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Price-Setting with Asynchronous Adjustments to Firm Prices and Outputs: Evidence using Direct Survey Measures

Kevin Lee, Michael Mahony, Paul Mizen

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DISCUSSION PAPER

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Keywords: Inflation, New Keynesian Phillips Curve, firm price setting, marginal costs

JEL classification: C80, E31, E32

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Price-Setting with Asynchronous Adjustments to Firm Prices and Output: Evidence using Direct Survey Measures*

Kevin Lee, Michael Mahony and Paul Mizen†

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This paper makes two key contributions to the existing literature on the standard New Keynesian Phillips Curve (NKPC). First, it drops the restrictive and unfounded assumption in the NKPC that a constant proportion of firms adjust their price each period. By introducing asynchronous adjustments to firm prices (measured using firm-level survey responses) into the NKPC microfoundations a new asynchronous NKPC is derived, which directly incorporates the forward-looking behaviour of firms. Second, this paper proposes a new direct measure of marginal costs based on firm-level survey responses to changes in output and average costs. The key results show that the new direct measure of marginal costs performs well in both the standard and new asynchronous NKPC. In general, marginal costs are comparatively more important in explaining inflation in the asynchronous NKPC.

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1 Introduction

This paper makes two contributions to existing literature by correcting for two shortcomings of the standard NKPC. First, in introducing sticky prices into the firm maximisation problem, the underlying the microfoundations of the NKPC assume a constant proportion of firms adjust their price each period. This is a simplifying assumption designed to ease solving the model and is at odds with observed firm price-setting behaviour. To overcome this, this paper introduces asynchronous adjustments to firm prices - the proportion of firms adjusting their prices is no longer fixed and can vary from period to period. The asynchronous adjustments to firm prices are directly measured using the underlying survey microdata of the Confederation of British Industry (CBI) Industrial Trends Survey (ITS). Relaxing this restrictive assumption (and incorporating directly observed firm price setting behaviour), alters the underlying microfoundations of the NKPC and results in a new NKPC specification. This new asynchronous NKPC embeds the forward-looking nature of firms directly in its specification and better reflects the behaviour of firms than the standard NKPC. This is reflected in the coefficient estimates of the key explanatory variables, which are larger than their standard counterparts. In addition, the role of real marginal costs in explaining inflation becomes comparatively more important.

Second, this study derives a direct measure of (log) real marginal costs which can be used in estimating either the standard or asynchronous NKPC. Typically, marginal costs are not directly observable and in estimating the standard NKPC alternative proxies need to be found. Classic examples include the output gap, the real labour share of income, real unit labour costs and unemployment related measures (such as the unemployment recession gap or the vacancy-to-unemployment ratio). However, existing literature has indicated these proxies often offer poor measurement of the underlying concept of (log) real marginal costs deviating from it's long-run equilibrium value. For example, the output gap often yields counterintuitive results (such as statistically insignificant coefficient estimates or statistically significant but negative) at odds with the theoretical model. Similarly, the counter-cyclical nature of labour share of income indicates this is a noisy proxy for marginal costs, and thus yields poor coefficient estimates. In addition, different marginal cost proxies are not necessarily strongly related or correlated with one another -

giving rise to a variety of coefficient estimates. The ability to directly measure (log) real marginal costs mitigates these issues. Again, the underlying survey microdata of the CBI ITS is used to construct an industry-wide direct measure of (nominal) marginal costs. Specifically, using firm-level survey returns related to changes in output and average costs. Using the standard definition of average costs (the sum of fixed and variable costs divided by output), then changes in average costs for firms whose output does not change equals the change in variable costs. Given that these firms have not changed their output, the change in variable costs equates to (nominal) marginal cost. A crucial condition for this direct measure of (nominal) marginal costs, given it is constructed using firms that do not change output, is it's representativeness for firms that do change output. Statistical tests show this direct measure of marginal costs is applicable to all firms, and not just the subset of firms that did not change output. Thus, the new direct measure of marginal costs presented in this paper is representative of all firms. Furthermore, estimates of both the standard and new asynchronous NKPC show this new direct measure is both statistically significant and positive, with plausible coefficient estimates.

This paper is related to three strands of literature. First, to the time series literature which examines the NKPC. This includes the seminal work of Roberts (1995), Galı and Gertler (1999), Woodford (2001) and Sbordone (2002) as well as Bårdsen et al. (2004), Jordi Galı et al. (2005), Jondeau and Le Bihan (2005), Brissimis and Magginas (2005), Zhang et al. (2009), Tsoukis et al. (2011), Fuhrer (2012), Nunes (2012), Mavroeidis et al. (2014),Abbas et al. (2016), Aristidou (2018) and Coibion et al. (2018). This literature has discussed the deficiencies of using the output gap as the forcing variable, introduced alternative proxies for real marginal costs (such as the real labour share of income, real unit labour costs and unemployment related measures), introduced the hybrid NKPC specification (which includes the first lag of inflation as an explanatory variable) and discussed NKPC estimation techniques - specifically, the the choice of instrument set and issue of weak instruments. Second, to the empirical literature that examines the frequency with which firms readjust their prices. This includes the work of Rotemberg and Woodford (1997), Clarida et al. (1999) and Erceg et al. (2000) - which suggest firms change their prices once a year. Similarly, Nakamura and Steinsson (2008) using Bureau of Labour Statistics data find prices change every 8 to 11 months - while Mark Bils and Klenow (2004) and Klenow and Kryvtsov (2008) using the same data source find prices change more frequently around every 4.3 months (or 5.5 months if temporary sales are excluded) and every 4 to 7 months (respectively). A comprehensive overview of this literature is provided by Klenow and Malin (2010). Studies focusing on the UK include Hall et al. (2000), Bunn and Ellis (2009) and Davies (2021) - which document firms changing prices twice a year, every four months and at least once a year (respectively). Third, to the empirical literature which utilises firm-survey responses in explaining macroeconomic dynamics. Previous studies (such as Driver et al. (2003), Driver et al. (2004), Driver and Urga (2004), Driver et al. (2005), Driver et al. (2006), Driver et al. (2008), Lui et al. (2011), Lee et al. (2020a), Lee et al. (2020b) and Lee et al. (2022)) have used the CBI dataset to examine issues related to rationality, uncertainty and investment dynamics. Boneva et al. (2020) use the CBI dataset to provide insight into the determinants of firm-level expectations, including on firm-level prices. However, this is the first study which uses the CBI survey microdata to update the standard NKPC to reflect asynchronous adjustments to firm prices.

