models, mark-up volatility tends to mimic inflation volatility. Both Smets and Wouters (2007) for the United States, and Kapetanios, Masolo, Petrova and Waldron (2017) for the United Kingdom, find evidence that mark-up volatility has fallen over the past three decades, just as inflation has been more stable. But the mark-up shocks have been found to reflect misspecification in DSGE models, see e.g. King and Watson (2012) and Del Negro, Giannoni and Schorfheide (2015).

the empirical evolution of (firm, sectoral and national) measures of market power and their implications for the macro-economy (for example, De Loecker and Eeckhout (2017, 2018) and Díez *et al* (2018)).

Perhaps the simplest way of capturing market power is through measures of market concentration, such as Herfindahl-Hirschman Indices (HHI) (Hirschman (1964)) or concentration ratios (the share of sales that accrues to the largest firms within an economy or sector). Evidence suggests that market concentration, measured either through HHIs or concentration ratios, may have increased in the US over recent decades, across a broad range of sectors (for example, Autor *et al* (2017)). This pattern is not uniform, however, with concentration among European companies showing no such trend (Gutiérrez and Philippon (2018)).

The evidence on industry concentration in the UK suggests it occupies a mid-Atlantic position. Chart 1 plots the turnover share of the largest 100 UK businesses since 1998 (i.e. concentration ratio).[6] This ticks up in the lead-up to the financial crisis, although this pick-up is more modest than in the US, from 20% to around 28%.[7] Concentration has flattened-off in the period since the crisis, however, in line with other European countries.

Chart 1: UK product market concentration (turnover share of largest 100 businesses)



Sources: ONS and Bank calculations. Notes: Data and calculations exclude the financial sector.

Concentration indices have their limitations, though, and need not always be associated with market power. Some firms may be able to exercise market power in setting prices even without having a large share of a market if, for example, there is brand loyalty. And in a world of differentiated products, concentration measures such as HHIs or concentration ratios no longer correlate closely with market power (Bresnahan (1989); De Loecker and Eeckhout (2018)).

Measures of firms' mark-ups – of price over marginal cost – suffer fewer of these draw-backs. The larger the mark-up, the greater the degree of market power, whether at the firm, sector or national level. Mark-ups also have the benefit of being the relevant measure of market power in the workhorse models of the macro-economy used by policymakers. In that spirit, a number of recent papers have estimated measures of mark-ups based on individual company accounts data. These cover a wide range of companies, sectors, countries and time periods (for example, Díez *et al* (2018)). The findings from these studies are, in macro-economic terms, both quite striking and quite strikingly uniform in the broad trends they reveal.

6 Excluding financial services firms.
7 See, also, Bell and Tomlinson (2018).

For example, De Loecker and Eeckhout (2018) have recently calculated mark-ups for around 70,000 firms across 134 countries over almost four decades.[8] Since 1980, they estimate that the sales-weighted mark-up for the average firm across countries has risen by a remarkable 50 percentage points.[9] Table 1 shows their mark-up measures for the G7 economies over the period.

Table 1: G7 mark-ups

Country	Mark-up level (2016)	Mark-up increase from 1980-2016	Implied impact on annual price inflation (pp)
Canada	1.53	0.61	1.3
France	1.50	0.53	1.2
Germany	1.35	0.29	0.7
Italy	2.46	1.46	2.5
Japan	1.33	0.30	0.7
UK	1.68	0.74	1.6
US	1.78	0.63	1.4
G7 average	**1.66**	**0.65**	**1.3**

Sources: De Loecker and Eeckhout (2018) and Bank calculations.

Notes: Final column shows a simple indicative calculation where we assume that higher firm-level mark-ups have been fully reflected in a higher economy-wide price level and therefore higher inflation rates between 1980 and 2016.

Though there is cross-country variation, average mark-ups have risen significantly in every G7 country, by between 30 and 150 percentage points. Taken at face value, the macro-economic implications of these shifts in mark-ups could be very large. The most direct and immediate impact would be on measured inflation rates. According to Table 1, estimated mark-ups will have been adding, on average, over one percentage point *each year* to measured inflation rates across the G7 countries between 1980 and 2016, other things equal. As context, over the same period average G7 inflation rates have fallen by over 10 percentage points.[10] For this stylised experiment, we assume that the estimated increase in mark-ups between 1980 and 2016 represents the extent to which the price level in 2016 was higher that it would otherwise have been, i.e. costs are unchanged and the rise in mark-ups feeds through to higher prices. We then calculate the implied upward pressure on average annual consumer price inflation rates between 1980 and 2016 that will have cumulated over time to generate that higher price level in 2016. For example, a 61% higher price level in Canada implies annual CPI inflation being 1.3pp higher than it would otherwise have been over that 36 year period.

A second potential macro-economic impact of higher mark-ups is on sales. Higher mark-ups will, other things equal, have pushed down on aggregate demand and generated a deadweight loss of consumer surplus. Baquee and Farhi (2018) estimate the size of this effect and find that *eliminating* mark-ups entirely would raise aggregate US total factor productivity (TFP) by as much as 35%.[11]

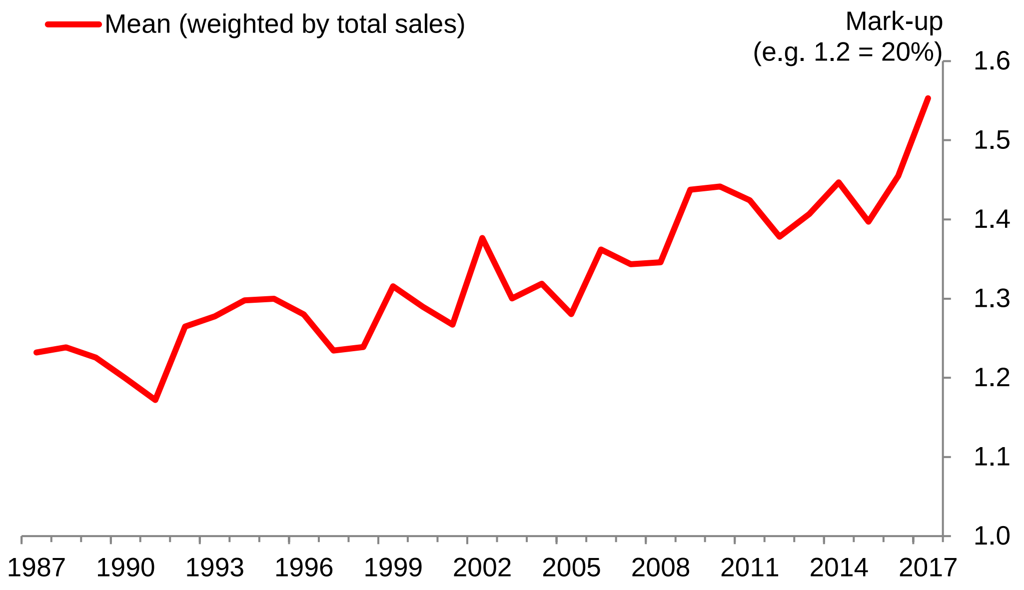
2.1 Firms and sectors

To better understand some of the drivers of higher mark-ups, it is useful to look at more granular data. Using a similar approach to De Loecker and Eeckhout (2017, 2018), we draw on data for around 3,500 unique UK-listed

[8] De Loecker and Eeckhout (2018) use a dataset that largely includes publicly-traded companies, but there are also some privately held firms.
[9] Similar estimates have recently been provided by Díez *et al* (2018).
[10] OECD data.
[11] De Loecker and Eeckhout (2018) estimate that mark-ups in the US are a little larger than in the UK, so the boost to UK TFP from eliminating them would be smaller than the 35% estimate for the US in Baquee and Farhi (2018), albeit of a similar order of magnitude.

companies from 1987 to 2017 to construct around 33,500 firm-year mark-up estimates.[12] Using that methodology, Chart 2 plots a sales-weighted measure of mean mark-ups for UK-listed companies since 1987. It shows a strong increase, from 1.2 to around 1.6, over the period. This broadly mirrors international trends.[13]

Chart 2: UK-listed firms' average mark-ups



Sources: Thomson Reuters Worldscope and Bank calculations.

Note: Details of how mark-ups are estimated are described in the Appendix. Individual mark-ups are weighted by their share of total sales in the sample in a given year.

Slicing mark-up data for non-financial companies on a sectoral basis, we can see that this rise has been reasonably broad-based (Chart 3). All but two of the ten sectors we analysed have seen mark-ups rise since 1987, although some are volatile. Six of the ten have seen them rise by more than 30 percentage points. Among the largest rises have been in manufacturing (70 percentage points), professional, scientific and technical (62 percentage points) and transport and storage (57 percentage points).[14] This broadly mirrors the international evidence.[15]

Another way of slicing the data is to ask how much of the rise in mark-ups is due to a compositional shift over time towards sectors whose mark-ups are already high and how much reflects a generalised rise in mark-ups within each sector. Chart 4 shows this decomposition for UK-listed firms. Compositional effects do not explain any of the rise in mark-ups in the UK; and even if we do the same exercise at the firm level, compositional shifts towards firms with high mark-ups cannot explain the rise. Rather, the rise in mark-ups appears to be reasonably generalised across sectors.[16]

[12] The methodology is explained in the Appendix. The data include around a little over 1000 firms, on average, per year. These firms represent around one-third of UK employment. Their sales are equivalent to around one-third of UK turnover and around two-thirds of UK nominal GDP. We exclude financial sector firms and, having estimated mark-ups, trim outliers, i.e. those firm-level mark-ups that are below the 1st percentile and above the 99th percentile of the firm-level mark-up distribution in a given year,

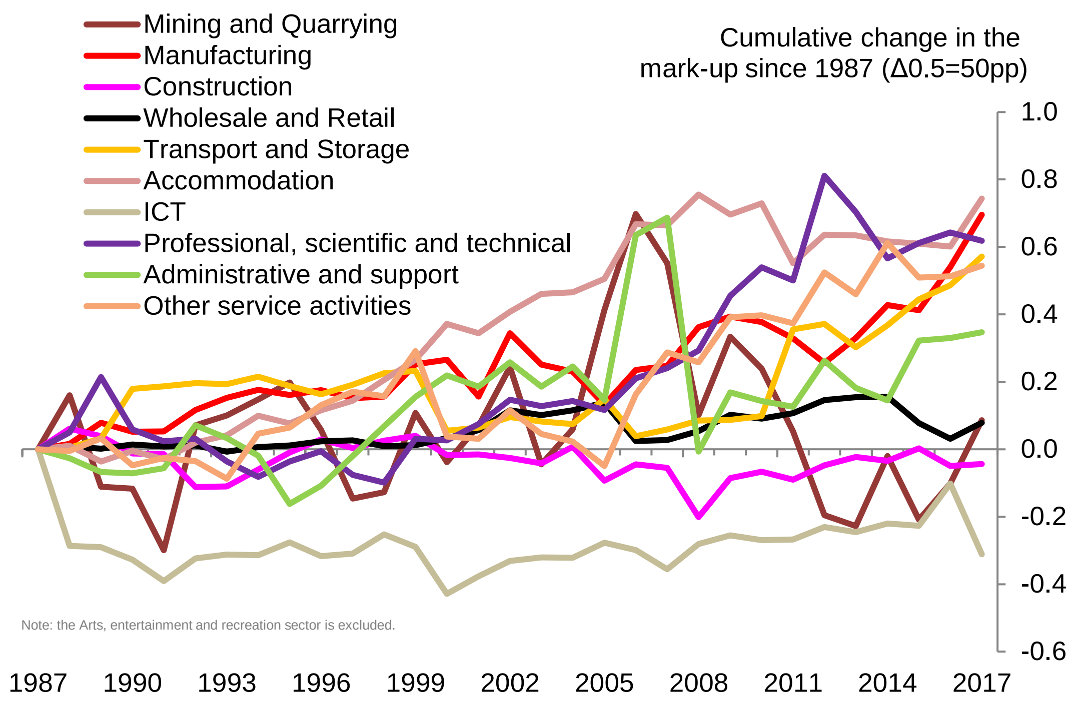
[13] As mentioned earlier, concentration indices need not always be associated with market power. However, in our sample, there is a weakly positive relationship between measures of mark-up and market concentration at the sector level, which is statistically significant at the firm level. A regression of individual firm-level mark-ups on market concentration in their sector (at the two-digit SIC level) also shows a statistically significant positive relationship when we include firm and time fixed effects. The same has been found among companies in other countries (Díez *et al* (2018)). This gives some degree of reassurance that the rise in measured market power has been a genuine one.

[14] The dynamics of markups in the ICT sector deserves further investigation: even excluding the first years of the sample, there has been hardly any significant increase in markups. This is in contrast with evidence on the US, where the ICT sector exhibits a stark increase in markups in recent decades, in line with the emergence of "superstar" firms.

[15] For example, Díez *et al* (2018) find that the majority of industries in the US have seen mark-ups rise since 1980.

[16] Díez *et al* (2018) find that the increase in US mark-ups since 1980 is also relatively broad-based across sectors.

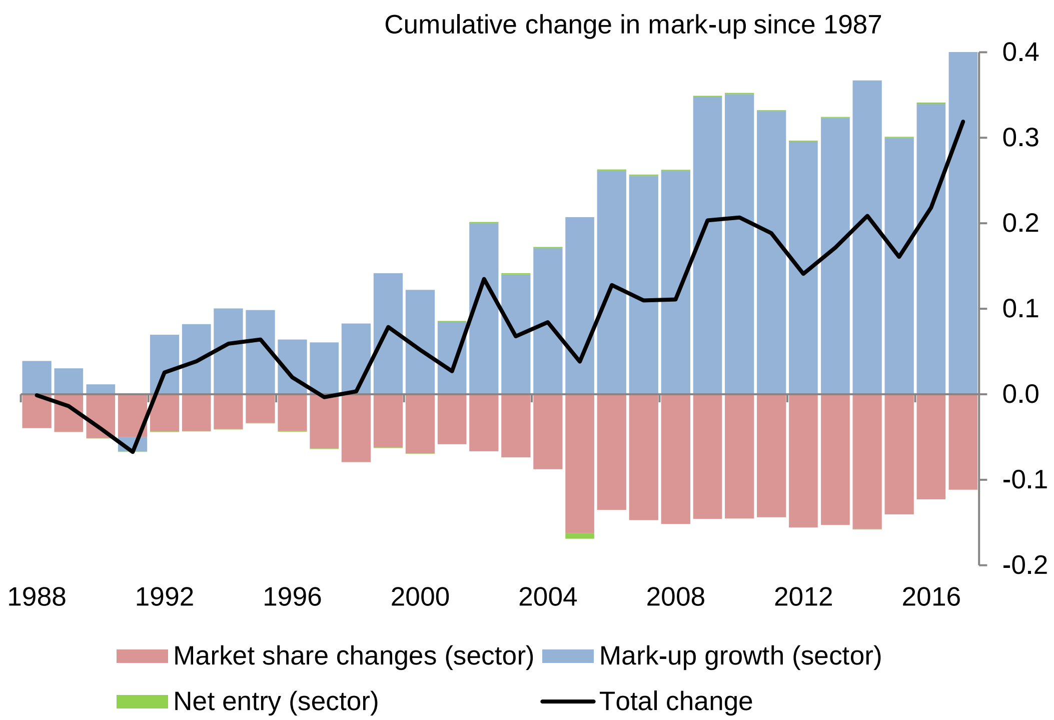
Chart 3: UK-listed firms' mark-ups by sector



Sources: Thomson Reuters Worldscope and Bank calculations.

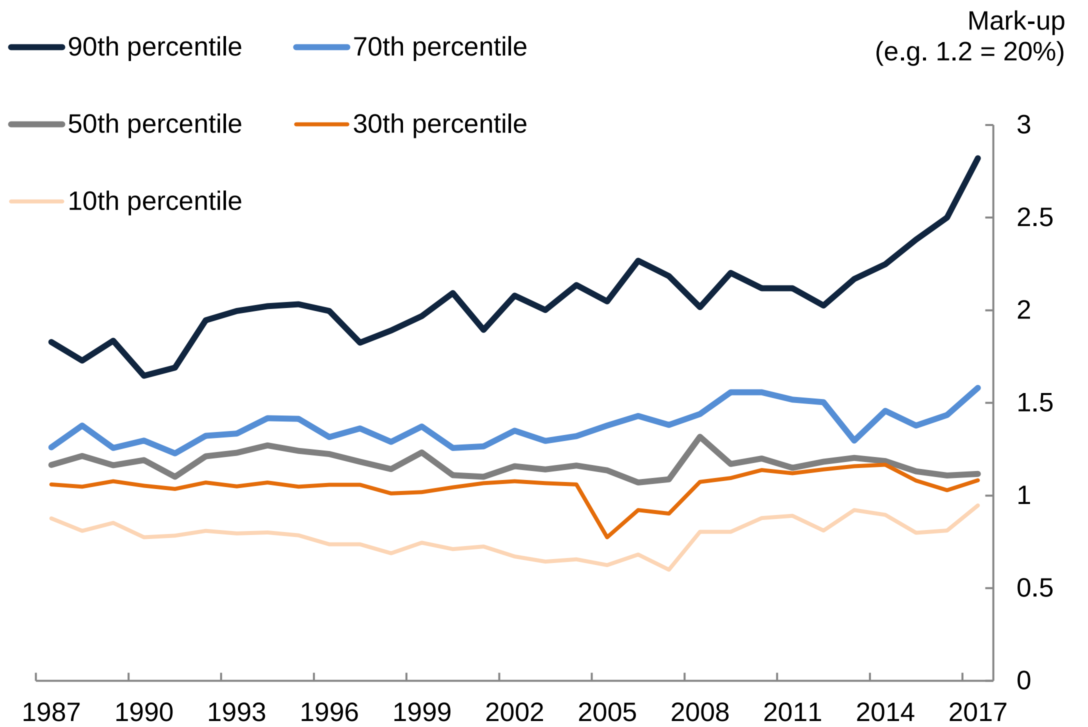
Note: the sectors in the chart above correspond to the ONS SIC2007 classification.

Chart 4: Contribution of changing sectoral composition to UK-listed firms' mark-ups



Sources: Thomson Reuters Worldscope and Bank calculations.

Chart 5: UK-listed firms' mark-up distribution over time



Sources: Thomson Reuters Worldscope and Bank calculations.

Although relatively broadly-based *across* sectors, the rise in mark-ups need not necessarily be broadly based *within* sectors. One way of showing that is by looking at the evolution of the distribution of mark-ups over time (Chart 5). This suggests the increase in mark-ups is heavily concentrated in the upper tail of the distribution – companies whose mark-ups are in, say, the top 10% of the distribution. Mark-ups among firms in this upper quartile have, on average, increased by a remarkable 50 percentage points since 1987.

By contrast, mark-ups among firms in the bottom three quartiles of the mark-up distribution have scarcely risen over the period. This distributional effect can also be seen from the large and widening gap between mean and median mark-ups (Chart 6). In 1987, this gap was 7 percentage points. By 2016, it had reached 44 percentage points. This strongly suggests that the rise in aggregate mark-ups over the past 30 years can largely be accounted for by a subset of high mark-up firms raising their mark-ups and/or market share.