The remainder of this paper is organised as follows: Section 2 alters the underlying microfoundations of the NKPC by introducing asynchronous adjustments to firm prices and deriving the new asynchronous NKPC. Section 3 discusses the CBI ITS which directly measures asynchronous adjustments to firm prices and provides data allowing for a direct measure of marginal costs. Section 4 presents the results from estimating the standard and the new asynchronous NKPC, while Section 5 concludes.

2 The New Keynesian Phillips Curve with Asynchronous Adjustments to Firm Prices

2.1 The Model Setup

The economy is populated with infinitely lived households, firms and government. There exists a continuum of monopolistically competitive, intermediate goods firms (indexed $i \in [0,1]$) that each produce a single differentiated good (of which it is the only producer[1]) - resulting in a continuum of differentiated goods ($Y_t(i)$). Household utility and firm investment depend on the single final good (Y_t) - produced by final goods firms

[1]Thus good produced by firm i is also denoted by i.

by aggregating the intermediate (differentiated goods), which are sold to households at price P_t. Following Dixit and Stiglitz (1977) aggregate output is defined by the Constant Elasticity of Substitution (CES) aggregator in Equation 1:

$$Y_t = \left(\int_0^1 Y_t(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}} \tag{1}$$

where $\varepsilon > 1$ is the constant elasticity of substitution among the intermediate goods, $Y_t(i)$ is the demand for good i and $P_t(i)$ is the price of good i set by firm i. This setup follows Blanchard and Kiyotaki (1987), Woodford (1996), Yun (1996), Rotemberg and Woodford (1997) and Chari et al. (2000) - with the models in Caballero and Engel (1993), Galı and Gertler (1999), Aoki (2001), Mankiw and Reis (2002), Christiano et al. (2005), Bakhshi et al. (2007) also based on this setup.

Equation 2 defines the *final* goods firms maximisation problem, subject to the constraint in Equation 1.

$$max P_t Y_t - \int_0^1 P_t(i) Y_t(i) di \tag{2}$$

The solution to the intermediate goods firms maximisation problem[2] is Equation 3, which defines the demand of good i, $Y_t(i)$.

$$Y_t(i) = \left(\frac{P_t(i)}{P_t} \right)^{-\varepsilon} Y_t \tag{3}$$

The corresponding aggregate price level[3], P_t, is defined in Equation 4.

$$P_t = \left(\int_0^1 P_t(i)^{1-\varepsilon} di \right)^{\frac{1}{1-\varepsilon}} \tag{4}$$

2.2 Including Asynchronous Adjustments to Firm Prices in the New Keynesian Model

Due to the staggered price setting behaviour of *intermediate* goods firms (i.e. intermediate goods firms do not adjust their prices simultaneously), the aggregate price level in period

[2]See Appendix B.1 for details.
[3]See Appendix B.2 for details.

t (P_t) consists of the subset of flexible prices chosen by adjusting firms and the subset of old prices chosen by non-adjusting firms. Let $Q_t(i)$ be the flexible price chosen by adjusting firm i (and $P_{t-1}(i)$ the price of non-adjusting firm i). Since all *intermediate* goods firms face the same maximisation problem they set the same flexible price when adjusting their price - so $Q_t(i) = Q_t$ [4]. In addition, the non-adjusting price index equates to the lagged price level, by the law of large numbers. Let $A(t) \subseteq [0, 1]$ be the set of firms changing prices and $\neg A(t) \subseteq [0, 1]$ be the set of firms keeping prices unchanged in period t. Then Equation 4 can be rewritten as Equation 5.

$$P_t = \left(\int_{A(t)} Q_t(i)^{1-\varepsilon} di + \int_{\neg A(t)} P_{t-1}(i)^{1-\varepsilon} di \right)^{\frac{1}{1-\varepsilon}} \tag{5}$$

Previous literature using this setup (such as Calvo (1983), Kimball (1995), Roberts (1995), Yun (1996), Clarida et al. (1999), Galı and Gertler (1999), Aoki (2001), Mankiw and Reis (2002), Christiano et al. (2005), Bakhshi et al. (2007), Dupor et al. (2010) and Coibion et al. (2018) to name a few) have assumed the subset of firms adjusting their price ($A(t)$) is a fixed proportion λ^p. This is a simplifying assumption for model tractability, neither justified by theory or empirical literature. While past empirical literature may support firms adjusting prices once a year[5], this does not mean firms do so uniformly.

The introduction of asynchronous adjustments to firm prices in this paper is a key departure from existing literature (and justified based on observed firm behaviour presented in Section 3.1). With asynchronous adjustments to firm prices, the proportion of firms adjusting their period $t-1$ price in period t (denoted $\lambda_t^p \in [0, 1]$) is no longer fixed and can vary from one time period to the next. In other words, $\lambda_t^p \neq \lambda_{t-1}^p$ a priori. Due to the presence of nominal rigidities $(1 - \lambda_t^p)$ of firms do not adjust prices in period t - they stick with their $t-1$ price. Note that $\lambda_t^p = 1$ when there is complete price flexibility, while $\lambda_t^p = 0$ indicates complete price rigidity. Note no reference has been made to the theory regarding how firms adjust their prices - such as deterministic price adjustment driven

[4]Note if it is assumed, since firms only infrequently adjust their prices, that when they do get the opportunity to adjust they choose their optimal price, then Q_t is also the optimal price level.

[5]Rotemberg and Woodford (1997), Clarida et al. (1999) and Erceg et al. (2000) suggest firms change their prices once a year. While Mark Bils and Klenow (2004), using Bureau of Labour Statistics data, find prices change around every 4.3 months (or 5.5 months if temporary sales are excluded), Klenow and Kryvtsov (2008) and Nakamura and Steinsson (2008) using the same data source find prices change every 4 to 7 months and 8 to 11 months (respectively).

by the expiration of multi-period contracts or pre-existing firm commitments in Fischer (1977) and Taylor (1979), stochastic price adjustment of Calvo (1983) or state-dependent pricing where firms adopt an Ss price-setting rule as in Caplin and Spulber (1987) and Golosov and Lucas (2007). Rather, the microdynamics use empirically observed firm behaviour (on asynchronous adjustments to firm prices) to explain the determinants of inflation.

Minor algebraic manipulation yields Equation 6, which is a Constant Elasticity of Substitution (CES) price index[6] [7].

$$P_t^{1-\varepsilon} = \lambda_t^p Q_t^{1-\varepsilon} + (1-\lambda_t^p) P_{t-1}^{1-\varepsilon} \tag{6}$$

Log-linearising Equation 6 around the zero-inflation steady-state[8] and minor algebraic manipulation yields Equation 7 [9].

$$\pi_t = \lambda_t^p (q_t - p_{t-1}) \tag{7}$$

where $\pi_t = p_t - p_{t-1}$ is the period t inflation rate. Equation 7 shows that inflation in period t depends on the proportion of firms adjusting from last period's price to their new flexible price in period t. Rearranging Equation 7 shows the (log) aggregate price level (p_t) in period t is a weighted average of firms period t (log) flexible price level and the (log) price level in period $t-1$ - with the weights determined by the proportion of firms adjusting their price in period t, λ_t^p (see Equation 8).

$$p_t = \lambda_t^p q_t + (1-\lambda_t^p) p_{t-1} \tag{8}$$

Simple manipulation of Equation 8 provides an expression for the (log) flexible price level in period t (Equation 9).

$$q_t = \frac{1}{\lambda_t^p} \left(p_t - (1-\lambda_t^p) p_{t-1}\right) \tag{9}$$

Thus, the (log) flexible price index is a weighted average of the current (log) price level

[6]See Appendix B.3 for details.

[7]Note if $\varepsilon = 0$ then Equation 6 becomes a Laspeyres index.

[8]Let $\Pi_t = \frac{P_t}{P_{t-1}}$. Then, in the zero-inflation steady-state $\Pi_t = 1$ which implies $P_t = P_{t-1} = Q_t \forall t$.

[9]Throughout, lower case letters denote the log of their uppercase counterpart. For example, $p_t = ln(P_t)$, where P_t is the aggregate price level

and last period's (log) price level - with weights determined by the proportion of firms that adjust prices this period. While Equation 7 and Equation 8 are similar to their standard counterparts (where λ^p is assumed), only by adopting asynchronous adjustments to firm prices can q_t in Equation 9 be properly identified - in the standard case, an assumed or imputed value for λ^p is needed which does not reflect actual firm behaviour and is therefore not an accurate measure of q_t.

2.3 Deriving the Asynchronous New Keynesian Phillips Curve

Any firm i that reoptimises in period t (i.e. sets new prices Q_t) solves the firm maximisation problem in Equation 10 subject to the constraints in Equation 11 and Equation 12.

$$
\begin{aligned}
&max\ \big((Q_t Y_{t|t}(i) - \Psi_t(Y_{t|t}(i)) + \\
&\qquad E_t \sum_{k=1}^{\infty} \left(\prod_{j=1}^{k} (1 - \lambda^p_{t+j}) \right) \beta^k \left(\frac{C_{t+k}}{C_t} \right)^{-\sigma} \frac{P_t}{P_{t+k}} (Q_t Y_{t+k|t}(i) - \Psi_{t+k}(Y_{t+k|t}(i))) \qquad (10)
\end{aligned}
$$

$$
Y_{t|t}(i) = \left(\frac{Q_t}{P_t} \right)^{-\varepsilon} C_t \qquad (11)
$$

$$
Y_{t+k|t}(i) = \left(\frac{Q_t}{P_{t+k}} \right)^{-\varepsilon} C_{t+k} \qquad (12)
$$

where $\prod_{j=1}^{k}(1 - E_t \lambda^p_{t+j})$ is the probability firm i does not change price until period $t+k$, $\beta^k \left(\frac{C_{t+k}}{C_t} \right)^{-\sigma} \frac{P_t}{P_{t+k}}$ is a stochastic discount factor, $\Psi_{t+k}(.)$ is a cost function, $Y_{t+k|t}(i)$ is firm i's output in $t+k$ given it changed it's price in t and $Q_t Y_{t+k|t}(i) - \Psi_{t+k}(Y_{t+k|t}(i))$ is the (nominal) undiscounted profit in $t+k$. In other words, firm i's maximisation problem is to set a new price (Q_t) such that for the length of time firms stick with this new price their present discounted value of profits is maximised.

The solution[10] to the reoptimising firm's maximisation problem (Equation 10 to Equation 12) is Equation 13

$$
Q_t = \frac{\varepsilon}{\varepsilon - 1} \frac{C_t^{1-\sigma} P_t^{\varepsilon} \frac{\psi_{t|t}(i)}{P_t} + E_t \sum_{k=1}^{\infty} \left(\prod_{j=1}^{k} (1 - \lambda^p_{t+j}) \right) \beta^k C_{t+k}^{1-\sigma} P_{t+k}^{\varepsilon} \frac{\psi_{t+k|t}(i)}{P_{t+k}}}{C_t^{1-\sigma} P_t^{\varepsilon-1} + E_t \sum_{k=1}^{\infty} \left(\prod_{j=1}^{k} (1 - \lambda^p_{t+j}) \right) \beta^k C_{t+k}^{1-\sigma} P_{t+k}^{\varepsilon-1}} \qquad (13)
$$

[10]See Appendix sec:derivation˙reoptimising˙max˙problem for details.

where $\frac{\varepsilon}{\varepsilon-1}$ is the desired mark-up and $\frac{\psi_{t+k|t}(i)}{P_{t+k}}$ is real marginal cost. Equation 13 states the price chosen by adjusting firms is set as a mark-up over a weighted average of current and future expected marginal costs - where the weights are proportional to the probability of the price remaining effective at each horizon $\prod_{j=1}^{k}(1 - E_t\lambda_{t+j}^p)$. Note, in the case of complete price flexibility ($\lambda_t^p = 1$) Equation 13 reduces to the flexible price optimal price-setting condition.

Taking the first order Taylor Expansion of $\frac{Q_t}{P_{t-1}}$ and some minor algebraic manipulation[11] yields Equation 14, the new asynchronous NKPC.

$$\pi_t = \beta\frac{\lambda_t^p(1 - E_t\lambda_{t+1}^p)}{(1 - \lambda_t^p)E_t\lambda_{t+1}^p}E_t\pi_{t+1} + (1 - (1 - E_t\lambda_{t+1}^p)\beta)\frac{1-\alpha}{1-\alpha(1-\varepsilon)}\frac{\lambda_t^p}{1-\lambda_t^p}\left(\phi_t - ln\left(\frac{\varepsilon - 1}{\varepsilon}\right)\right) \tag{14}$$

where $E_t\pi_{t+1}$ is the one period ahead expected inflation, $E_t\lambda_{t+1}^p$ is the one period ahead proportion of firms who expect to adjust their prices, ϕ_t is (log) real marginal cost and $\left(\phi_t - ln\left(\frac{\varepsilon-1}{\varepsilon}\right)\right)$ is the deviation of (log) real marginal cost from it's long-run steady-state value. Contrast this with the standard NKPC, presented in Equation 15.

$$\pi_t = \beta E_t\pi_{t+1} + (1 - (1 - \lambda^p)\beta)\frac{1-\alpha}{1-\alpha(1-\varepsilon)}\frac{\lambda^p}{1-\lambda^p}\left(\phi_t - ln\left(\frac{\varepsilon - 1}{\varepsilon}\right)\right) \tag{15}$$