This fattening of the upper tail of the mark-up distribution is not uniform across sectors. Chart 7 plots a measure of the skew of the mark-up distribution across different sectors over time. The fattening of the upper tail of the distribution is most pronounced in the ICT, transport and storage and manufacturing sectors, each of which is associated with higher average levels of mark-up.

In understanding the characteristics of these firms, one revealing cut comes from taking into the account the extent to which UK-based firms' sales are domestic or foreign-focussed (Chart 8). While both categories have seen their mark-ups rise somewhat, this has been far larger among firms selling predominantly into foreign markets (almost 60 percentage points) than domestic markets (around 15 percentage points).[17] Within that, this rise in mark-ups among foreign relative to domestic sales-focussed firms is largest in the manufacturing and ICT sectors.

[17] Our results are consistent with De Loecker and Warzynski (2012) who find that exporters charge, on average, higher mark-ups and that firm mark-ups increase upon export entry.

Chart 6: Mean and median UK-listed firms' mark-ups

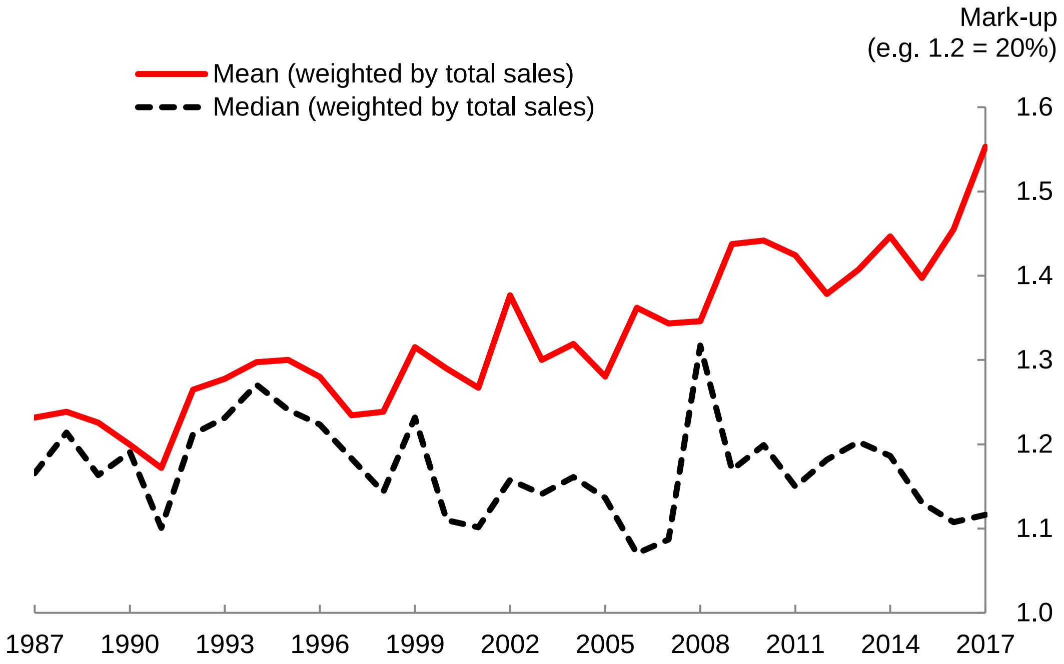
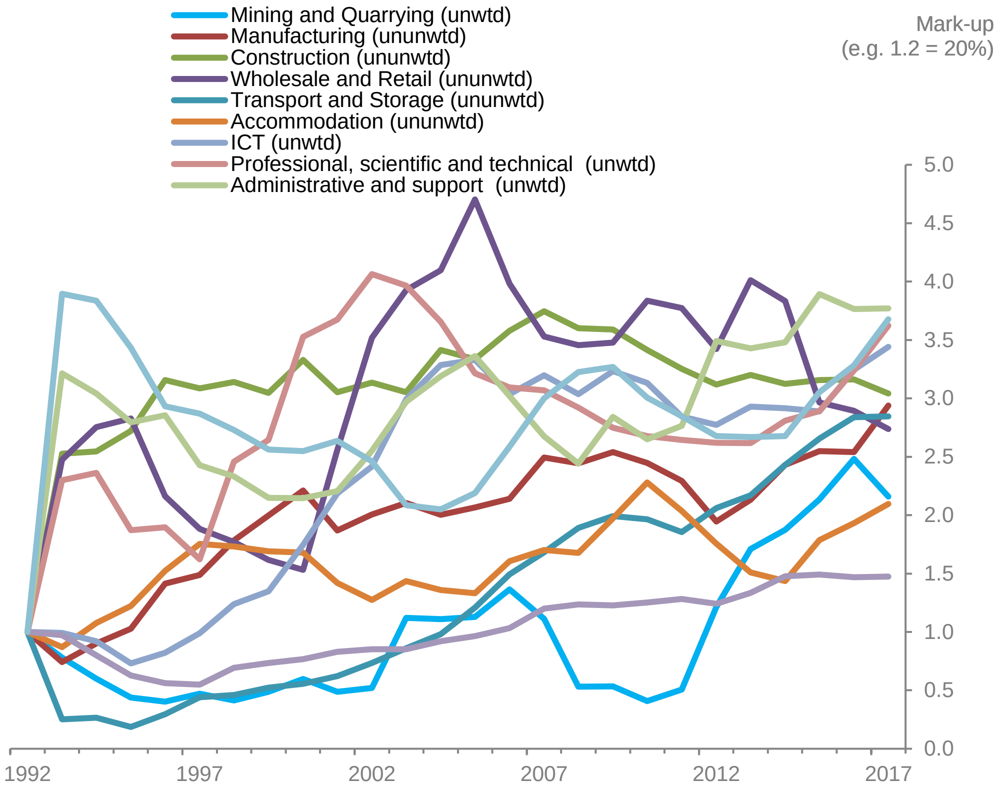
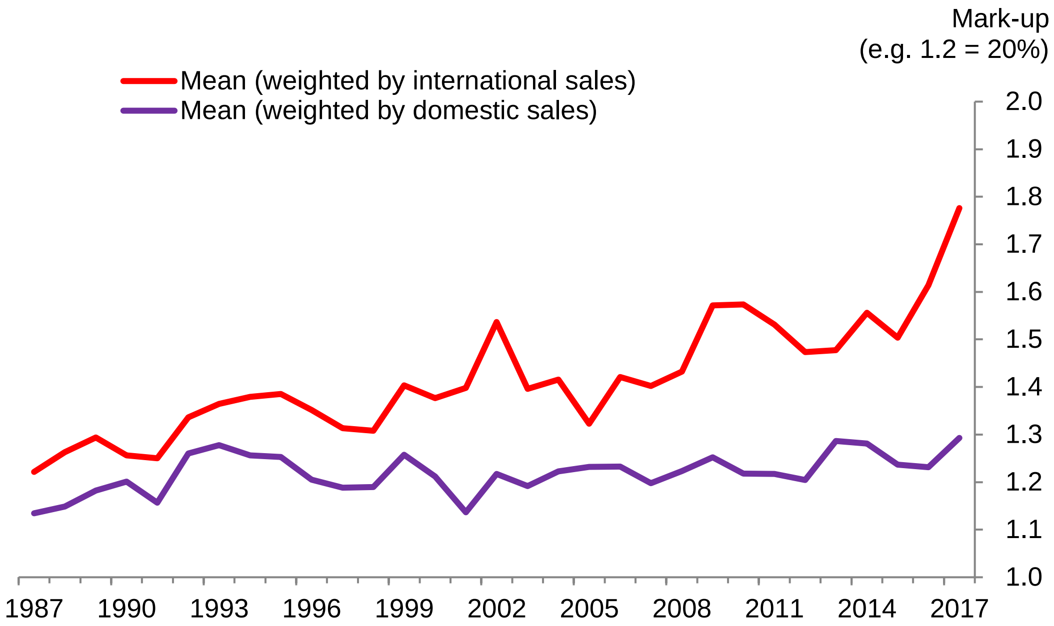


Chart 7: Skewness of UK-listed firms' mark-up distribution by sector



Sources: Thomson Reuters Worldscope and Bank calculations. The charts shows 5-year moving averages of skewness coefficients.

Chart 8: Mark-ups for domestic and foreign-focussed UK-listed firms



Sources: Thomson Reuters Worldscope and Bank calculations.

Taken together, this evidence is consistent with a story of rising mark-ups being concentrated among internationally-operating firms, who perhaps benefit disproportionately from global network economies of scale and scope. These firms tend to occupy the fat and fattening upper tail of the mark-up distribution. These are firms that might legitimately be termed “superstars” (Autor *et al* (2017)).

2.2 Markups and macroeconomic outcomes

Given this diagnosis, what impact might the rise in mark-ups have had on the macro-economy? One aspect is what impact increased market power may have had on firms’ incentives to invest and innovate and hence on firms’ productivity. With investment and productivity each having under-performed over recent years, the relationship with market power has been subject to increased academic scrutiny recently (for example, Eggertsson, Robbins and Wold (2018)).

The relationship between mark-ups and productivity is important in understanding their macro-economic effects (Van Reenen (2018)). On the one hand, if highly productive ‘superstar’ firms, benefitting from network economies of scale and scope, have become more dominant, then higher mark-ups could be the side-effect of a *positive* supply shock in the economy. On the other hand, if mark-ups are the counterpart to increased market power and reduced competitive pressure, that would suggest a *negative* supply shock.

These effects are not mutually exclusive. For example, Aghion *et al* (2005) develop a model which generates a concave relationship between competition and investment. Within some range, increased market power raises rents and acts as a spur to investment, innovation and productivity. But beyond a point, those forces go into reverse. Market power is associated with a fall in innovation and investment incentives, with knock-on negative effects for productivity.

There is some empirical support for such a relationship. Jones and Philippon (2016) and Gutiérrez and Philippon (2017) suggest increased market power may have reduced investment among US companies. De Loecker and Eeckhout (2017) document a negative relationship between mark-ups and the capital share among global companies. And Díez *et al* (2018) identify empirically a concave relationship between mark-ups and investment, in line with Aghion *et al* (2005).

We can re-run the Díez *et al* (2018) reduced-form investment regressions using the panel of UK-listed firms. This also finds a concave relationship with mark-ups (Table 2, column 1). The same relationship holds between mark-ups and R&D expenditure (Table 2, column 2). Chart 9 plots the estimated investment curve. It suggests that firms with mark-ups above around two tend to be associated with lower investment rates, in line with Díez *et al*. With estimated firm-level mark-ups having risen secularly in a number of countries, this is potentially a cause for concern. However, results in Table 2 and 3 are derived from reduced-form regressions, so caution is advisable when drawing conclusions based on them.

It is also important not to overstate the likely impact of this rise in mark-ups on aggregate investment, innovation and productivity. The rise in mean mark-ups in the UK over the past 30 years would still leave them below the levels at which investment rates start falling. The same is true among global firms. Indeed, among our panel of UK-listed companies, the shift in average UK mark-ups since the late-1980s would, using the estimated investment equation, be expected to have *raised* average investment rates by around 1 percentage point. Finally, there is the question of whether any potential negative effects of increased market power on investment and R&D translate into a negative effect on productivity.[18] Evidence suggests there could be an effect.

Table 2: Regressions of investment and R&D on UK-listed firms' mark-ups

	Investment rate	**Innovation rate**
$LogMarkup_{it}$	0.095*** (0.027)	0.023*** (0.009)
$LogMarkup_{it} \times LogMarkup_{it}$	-0.041** (0.017)	-0.018** (0.008)
TFP_{it}^{d}	-0.002 (0.006)	-0.000 (0.002)
$LogMarkup_{it} \times TFP_{it}^{d}$	-0.011 (0.012)	-0.007** (0.003)
$LogMarkup_{it} \times LogMarkup_{it} \times TFP_{it}^{d}$	0.018 (0.012)	0.009*** (0.003)
Firm controls	Yes	Yes
Firm fixed effects	Yes	Yes
Time fixed effects	Yes	Yes
Observations	21874	7386
R^2	0.058	0.057

Sources: Thomson Reuters Worldscope and Bank calculations. Notes: Robust standard errors in parentheses; * p < 0.10; ** p < 0.05; ***p < 0.01. Regressions include lagged Tobin's Q and the lagged sales-to-assets ratio (firm controls). 'Investment rate' is defined as capital expenditure as a proportion of the previous year's net property, plant and equipment level (PPE). 'Innovation rate' is defined as R&D expenditure as a proportion of the previous year's total assets. 'TFP' is defined as (the exponential of) the log of net sales, minus the log of COGS, log of net property, plant and equipment level (PPE) multiplied by their respective coefficients retrieved in the estimation of mark-ups, and minus the estimated measurement error. TFP_{it}^{d} is the gap in a firm's TFP from the most productive firm (in TFP terms) in a given year within the industry (measured at the 1-digit SIC level). To deal with outliers, and similar to De Loecker and Eeckhout (2018) and Díez *et al* (2018), we trim the top and bottom of 2% of observations for the investment rate, innovation rate, labour productivity and TFP before running regressions.

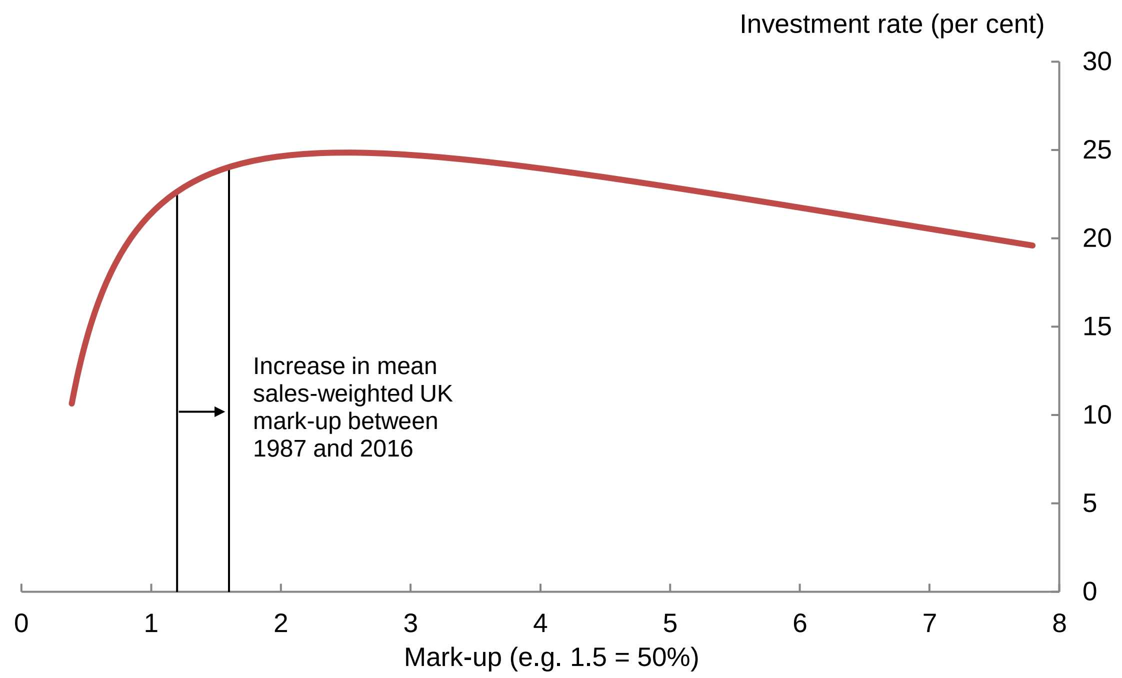
[18] For example, De Loecker and Eeckhout (2017) argue that, once account is taken of the rise in mark-ups, it is possible to account for the slowdown in US productivity growth after 1980. And Díez *et al* (2018) find that the greater the distance to the technological frontier, the lower a firm's investment – a "reverse catch-up" effect.

Overall, then, while the theoretical and empirical evidence suggests it is possible higher market power and mark-ups may have come at some cost in lower investment and innovation, the evidence is not overwhelming and certainly would not imply that the aggregate effect is large.

A second relationship explored recently is between market power and the labour share.[19] Autor *et al* (2017) find a negative empirical relationship using measures of market concentration among US companies. And Díez *et al* (2018) and De Loecker and Eeckhout (2018) identify a weakly negative relationship between mark-ups and the labour share. If we run regressions similar to those in Díez *et al* for UK-listed companies (Table 3), we also find a negative relationship between mark-ups and the labour share.[20]

Assuming that the aggregate-level elasticity of the labour share to changes in mark-ups is in the range of our estimates in Table 3, the increase in the average mark-up from 1.23 in 1987 to 1.55 in 2017 (Chart 2) would have, up to first order, reduced the aggregate labour share by 1.7-2.5%. Yet, over the same period, the labour share has increased in the UK. Although this could reflect the effect of other factors on the labour share, it is worth noting that our data does not allow us to distinguish between firms' labour shares associated with domestic and foreign sales. Therefore, the results in Table 3 could mirror the pattern seen in Chart 8: the domestic-sales-weighted average mark-up in the UK has hardly increased since 1987.

Chart 9: UK-listed firms' mark-ups and investment rates



Sources: Thomson Reuters Worldscope and Bank calculations. Investment function based around the firm-level regression in Table 2. 'Investment rate' defined as capital expenditure as a proportion of the previous year's net property, plant and equipment level (PPE).

[19] The relationship between labour, capital and profit shares is discussed in Barkai (2017).
[20] Unlike Díez *et al* (2018), we use the reported data on staff costs in our firm-level dataset when calculating the labour share.

Table 3: Regressions of labour share on UK-listed firms' mark-ups

	Log labour share	Log labour share	Log labour share
$LogMarkup_{it}$	-0.094*** (0.019)	-0.093*** (0.024)	-0.067*** (0.020)
$LogMarkup_{it} \times LogMarkup_{it}$	-0.024 (0.019)		-0.033 (0.020)
HHI_{kt}		0.061 (0.074)	0.062 (0.073)
$LogMarkup_{it} \times HHI_{kt}$		-0.225 (0.151)	-0.233 (0.151)
Firm fixed effects	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes
Observations	21997	17218	17218
R^2	0.013	0.014	0.015

Sources: Thomson Reuters Worldscope and Bank calculations. Notes: Standard errors in parentheses; * p < 0.10; ** p < 0.05; ***p < 0.01. Labour share is defined as nominal wage bill divided by nominal value-added, where value-added is defined as the sum of operating income (before depreciation, depletion and amortisation costs) and labour expenses. To deal with outliers, we trim observations where the measured labour share is less than zero or greater than one before running regressions.

3 Market Power and the Macro-Economy – A Theoretical Approach

Having assessed some evidence on the evolution and macro-economic effects of increased mark-ups and market power, the next question is what implications these may have for the setting of monetary policy. This has not been extensively examined.[21] What follows is an initial exploration of some of the potential channels drawing on a textbook New Keynesian model of the macro-economy, the type of which is often used assess the effects of flexible inflation targeting (Clarida *et al* (1999), Woodford (2003)). Specifically, we use the model in Galí (2015) to consider how a secular rise in market power might affect the setting of monetary policy.