Both Equation 14 and Equation 15 relate inflation in period t (π_t) to the one period ahead expected inflation, $E_t\pi_{t+1}$, and the deviation of (log) real marginal cost from it's long-run steady-state value, $\left(\phi_t - ln\left(\frac{\varepsilon-1}{\varepsilon}\right)\right)$. However, while $E_t\pi_{t+1}$ is the explanatory variable in Equation 15, in Equation 14 $E_t\pi_{t+1}$ is weighted by $\frac{\lambda_t^p(1-E_t\lambda_{t+1}^p)}{(1-\lambda_t^p)E_t\lambda_{t+1}^p}$ - the ratio of the probability that a firm changes price this period and not next period to the probability that a firm does not change price this period and changes prices next period. Thus Equation 14 directly incorporates the forward-looking nature of firm behaviour in its specification, in contrast to Equation 15. Similarly, while $\left(\phi_t - ln\left(\frac{\varepsilon-1}{\varepsilon}\right)\right)$ is interacted with ratio of the proportion of firms that adjust to a new price this period to the proportion of firms that do not adjust prices this period in both Equation 14 and Equation 15 - only in Equation 14 is this time-varying. Given the necessary data, $\left(\phi_t - ln\left(\frac{\varepsilon-1}{\varepsilon}\right)\right)$ can thus be weighted by $\frac{\lambda_t^p}{1-\lambda_t^p}$ in estimating Equation 14. Note higher values of λ_t^p (which correspond to lower values of $(1 - \lambda_t^p)$) increase the weights on both $E_t\pi_{t+1}$ and $\left(\phi_t - ln\left(\frac{\varepsilon-1}{\varepsilon}\right)\right)$ in

[11] See Appendix sec:derivation˙nkpc for details.

the NKPC specification. Intuitively, the greater (lesser) the proportion of firms adjusting prices in period t, the greater (lesser) the weighted values of $E_t\pi_{t+1}$ and $\left(\phi_t - ln\left(\frac{\varepsilon-1}{\varepsilon}\right)\right)$ in explaining inflation in period t. This change in the value of λ_t^p and it's role in interacting with $E_t\pi_{t+1}$ and $\left(\phi_t - ln\left(\frac{\varepsilon-1}{\varepsilon}\right)\right)$ in explaining π_t is absent from the standard NKPC specification in Equation 15.

Following Galı and Gertler (1999), both Equation 14 and Equation 15 can be augmented by including the lagged dependent variable (π_{t-1}) as an additional explanatory variable - to form hybrid specifications of the NKPC. It is expected that the coefficient on $E_t\pi_{t+1}$ dominates the π_{t-1} coefficient - suggesting inflation dynamics are forward looking. It is also expected that the $E_t\pi_{t+1}$ coefficient is greater in Equation 14 than Equation 15 - capturing the forward-looking behaviour of firms encapsulated directly in Equation 14, but absent in Equation 15.

3 Data

Data for this paper is sourced from the Confederation of British Industry (CBI) Industrial Trends Survey (ITS) and the Office for National Statistics (ONS). Data used to construct the proportion of firms that adjust prices in period t (λ_t^p), the one period ahead proportion of firms who expect to adjust their prices ($E_t\lambda_{t+1}^p$), the one period ahead expected inflation ($E_t\pi_{t+1}$) and (nominal) marginal costs are taken from the underlying survey microdata of the ITS. Data provided by the ONS is used to construct the aggregate price level, p_t and p_{t-1}, and alternative marginal cost proxies commonly discussed in the literature (such as the output gap, the real labour share of income, real unit labour costs, the unemployment recession gap and the vacancy-to-unemployment ratio).

A full in-depth discussion of the ITS is found in Lee et al. (2020a)[12]. The available ITS dataset consists primarily of manufacturing (and some mining) firms[13], with survey responses from 2000Q1 to 2021Q3[14]. Collection for the survey published in month t begins

[12]Lee et al. (2020a) also discuss other business surveys in the CBI suite of business surveys which relate to the services, distributive trades and financial services sectors. They are excluded from this paper as they do not contain the necessary data to measure (nominal) marginal costs.

[13]Specifically, the ITS covers firms categorised in SIC07 level B (mining and quarrying) and C (manufacturing). However, it has no returns for firms in two-digit SIC07 levels 5, 6, 11, 21, 31 and 33. Note the ITS primarily uses old SIC07 classifications - see Appendix C for details on how these are converted to SIC07.

[14]While the ITS started in 1958, this study only has access to data from 2000Q1.

around the final week of month $t-1$ with publication of results around the final week of month t. Participation in survey waves is voluntary (not limited by CBI membership) and new surveys are conducted monthly with *enhanced* survey waves (containing additional questions) once a quarter. Only enhanced survey waves are used in this paper - since it is the additional questions which are relevant for this study. Minor cleaning of the ITS dataset is discussed in Appendix D. Figure 1 plots the sample size (i.e. number of firm responses) each quarter for the manufacturing sector. While there has been a continuous decline in survey responses since 2001, the ITS still exhibits a strong survey completion record.

Figure 1: Sample Size in Total Manufacturing

Note: Data from the manufacturing sector is taken from the enhanced Industrial Trends Survey (ITS). Note the enhanced ITS is missing firm responses from two-digit SIC07 levels 5, 6, 11, 21, 31 and 33. Firm survey responses are available from 2000Q1.

3.1 Measuring Asynchronous Adjustments to Firm Prices

The *enhanced* ITS measures realised (expected) asynchronous adjustments to firm prices by asking firms if their selling price went (will go) up, the same or down over the past (next) three months[15]. Specifically, λ_t^p ($E_t\lambda_{t+1}^p$) is defined as the proportion of firms, in survey wave $t+1$ (t), which selected their selling prices went (will go) up or down over the past (next) three months. Conversely, the proportion of firms which selected their selling prices remained (will remain) the same over the past (next) three months measures $1-\lambda_t^p$ ($1 - E_t\lambda_{t+1}^p$).

Figure 2 depicts λ_t^p for the manufacturing sector[16]. Allowing for asynchronous adjustments to firm prices is a key departure made by this paper from existing literature, which (absent data on price changes) assumes a constant proportion of firms change prices each period. Typically it is assumed firms change their prices once a year, which for quarterly data implies $\lambda^p = 0.25$. For comparative purposes, Figure 2 also includes λ^p set at 0.25.

It is clear the assumption of fixed λ^p at 0.25 is not consistent with actual firm behaviour. In fact, the average value of λ_t^p in each sector is at least 0.33 and reaches a high of 0.5. There is a notable decrease in the number of firms adjusting their prices between 2012 and 2016. In fact, this is the only period that λ_t^p is consistently below 0.25.