The model takes the following generic form:

$$\pi_t = \beta E_t \pi_{t+1} + \kappa x_t + u_t \qquad (1)$$

$$x_t = E_t x_{t+1} - \sigma(i_t - E_t \pi_{t+1} - r_t^*) \qquad (2)$$

where π is inflation, x is the output gap, i is the policy rate, while u is a cost-push shock.

The first equation is a New Keynesian Phillips curve, the second a forward-looking IS curve. This two-equation system contains three key structural parameters: the slope of the Phillips curve, κ; the interest elasticity of demand, σ; and the long-run neutral rate of interest, r^*. We discuss in turn how each might potentially be affected by the degree of market power in product markets and higher mark-ups.

(i) Phillips curve

[21] A recent exception would be the work of Mongey (2018).

In the New Keynesian model, firms operate in imperfectly competitive product markets defined by monopolistic competition (Blanchard and Kiyotaki (1987)), with nominal rigidities (Calvo (1983)). As first described by Chamberlin (1933), and formalised by Dixit and Stiglitz (1977), monopolistic competition is an environment in which a large number of firms each face a downward-sloping demand curve for their respective differentiated product. This typically takes the functional form:

$$Y^d(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\epsilon} Y_t \quad (3)$$

Here, $Y^d(i)$ is the demand for good i, whose price is $P_t(i)$. P_t and Y_t are the overall price level and aggregate demand at time t, respectively, while $\epsilon > 1$ is the elasticity of substitution between the monopolistically competitive products.

Individual firms are assumed to be small enough that a price change by one firm has a negligible effect on the demand faced by other firms. By implication, there is no strategic interaction between firms. Firms can set prices above marginal costs because of a finite elasticity of substitution between individual goods in consumer preferences, regardless of the fact that their share of the total market is small.

There are clear limitations of this product market formulation when addressing issues of market power. Market power, in this setting, is captured by the capacity of firms to charge prices in excess of marginal costs as result of a finite elasticity of substitution between individual goods. Structural changes in the model reduce to a comparative static analysis of changes in the trend level of the elasticity of substitution between products. Different competitive settings might generate quite different pricing behaviour and Phillips curves.

In the baseline New Keynesian model, the monopolistically competitive firm maximises profits by setting its price ($P^*(i)$) as a mark-up over nominal marginal costs (MC):

$$P_t^*(i) = \mu MC_t \quad (4)$$

The mark-up can be derived in terms of the elasticity of substitution:

$$\mu = \frac{\epsilon}{\epsilon - 1} \quad (5)$$

This tells us a firm increases its mark-up as the demand for its good becomes inelastic. That might arise for a variety of reasons. Customer loyalty or brand might be one reason. Network economies of scale and scope might be another. In either case, the implication is that prices are being set above (and sales below) their socially optimal value – that is to say, their value under perfect competition when price equals marginal cost (ϵ tends towards infinity).

When prices are sticky, firms set prices in a forward-looking manner to get as close as possible to the desired mark-up over time. The forward-looking Phillips curve in (1) summarises that price-setting behaviour in the economy at large. The slope of the Phillips-curve, κ, is a composite of deep structural parameters in the model. In the baseline specification in Galí (2015), the slope is:

$$\kappa = \frac{(1-\theta)(1-\beta\theta)}{\theta} \frac{1-\alpha}{1-\alpha+\alpha\epsilon}\left(\sigma + \frac{\varphi+\alpha}{1-\alpha}\right) \quad (6)$$

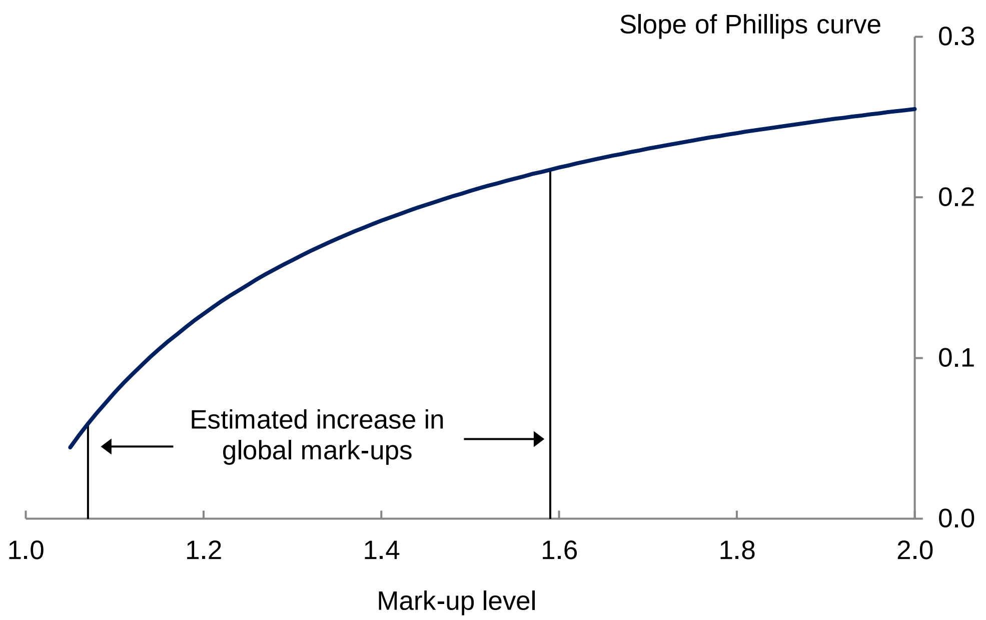
Where θ is the degree of price stickiness, β is the discount factor in household preferences, α is the degree of decreasing returns to labour in production, φ is the inverse of the elasticity of labour supply with respect to real wages (holding marginal utility of consumption constant), and σ is the inverse of the elasticity of intertemporal substitution in consumption.

Significantly, the elasticity of demand, ϵ, and hence the mark-up, μ, affect the slope of the Phillips curve. The higher the degree of market power and higher the mark-ups firms charge, the steeper the slope of the Phillips curve (or, equivalently, the smaller the sacrifice ratio). We can illustrate this effect by parameterising the model. Chart 12 looks at the relationship between the slope of the Phillips curve, κ and mark-ups, μ, for a given set of parameter values.

The relationship is, as we expect, a positive one. As a thought experiment, consider the scale of increase in mark-ups seen by the average firm globally since 1980, from around 1.1 to around 1.6.[22] Other things equal, this would be expected on this calibration to have steepened the slope of the Phillips curve from just under 0.1 to around 0.2. This is a significant change in the parameterisation of a key macro-economic relationship for the setting of monetary policy.

One way of explaining the intuition behind this steepening of the Phillips Curve is that market power reduces the degree of strategic complementarity in price-setting. In a product market closer to perfect competition, firms will be reluctant to raise prices fearful that, with other prices in the economy sticky, demand would fall-away sharply. By reducing the elasticity of demand, market power reduces this risk and thus gives rise to greater flexibility in prices – and hence a lower sacrifice ratio (for example, Ball and Romer (1990)).

Chart 12: Mark-ups and the slope of the Phillips curve



Sources: De Loecker and Eeckhout (2018), Galí (2015) model and Bank calculations.
Notes: Parametrisation such that β = 0.99, θ = 2/3, α = 1/3, φ = σ =1.

(ii) Impact on IS curve

The second way in which a shift in market power could potentially influence macro-economic outcomes is through the IS curve. One structural parameter in that relationship is r*, the neutral rate of interest. In the baseline model,

[22] De Loecker and Eeckhout (2018).

the path of r* is determined by the path of shocks to households' marginal utility of consumption (z) and firms' TFP (a):

$$r_t^* = (1-\rho_z)z_t - \frac{1-\rho_a}{\sigma}\frac{1+\varphi}{\sigma^{-1}(1-\alpha)+\varphi+\alpha}a_t \quad (7)$$

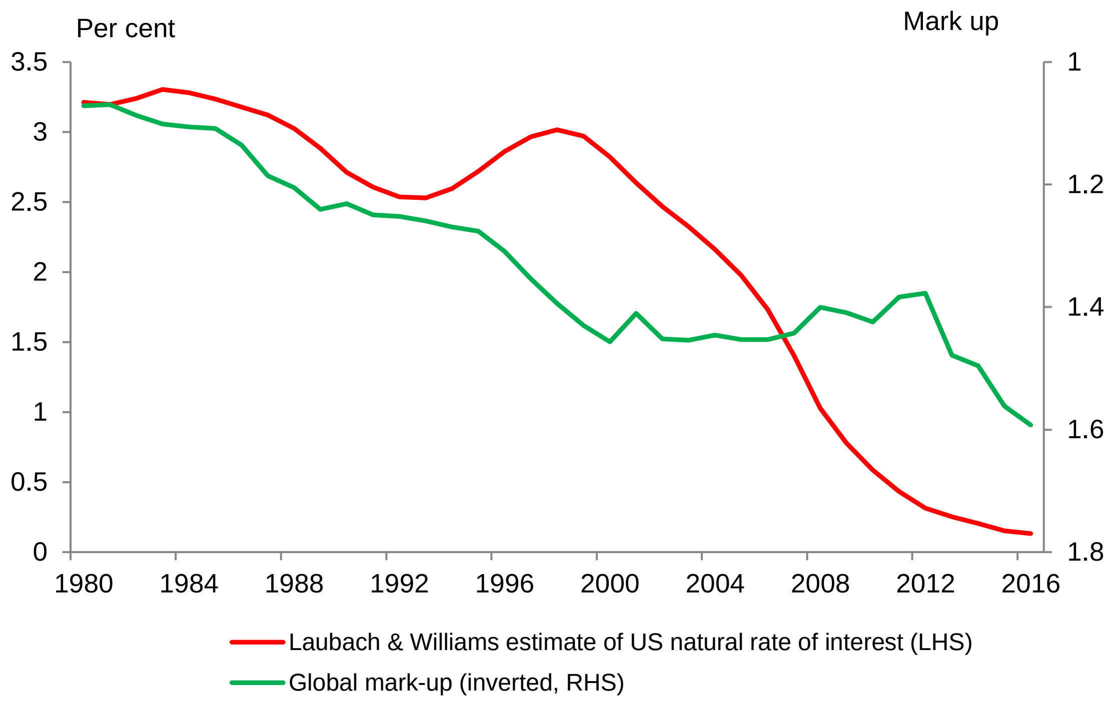
In steady-state, the equilibrium real rate is determined by household discount rates (determining saving) and firms' trend productivity growth (determining investment).

$$r^* = -\log\beta + \Delta a \quad (8)$$

This suggests that, if there is any impact of market power and mark-ups on productivity, this could in turn have an impact on r*.[23] Consistent with that, and taken at face value, there is a positive correlation between estimates of the US natural rate of interest and (the inverse) of global mark-ups since 1980 (Chart 13).

But whether higher mark-ups might in practice have contributed significantly to the global slowdown in investment and productivity, and hence r*, is far from clear. The micro-economic evidence discussed earlier suggests these effects are difficult to detect and, to the extent they do exist, might be relatively modest in the contribution they have made to slowing aggregate investment and productivity growth. And if higher mark-ups have, in fact, been the counterpart to a rise of 'superstar' firms, benefiting from network economies, that would, in principle, *raise* productivity growth and r*.

Chart 13: Global mark-ups and real interest rates



Sources: Updated estimates from Laubach and Williams (2003) (available online), De Loecker and Eeckhout (2018) and Bank calculations.

Notes: Estimate of US natural rate of interest shown here uses annual averages of quarterly Laubach and Williams estimates. We would like to thank Jan De Loecker and Jan Eeckhout for kindly sharing their series of global mark-ups.

A second structural parameter in the IS curve is the interest elasticity of aggregate demand, σ. In the simplest baseline model, this is determined by (the inverse of) the intertemporal elasticity of substitution. In more general settings, with credit constraints, it may depend additionally on the balance sheet characteristics either of borrowers

[23] Equation (9) is specific to the Galí model presented here, but equation (10) is a more general feature of macro-economic models, where r* is a function of the household discount rate and productivity growth.

or lenders or both (for example, Kashyap, Stein and Wilcox (1993)). A rise in market power could, in principle at least, affect the balance sheets of borrowers and/or lenders in ways which could influence σ.

For borrowers, a rise in market power might raise equilibrium profit rates and market valuations. It may thus reduce companies' collateral constraints and their reliance on external sources of finance (for example, Bernanke, Gertler and Gilchrist (1999)). For lenders, a rise in market concentration could in principle reduce the speed of pass-through of policy rates to retail deposit and lending rates (Gerali *et al* (2010)). Each of these would tend, therefore, to reduce the interest elasticity of investment demand, σ. Whether these effects are significant at the macro-economic level is, however, far from clear.

3.1 Market power and monetary policy

Consider now the period loss function for monetary policymakers in the textbook model. This can be derived from the utility function of the representative household (Galí (2015)). It takes the form:

$$L_t = \pi_t^2 + \lambda x_t^2 \qquad (9)$$

where the weight on the output gap is:

$$\lambda = \frac{\kappa}{\epsilon} \qquad (10)$$

Under optimal discretionary monetary policy, the policymaker minimises this loss function each period, subject to the Phillips curve, taking expectations as given. The optimal targeting rule for monetary policy is:

$$\pi_t = -\frac{\lambda}{\kappa} x_t \qquad (11)$$

This "Golden Rule" of monetary policy strategy simply states that the policymaker should let inflation absorb more of the adjustment, after a trade-off inducing shock, either when the relative weight on output in the loss function is high (λ) or when the sacrifice ratio is low (κ). If λ is set to its welfare-optimising level, this gives a refinement of the "Golden Rule":

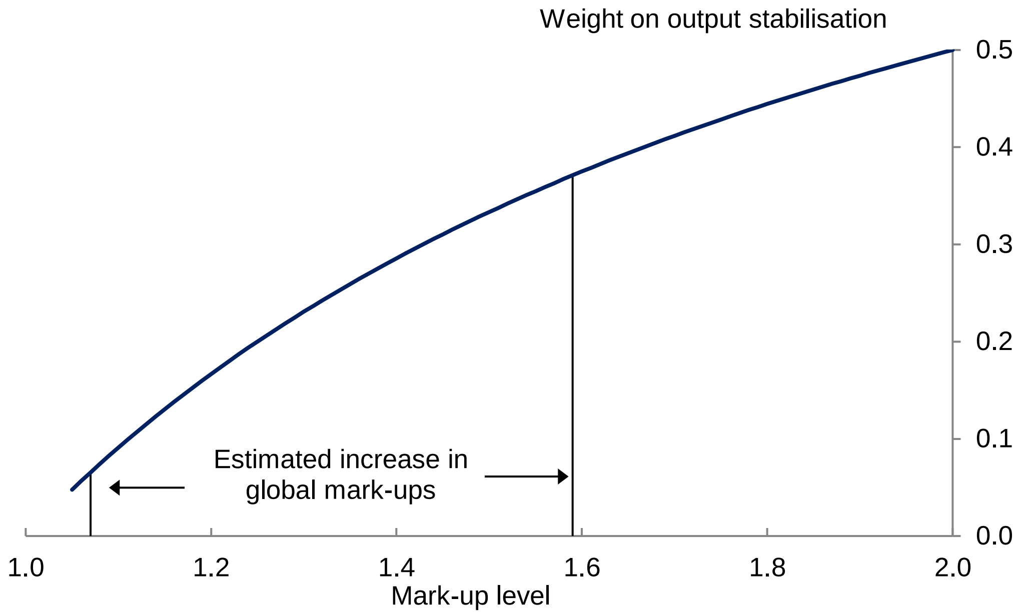
$$\pi_t = -\frac{1}{\epsilon} x_t \qquad (12)$$

This tells us that, once the dust has settled, the degree of market power in steady state is *all* that matters for monetary policymakers in our simple framework when choosing the optimal trade-off between inflation and the output gap.

Specifically, the greater this degree of market power, the steeper the slope of the optimal targeting rule: the policymaker should let inflation absorb more, and the output gap less, of a trade-off inducing shock. The intuition here is simply that market power increases the degree of price flexibility in the model and lowers the sacrifice ratio. This makes it optimal to do a greater amount of (now less costly) output-smoothing in the face of trade-off inducing shocks in the optimal policy rule.

Chart 14 plots the relationship between the slope of the targeting rule and mark-ups for our parameterisation. The rise in average mark-ups globally since 1980 would, on this calibration, be expected to raise the trade-off parameter in the Golden Rule $\left(\frac{1}{\epsilon}\right)$ from around 0.1 to 0.4. This is a reasonably significant shift in the terms of trade between inflation and output variability.

Chart 14: Mark-ups and optimal policy weight on output stabilisation in targeting rule



Sources: De Loecker and Eeckhout (2018), Galí (2015) model and Bank calculations.

Notes: Parametrisation such that β = 0.99, θ = 2/3, α = 1/3, $\varphi = \sigma$ =1.

The presence of market power and higher mark-ups also has implications for the level of output in the economy which could provide additional incentives to generate inflation. Monopolistic competition implies that output is inefficiently low relative to its (perfectly competitive) social optimum. For sufficiently small deviations from the steady state, the policymakers' loss function can be re-written to reflect that inefficiency:

$$L_t = \pi_t^2 + \lambda x_t^2 - \Lambda x_t \tag{13}$$

where

$$\Lambda = \frac{1}{\epsilon^2}\frac{(1-\theta)(1-\beta\theta)}{\theta}\frac{1-\alpha}{1-\alpha+(\varsigma+\varphi)\epsilon} \tag{14}$$

The optimal targeting rule is also then altered to become:

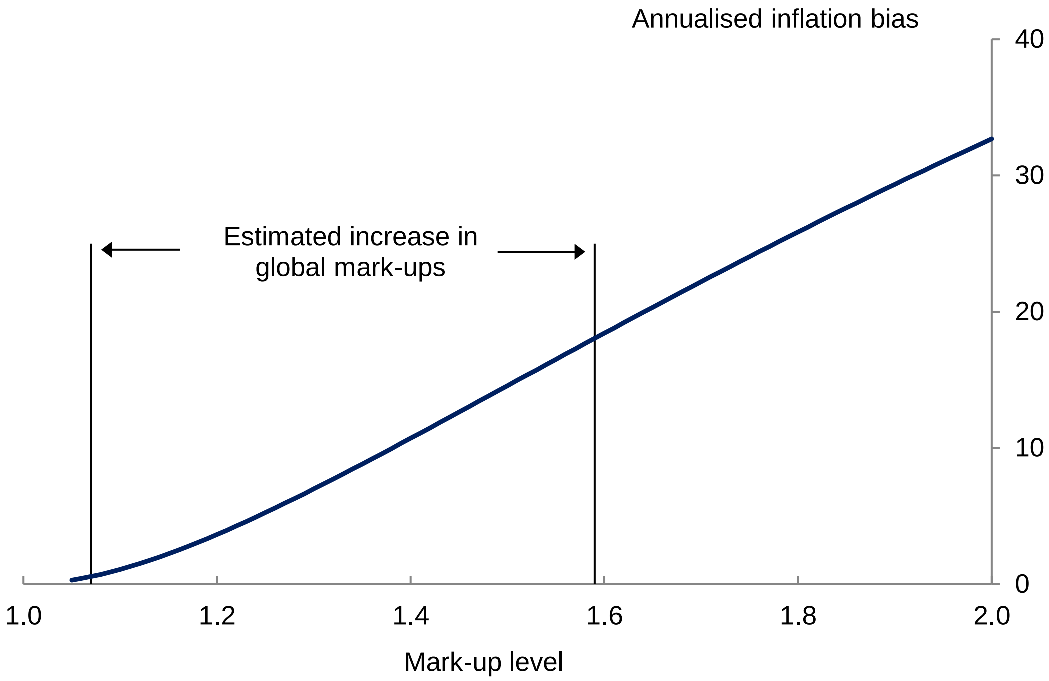
$$\pi_t = \frac{1}{\epsilon^2}\left(\sigma^{-1}+\frac{\varphi+\alpha}{1-\alpha}\right)^{-1} - \frac{1}{\epsilon}x_t \tag{15}$$