3.2 Measuring Inflation and One Period Ahead Inflation Expectations

Recall from Section 2.2 that the inflation rate in period t (π_t) is defined as the first difference in the (log) aggregate price level ($p_t - p_{t-1}$). Official data is used to measure p_t (and thus π_t) for the manufacturing sector - which is constructed by weighting the contributing two-digit SIC07 level price levels[17] using data from the ONS Producer Price Inflation (PPI)[18]. Weighting is implemented using the same chain-linked PPI weights[19] used by the ONS. Chain-linked PPI weights are unavailable pre-2009, and remain un-

[15] The exact wording of the enhanced ITS question 12a is: "excluding seasonal variations, what has been the trend over the past three months and what are the expected trends for the next three months, with regard to average selling prices at which domestic orders (sales) are booked".

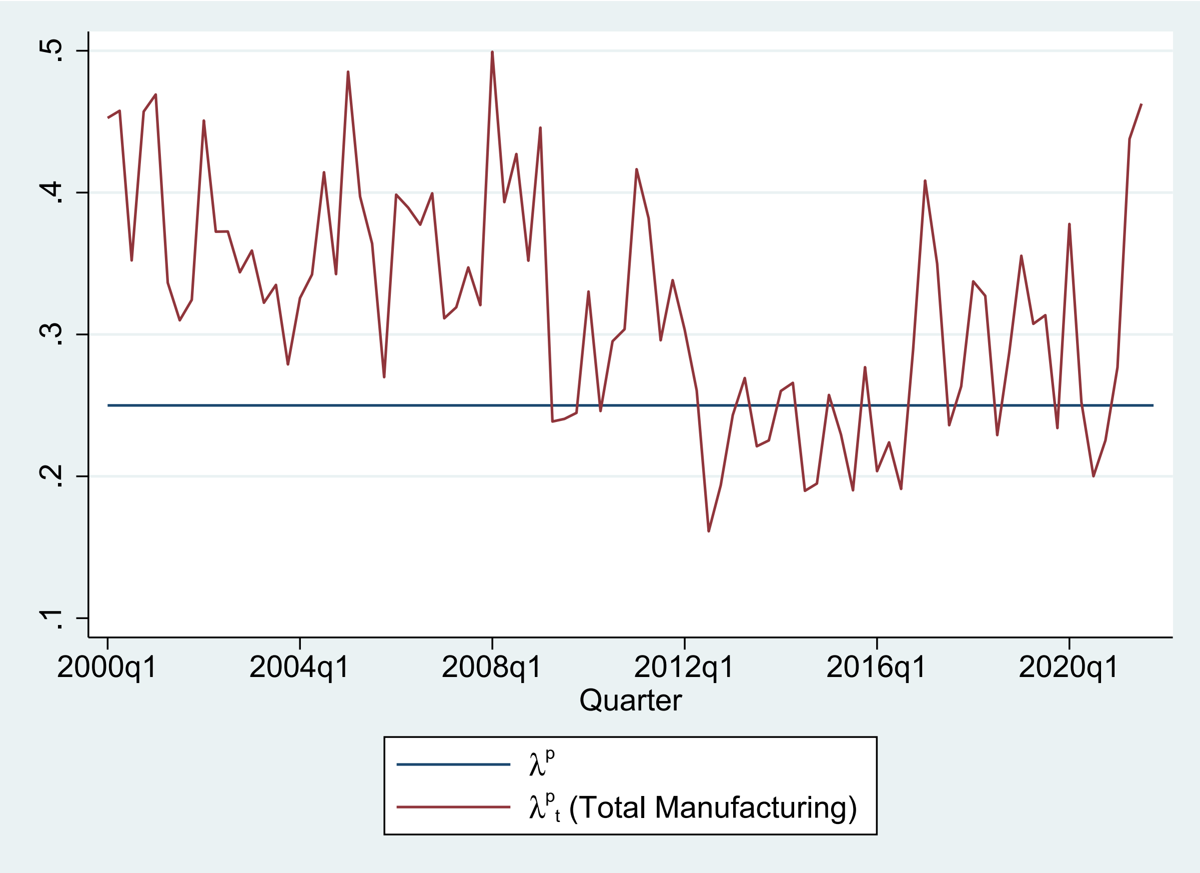
[16] Note λ_t^p is calculated as a weighted average of $\lambda_t^p(j)$, where j are the contributing two-digit SIC07 levels that compose the relevant aggregate industrial sector and are also recorded in the ITS. The weights used are the same weights used by the ONS to create aggregate price levels. See Appendix F for comparison between weighted and unweighted series.

[17] Note since the enhanced ITS is missing firm responses from two-digit SIC07 levels 5, 6, 11, 21, 31 and 33, these sectors are excluded in the weighted manufacturing aggregates

[18] Specifically, ONS series GB9U, GBA6, G6SI, G6SJ, G6SN, G6SO, G6SP, G6SQ, G6SR, G6SS, G6ST, G6SV, G6SW, G6SX, G6SY, G6SZ, G6T3, G6T5, G6VF, G6VG, G6WH, G72N, G75I, G776 and G777 are used.

[19] Kindly provided by the ONS and based on sales data.

Figure 2: The Proportion of Firms Adjusting Prices (λ_t^p)



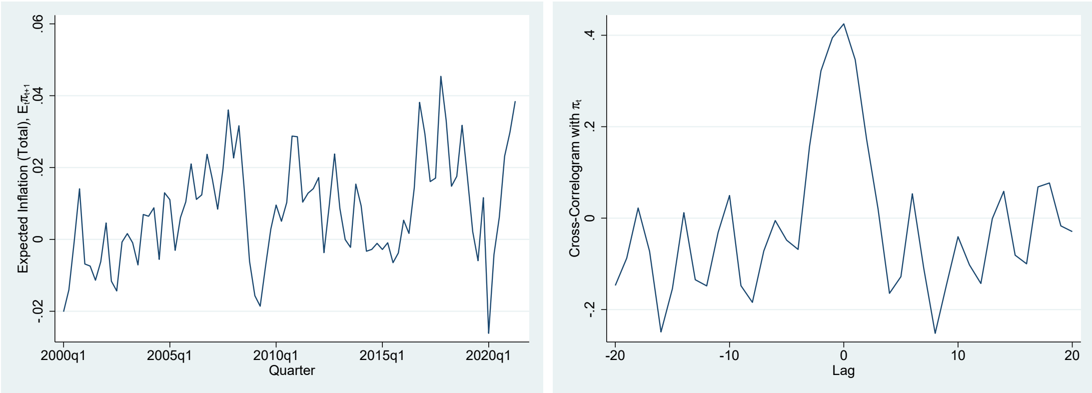
Note: λ^p assumes a fixed proportion of firms change prices each quarter (set at 0.25 on the assumption that firms change prices once a year). λ_t^p is the time-varying proportion of manufacturing firms changing prices each quarter. Data measuring when manufacturing firms change prices is taken from the enhanced Industrial Trends Survey (ITS), where question 12a asks "excluding seasonal variations, what has been the trend over the past three months and what are the expected trends for the next three months, with regard to average selling prices at which domestic orders (sales) are booked". Note the enhanced ITS is missing firm responses from two-digit SIC07 levels 5, 6, 11, 21, 31 and 33. Firm survey responses are available from 2000Q1.

changed between 2009 and 2013. Thus, the 2009 to 2013 chain-linked PPI weight values are used pre-2009.

The one-period ahead expected inflation rate ($E_t\pi_{t+1}$) is defined as the proportion of firms expecting prices will go up less the proportion of firms expecting prices will go down over the next three months - as reported in the *enhanced* ITS. This balance statistic constitutes a *direct* measure of industry-level one-period ahead inflation expectations, mitigating the need to rely on the assumption of rational expectations or noisy expectation proxies. Figure 3a depicts $E_t\pi_{t+1}$ for the manufacturing sector, while Figure 3b depicts the cross-correlogram between $E_t\pi_{t+1}$ and lags/leads of π_t.

Pre-financial crisis inflation expectations were generally trending upwards. A sharp decline in expectations followed the onset of the financial crisis, but by 2013Q1 expectations

Figure 3: Measuring One-Period Ahead Inflation Expectations ($E_t\pi_{t+1}$)



(a) $E_t\pi_{t+1}$ for the Manufacturing Sector

(b) Cross-Correlogram between $E_t\pi_{t+1}$ and Lags/Leads of π_t

Note: Data from the manufacturing sector is taken from the enhanced Industrial Trends Survey (ITS). Note the enhanced ITS is missing firm responses from two-digit SIC07 levels 5, 6, 11, 21, 31 and 33. Firm survey responses are available from 2000Q1.

remain steady (around zero) and continue to do so until 2016Q1. Hereafter, inflation expectations sharply increase until 2017Q4 before steadily declining until 2020Q1. Furthermore, $E_t\pi_{t+1}$ is strongly correlated with π_t at 0.43. Note that $E_t\pi_{t+1}$ is most highly correlated with π_t.

3.3 Measuring Real Marginal Costs

With no assumptions regarding functional form, (nominal) marginal costs in period t are defined as $\psi_t = \frac{\Delta VC_t}{\Delta Y_t}$ - where ΔVC_t is the change in variable costs between periods $t-1$ and t. This is derived from differentiating the standard definition of average costs, $AC_t = \frac{FC_t+VC_t}{Y_t}$, with respect to Y_t - where in period t AC_t are average costs and FC_t are fixed costs. Traditionally in estimating the standard New Keynesian Phillips Curve the deviation of (log) real marginal cost from it's long-run steady-state value, $\left(\phi_t - ln\left(\frac{\varepsilon-1}{\varepsilon}\right)\right)$, is proxied using variables such as the output gap, real labour share of income, real unit labour costs, the unemployment recession gap or the vacancy-to-unemployment ratio (see Galı and Gertler (1999), Woodford (2001), Sbordone (2002) and Stock and Watson (2010) for pioneering examples) due to the difficulty in measuring (log) real marginal costs, ϕ_t.

However, using the ITS survey micordata (combined with official data from the ONS) this paper provides a *direct* measure of industry-level (log) real marginal costs. Totally differentiating the standard expression for average costs yields Equation 16.

$$\Delta AC_t = \frac{1}{Y_t}\Delta FC_t + \frac{1}{Y_t}\Delta VC_t - \frac{1}{Y_t^2}(FC_t + VC_t)\Delta Y_t \tag{16}$$

where $\Delta Z_t = Z_t - Z_{t-1}$, for $Z_t \in \{FC_t, VC_t, Y_t\}$. For the proportion of firms which do not alter production plans, $(1 - \lambda_t^y)$, $\Delta Y_t = 0$ - meaning the final term in Equation 16 disappears. Furthermore, given no change in production it is very unlikely that fixed costs can dramatically change - implying $\Delta FC_t = 0$ in Equation 16. Some minor algebraic manipulation[20] yields the relations in Equation 17.

$$\Delta ac_t|_{\Delta Y_t = 0} - p_t \approx \Delta vc_t - p_t = \phi_t \tag{17}$$

The first relation in Equation 17 states that for firms which do not alter their output between period $t-1$ and t ($\Delta Y_t = 0$), changes in the (log) real average cost ($\Delta ac_t|_{\Delta Y_t=0} - p_t$) approximately equal changes in (log) real variable cost ($\Delta vc_t - p_t$), which given output remains unchanged between $t-1$ and t equals (log) real marginal cost ϕ_t (the second relation). When output remains unchanged, increased (decreased) real average costs imply increased (decreased) real marginal costs.