The additional constant term reflects the well-known inflationary bias under discretionary policy, first articulated by Barro and Gordon (1983). Output at a sub-optimally low level increases the incentives of a discretionary policymaker to run looser monetary policy to push output towards its social optimum, thereby generating an inflation bias. In steady-state, this inflation bias is:

$$\pi_t = \frac{\Lambda\kappa}{\kappa^2+\lambda(1-\beta)} \tag{16}$$

This inflation bias is clearly bigger, the greater is the degree of market power. Chart 15 plots the relationship between mark-ups and the inflation bias implied by the model. Using our simple model, the rise in mark-ups by global firms since 1980 might have added as much as 20 percentage points to the inflation bias.

Chart 15: Mark-ups and inflation bias



Sources: De Loecker and Eeckhout (2018), Galí (2015) model and Bank calculations.
Notes: Parametrisation such that β = 0.99, θ = 2/3, α = 1/3, φ = σ =1.

This calibrated effect is implausibly large. Nonetheless, the qualitative point remains: a rise in market power may, by constraining demand, generate an added incentive to run loose monetary policy. That makes institutional arrangements which resist those temptations – such as independent central banks charged with meeting an inflation target – more important than ever (Rogoff (1985), Svensson (1997)).

Finally, while we find little evidence of mark-ups having a material effect on investment, market power also gives rise to at least the possibility of lower productivity growth, and hence, r*. There are a number of other structural forces currently lowering productivity growth (for example, Gordon (2012), Andrews *et al* (2016)). And there are a larger number still of structural factors bearing down on r* (for example, Monetary Policy Committee (2018)). To the extent market power is another, this increases the chances of those falls in productivity growth and r* proving long-lasting.

The empirical link between market power and productivity is not, at present, well-defined. But the implications of a persistently lower r* for the setting of monetary policy are reasonably well understood. They include the fact that the probability of the zero lower bound constraint binding is likely to be materially higher than it has been historically. Recent simulation studies have suggested this probability may be as high as around one-third, if r* remains around current levels (for example, Kiley and Roberts (2017)).

3.2 Mark-ups over the business cycle

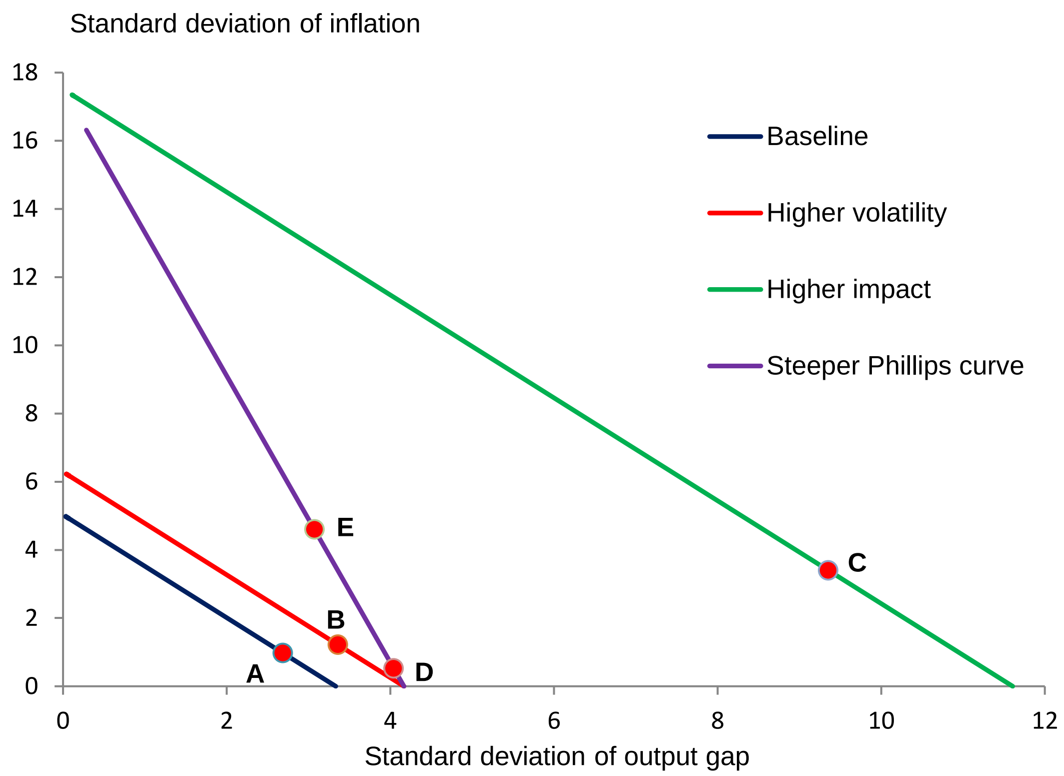
Finally, let us now put this model into a stochastic setting, by assuming desired mark-ups fluctuate around a trend level according to some stationary stochastic process, $\log \mu_t$. These would now appear as cost-push disturbances in the Phillips curve:

$$u_t = \frac{(1-\theta)(1-\beta\theta)}{\theta}\frac{1-\alpha}{1-\alpha+\alpha\epsilon}\log\mu_t \quad (17)$$

This shows that the effect of a given per cent deviation of market power from trend is higher when the trend level of market power is high. A rise in market power has the potential to increase the impact of variations over the business cycle.

Chart 16 seeks to illustrate this point graphically in the form of a policy possibility frontiers tracing out the combinations of output and inflation volatilities under optimal policy for different values of λ. In the textbook model, the frontier is linear with slope parameter -$\kappa/(1-\beta\rho_u)$, intersecting the inflation volatility axis at $\sigma_u/(1-\beta\rho_u)$ and the output volatility axis at σ_u/κ, where ρ_u is the persistence of the cost-push shock process and σ_u is its standard deviation. Point A is the starting equilibrium, before any rise in mark-ups, with the policy possibility curve tangent to the policymaker's loss function where λ is given by (10). A rise in mark-ups can be decomposed into several distinct effects.

Chart 16: Impact of mark-ups on inflation and output gap volatility



Sources: Galí (2015) model and Bank calculations.

Notes: Parametrisation such that β = 0.99, θ = 2/3, α = 1/3, φ = σ =1. Standard deviation of mark-up shock increases from 0.1 to 0.125 when moving from the blue to red line. The steady-state mark-up level increases from 1.1 to 1.6 when moving from the red to the green line. The policymaker re-optimises λ when moving from point C to D.

First, any increase in cyclical volatility of $\log\mu_t$ causes an outward shift in the policy possibility frontier. When mark-up shocks hitting the economy are larger, policymakers have no choice but to accept higher volatilities of both inflation and the output gap (A to B). Second, a secular rise in the trend level of mark-ups increases the impact of any per cent change in mark-ups, further shifting out the frontier through its effect on σ_u through (17). The trade-off worsens again as cost-push effects become stronger (B to C). Third, a steeper Phillips curve rotates the frontier by shifting the intersection with the output volatility axis. As the sacrifice ratio falls, policymakers are able to reduce inflation volatility at a lower cost in terms of output gap volatility (C to D). And fourth, there is a shift in the relative weight placed on output stabilisation by the policymaker (10), calibrated in line with the secular rise in mark-ups.

With a higher λ, policymakers shoose a point on the possibilities frontier with lower output gap volatility and higher inflation volatility (D to E).

The net effect of a rise in both the trend and volatility of market power is a significant rise in inflation variability but relatively less change in output variability (A to E). For a given volatility of cost-push disturbances, however, a secular increase in trend mark-ups *reduces* the volatilities of both output and inflation (C to E). By lowering the sacrifice ratio, higher mark-ups improve monetary policy's ability to stabilise inflation without inducing large movements in output.

The change in volatilities is also summarised in Table 4. The table reiterates how the shifts from A to C are caused by higher volatility in cost-push disturbances. The shift from C to D, reducing volatilities of both the output gap and inflation, is due to the structural change in the economy associated with a higher level of mark-ups in (5). And finally the shift from D to E follows from an increase in the weight on the output gap (10), making it optimal for the policymaker to move up the possibilities frontier and stabilise inflation less and the output more.

Table 4: Decomposition of shift in policy possibilities frontier

	σ_u	μ	λ	Std. dev. of inflation	Std. dev. of output gap
Point A	0.0026	1.1	0.1	0.98	2.69
Point B	0.0033	1.1	0.1	1.22	3.36
Point C	0.0091	1.1	0.1	3.40	9.35
Point D	0.0091	1.6	0.1	0.53	4.04
Point E	0.0091	1.6	1.3	4.61	3.07

Notes: The parameters σ_u denotes the standard deviation of the cost-push shock process in (17), μ is the level of mark-ups implied by ϵ in other equations of the model, and λ is the weight on output stabilisation in the loss function.