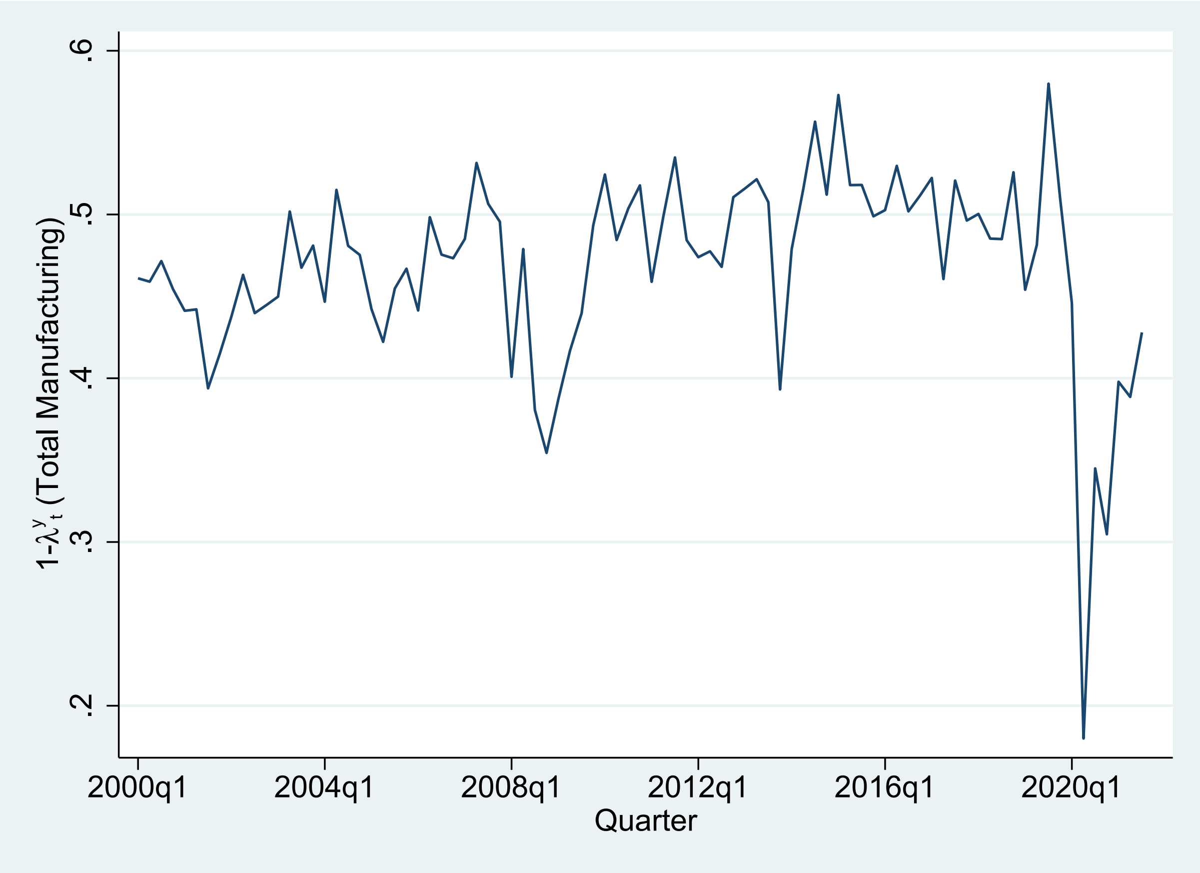
The direct measure of (log) real marginal costs (ϕ_t) is derived from the proportion of firms who reported average costs went up less the proportion who stated average costs went down, while also reporting their output remain unchanged over the same three month horizon[21]. Figure 4 depicts $(1 - \lambda_t^y)$ - the proportion of firms who did not alter their production plans over the previous quarter.

On average, just under half of firms do not alter their output each quarter. Both 2008 and 2020 (corresponding to significant changes in the economic environment) see large decreases in the proportion of firms keeping output unchanged - with the alterations being greater in 2020. Figure 5a depicts $\left(\phi_t - ln\left(\frac{\varepsilon-1}{\varepsilon}\right)\right)$, while Figure 5b depicts the cross-correlogram between $\left(\phi_t - ln\left(\frac{\varepsilon-1}{\varepsilon}\right)\right)$ and lags/leads of π_t.

[20]Substituting $\Delta FC_t = 0$ and $\Delta Y_t = 0$ in Equation 16 yields $\Delta AC_t = \frac{1}{Y_t}\Delta VC_t$. Following the standard definition of average costs $\frac{1}{Y_t} = \frac{AC_t}{TC_t}$ and $Y_t = Y_{t-1}$ (since $\Delta Y_t = 0$). Substitution into the expression for ΔAC_t yields $\frac{\Delta AC_t}{AC_{t-1}} = \frac{\Delta TC_t}{TC_{t-1}}$, which given $\Delta Y_t = 0$ yields Equation 17.

[21]Specifically, question 11 of the enhanced ITS which asks "excluding seasonal variations, what has been the trend over the past three months [...], with regard to average costs per unit of output", while question 8 asks "excluding seasonal variations, what has been the trend over the past three months [...],

Figure 4: Proportion of Firms Altering Output Each Quarter (λ_t^y)



Note: $1-\lambda_t^y$ is the time-varying proportion of manufacturing firms not changing output each quarter. Data measuring when manufacturing firms change output is taken from the enhanced Industrial Trends Survey (ITS), where question 8 asks "excluding seasonal variations, what has been the trend over the past three months and what are the expected trends for the next three months, with regard to volume of output (i.e. production)". Note the enhanced ITS is missing firm responses from two-digit SIC07 levels 5, 6, 11, 21, 31 and 33. Firm survey responses are available from 2000Q1.

The deviation of direct (log) real marginal costs from its steady-state value remains steady until 2005, before continually falling until around 2013 and then rebounding and settling by 2020. While $\left(\phi_t - ln\left(\frac{\varepsilon-1}{\varepsilon}\right)\right)$ is effectively uncorrelated with π_t, the correlation with $\pi_{t+j}\ \forall j > 0$ sharply increases.

3.3.1 Are Firms which do not Alter Output Different from those that do?

Defining (log) real marginal costs (ϕ_t) in Equation 17 involved focusing on the $(1-\lambda_t^y)$ proportion of firms that did not alter their production plans. However, is this subset of firms representative of the sample? Specifically, are there any substantial differences between the subsample of firms that keep output unchanged and the subsample that don't? Figure 6a to Figure 6d provides good evidence of no substantial differences between the

with regard to volume of output (i.e. production)".

Figure 5: Direct Measures of (Log) Deviation of Real Marginal Costs from it's Steady-State $\left(\phi_t - \overline{\phi}\right)$

(a) (Log) Real Marginal Cost Deviation $(\phi_t - \overline{\phi})$ for the Total Manufacturing Sector

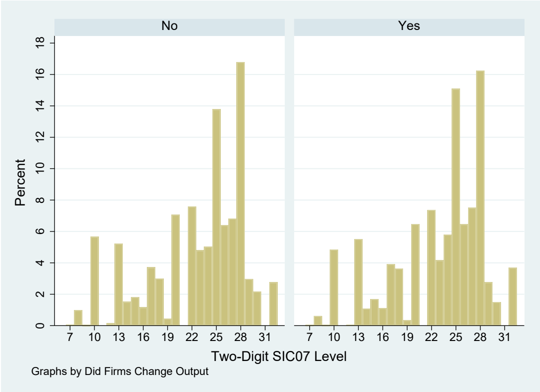
(b) Cross-Correlogram between ϕ_t and Lags/Leads of π_t

Note: Data from the manufacturing sector is taken from the enhanced Industrial Trends Survey (ITS). Question 11 of the enhanced ITS which asks "excluding seasonal variations, what has been the trend over the past three months [...], with regard to average costs per unit of output", while question 8 asks "excluding seasonal variations, what has been the trend over the past three months [...], with regard to volume of output (i.e. production)". Note the enhanced ITS is missing firm responses from two-digit SIC07 levels 5, 6, 11, 21, 31 and 33. Firm survey responses are available from 2000Q1.