4 Conclusion

The link between the competitive structure of product markets, the macro-economy and the setting of monetary policy is a relatively under-researched area. This paper has begun to scratch the surface of this important topic. Trends in concentration and market power have clear potential to impact on the macro-economy and monetary policy, justifying ongoing research on the topic. To that end, we conclude with a few reflections on potentially fruitful future research avenues.

First, the framework used here to understand the macro-economic implications of increased market power assumes a particular competitive structure – monopolistic competition – and a particular pricing scheme – a Calvo price lottery. This has limitations, assuming as it does that no one firm is sufficiently large to have a significant bearing on others' behaviour. In practice, strategic interactions between firms are likely to be important in many markets, especially network markets (for example, Bramoullé, Kranton and D'Amours (2014)), with potentially important implications for pricing and the Phillips curve.

Second, the framework developed here also sidesteps questions about the competitive structure of the market for inputs, especially labour inputs. Dominant firms may exercise monopsonistic power over workers, in ways which have implications for profit and labour shares. Consistent with that, there is some empirical evidence linking market concentration to a lower labour share (Autor et al (2017)). How monopsony power influences wage growth and the slope of the Phillips curve are important areas to consider further.

Third, we have shown that heavily internationalized firms are the driving force behind the increase in markups of UK-listed firms. The data at hand do not allow us to distinguish between the markups firms charge domestically from those charged abroad. However, by weighting relatively more those firms with larger domestic sales, we showed that the average markup in the UK may have risen by much less than the baseline results suggest. More detailed data on domestic and foreign sales and inputs could help in shedding light on this issue.

Fourth, there is further work to be done in understanding the balance sheets and decision incentives of so-called "superstar" firms. This includes their choice of debt versus equity, distributing versus reinvesting profits and intangible versus tangible sources of capital. These choices might imply quite different incentives and behaviours – for example, about the level of investment and its interest elasticity. These are yet to be fully explored, at a micro and macro level.

Fifth, the emergence of a set of firms with significant degrees of market power clearly raises big questions about the appropriate stance of competition policy (Gutiérrez and Philippon (2018)). These policy issues are clearly outside of the remit of central banks. Nonetheless, how these anti-trust issues are tackled could have implications for the structure and dynamics of the economy and hence for the setting of monetary policy. This, too, is an area ripe for further research.

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Appendix – estimation of firm-level mark-ups

To estimate firm-level mark-ups, we follow De Loecker and Eeckhout (2017, 2018) and Díez *et al* (2018), all of which are based on the original methodology proposed by De Loecker and Warzynski (2012).

Theory

Consider a firm i at time t that produces output with a production function whose arguments are variable inputs, capital, and technology. Assume firms are cost-minimizers. Then, the Lagrangian associated with the cost minimisation problem (subject to the production function) leads to the following first-order condition for any variable input V (free of adjustment costs):

$$P_{it}^{V} = \lambda_{it}\left(\frac{\partial Q_{it}(\cdot)}{\partial V_{it}}\right) \qquad (A1)$$

where P_{it}^{V} is the input price of variable input V faced by firm i at time t, λ_{it} denotes the marginal cost of production, and $\left(\frac{\partial Q_{it}(\cdot)}{\partial V_{it}}\right)$ denotes the marginal product of this input. Defining the mark-up as the ratio of price to marginal cost, $\mu_{it} \equiv \frac{P_{it}}{\lambda_{it}}$, we have that the above equation can be rearranged to give

$$\mu_{it} = \frac{P_{it}}{P_{it}^{V}}\left(\frac{\partial Q_{it}(\cdot)}{\partial V_{it}}\right) \qquad (A2)$$

We can rewrite this as

$$\mu_{it} = \frac{P_{it}}{P_{it}^{V}}\frac{Q_{it}}{V_{it}}\left(\frac{\partial Q_{it}(\cdot)}{\partial V_{it}}\right)\frac{V_{it}}{Q_{it}} = \left(\alpha_{it}^{V}\right)^{-1}\theta_{it}^{V} \qquad (A3)$$

where α_{it}^{V} denotes the share of expenditures on input V_{it} in total sales ($P_{it}Q_{it}$), and θ_{it}^{V} denotes the output elasticity of input V. This gives us an expression for the firm-level markup in terms of observable α_{it}^{V} and the unobserved (but estimable) θ_{it}^{V}. The procedure below is all about consistently estimating this output elasticity.

Estimation

We generally follow De Loecker and Eeckhout (2017, 2018) and Díez *et al* (2018) in our empirical application of the theory above. The production function they take to the data is given by

$$y_{it} = f\left(v_{it}, k_{it}; \boldsymbol{\beta}_j\right) + \omega_{it} + \epsilon_{it} \quad \text{for all} \quad i \in j \quad (A4)$$

where i indexes a firm and j denotes a 2-digit SIC07 industry, lower cases denote logs, y_{it} denotes deflated net sales, v_{it} denotes deflated cost of goods sold (COGS) (which are taken to be a measure of variable inputs), k_{it} denotes deflated net plant, property & equipment (PPE), ω_{it} denotes unobserved (to the econometrician) technology, and ϵ_{it} denotes the measurement error of net sales. Note that the production function parameters $\boldsymbol{\beta}_j$ are assumed to be *industry-specific* and time-invariant.

We consider two specifications for f: Cobb-Douglas and translog. Under the former, the output elasticity with respect to COGS is exactly equal to β_j^{v}. Under the latter, the output elasticity with respect to COGS is equal to $\beta_j^{v} + 2\beta_j^{vv}v_{it} + \beta_j^{vk}k_{it}$.

A key challenge in estimating (A4) is the endogeneity of optimal input choices with respect to technology ω_{it}. More precisely, whilst ω_{it} is unobserved to the econometrician directly, it is assumed to consist of two components: a part that's *observable* to the firm (but not to the econometrician) and a part that's *unanticipated* to the firm itself when it makes its input demand choices. The key identifying assumption is that we can express ω_{it} as a function of inputs (one of which is a so-called *control variable*, in our case COGS), i.e. $\omega_{it} = h(v_{it}, k_{it})$. We don't know what $h(\cdot)$ is, but we can approximate it as a high-order polynomial (in our case, of order 2).

The estimation approach, which we run separately for all observations in a given 2-digit industry since $\boldsymbol{\beta}_j$ are assumed to be industry-specific, relies on two stages:

First stage: In the first stage, we run a regression of y_{ijt} on $v_{it}, v_{it}^2, k_{it}, k_{it}^2$, and $v_{it}k_{it}$. Note that – to the extent that ω_{it} depends linearly on v_{it} and k_{it} – the estimated coefficients on these two variables will subsume the coefficients corresponding to these inputs *and* how ω_{it} depends on them. This step allows us to control for unobserved productivity (up to our approximation) and obtain an estimate of expected output, $\hat{y}_{ijt}$, and an estimate of the measurement error, $\hat{\epsilon}_{it}$. Since we have arguably controlled for unobserved productivity, our $\hat{y}_{ijt}$ should be a consistent estimate of $E(y_{ijt})$.

Second stage: As mentioned earlier, to get the GMM moment conditions, we need to purge ω_{it} from its component observable to the firm. We assume ω_{it} follows an AR(1) process so that

$$\omega_{it} = \rho\omega_{i,t-1} + \xi_{it} \qquad (A5)$$

where ξ_{it} is an idiosyncratic, unobservable (to both the firm and econometrician) shock to technology. This is the part of ω_{it} that is assumed to be uncorrelated with optimal input choices and thus forms the basis for the GMM conditions. We know that our $\hat{y}_{ijt}$ estimate subsumes both the inputs v_{it}, k_{it} directly and indirectly through $\omega_{it} = h(v_{it}, k_{it})$. But since it is consistent, we can express unobserved technology ω_{it} as a function of to-be-estimated $\boldsymbol{\beta}_j$:

$$\omega_{it}(\boldsymbol{\beta}_j) = \hat{y}_{ijt} - f(v_{it}, k_{it}; \boldsymbol{\beta}_j) \qquad (A6)$$

So, given a $\boldsymbol{\beta}_j$, we can estimate equation (A5) to back out $\xi_{it}(\boldsymbol{\beta}_j)$. In the Cobb-Douglas case, we then have the GMM moment conditions

$$E\left(\xi_{it}(\boldsymbol{\beta}_j)\begin{pmatrix} k_{it} \\ v_{i,t-1} \end{pmatrix}\right) = 0 \qquad (A7)$$

Note that capital is assumed to be decided one period ahead and therefore should not be correlated with the innovation in productivity. We rely on *lagged* COGS to identify the coefficients on COGS since current COGS is expected to react to shocks to productivity and hence $E(v_{it}\xi_{it})$ is expected to be non-zero.

The GMM estimation thus boils down to searching for those $\boldsymbol{\beta}_j$ that simultaneously minimise the sample moment conditions in (A7). Once we have finally obtained $\hat{\boldsymbol{\beta}}_j$ from the above procedure, we can compute the output elasticity w.r.t. COGS θ_{it}^V (which is just equal to β_j^v in the Cobb-Douglas case). In addition, we can use the estimated measurement error in net sales, $\hat{\epsilon}_{it}$, to adjust the denominator in the COGS share of net sales, α_{it}^V. We can then compute our estimates of firm-level mark-ups $\hat{\mu}_{it} = \left(\tilde{\alpha}_{it}^V\right)^{-1}\hat{\theta}_{it}^V$ where $\tilde{\alpha}_{it}^V$ is the measurement-error adjusted (COGS/net sales) ratio, and $\hat{\theta}_{it}^V$ is the estimated output elasticity with respect to COGS.