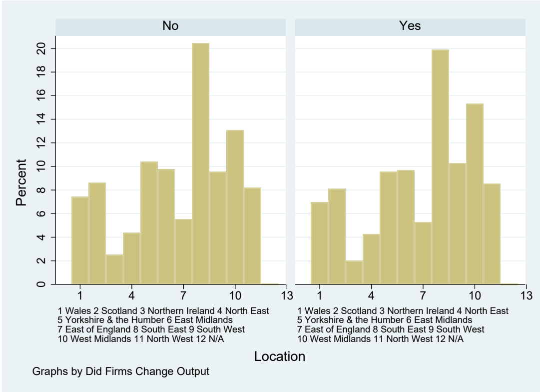
two subsamples of firms (or in their answers regarding average costs). This is important as it provides evidence that (log) real marginal costs (ϕ_t) defined in Equation 17 (and depicted in Figure 5a) is representative of all firms.

Figure 6a to Figure 6c shows the percentage of firms in both subsamples from each two-digit SIC07 level, NUTS1 location and firm size (as defined using the standard numbers employed classification). Evidently, there are no substantial differences across firm characteristics between subsamples. Moreover, comparing the balance of firm answers regarding average costs between subsamples in Figure 6d does not yield any substantial differences. In fact, the correlation between the two series is 0.95. Furthermore, the output unchanged series has a mean (standard deviation) of 0.208 (0.157) while the output changed series has a mean (standard deviation) of 0.228 (0.178). Crucially, the difference in the means of these two series is not statistically significant (with a p-value of 0.421 under the null hypothesis of equal means).

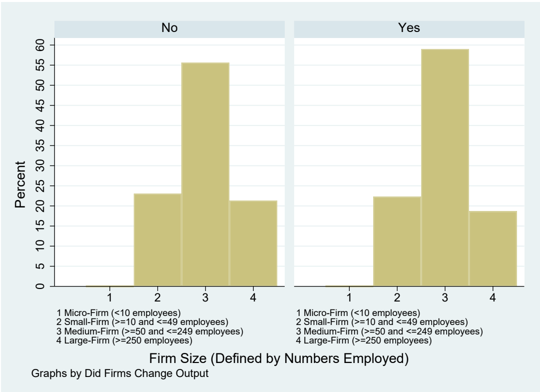
Figure 6: Comparing Firms Based on their Output Decision



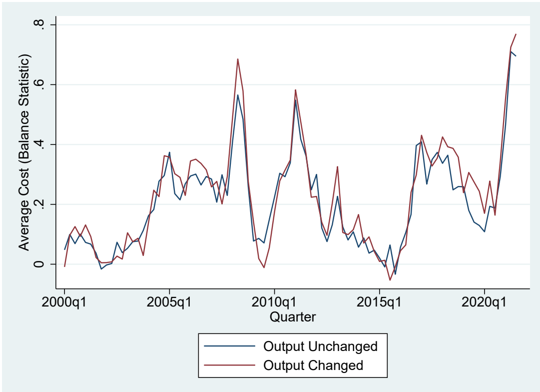
(a) SIC07 Classification across Output Decisions



(b) Location across Output Decisions



(c) Firm Size across Output Decisions



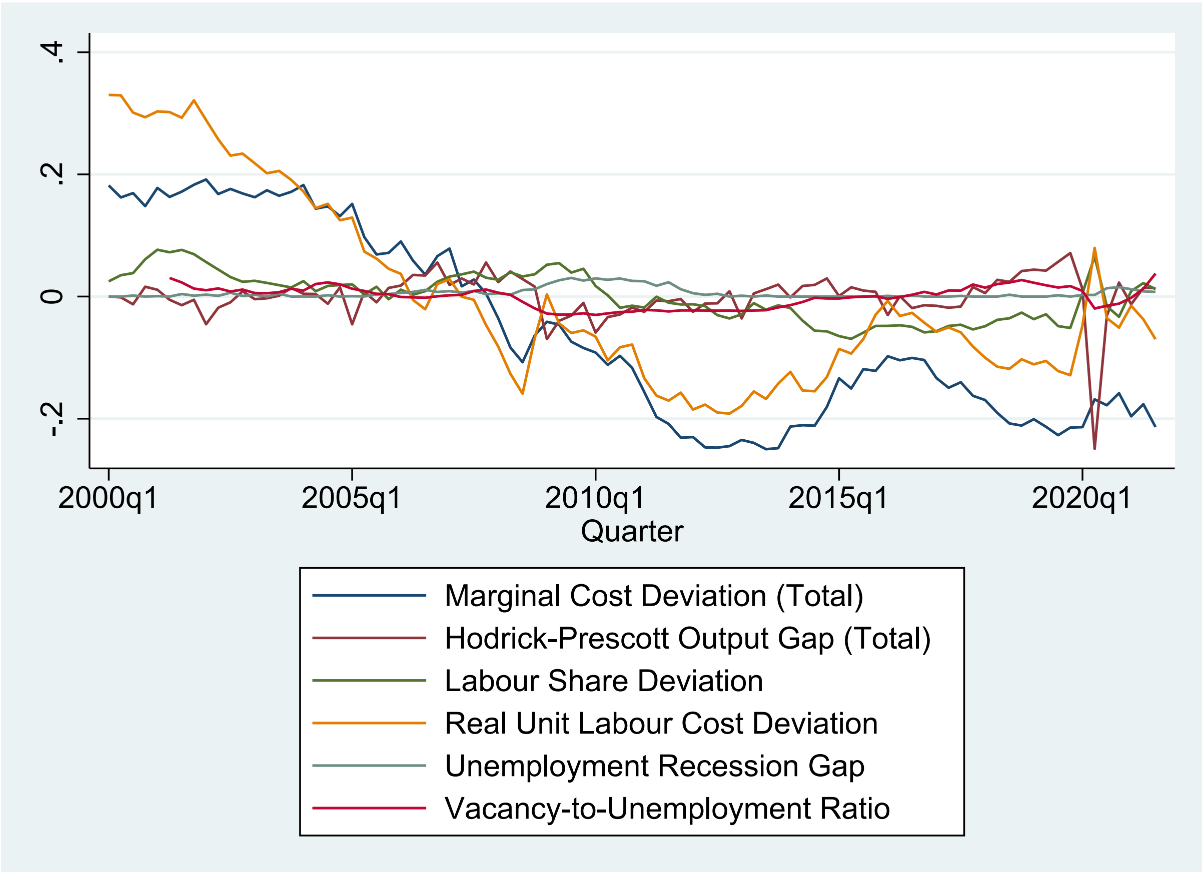
(d) Average Cost (Balance Statistic) across Output Decisions

Note: Manufacturing firms survey responses are taken from the enhanced Industrial Trends Survey (ITS). Question 11 of the enhanced ITS which asks "excluding seasonal variations, what has been the trend over the past three months [...], with regard to average costs per unit of output". Industry classification is defined using the two-digit SIC07 level, location is defined as NUTS1 location and firm size is defined using the standard numbers employed classification. Note the enhanced ITS is missing firm responses from two-digit SIC07 levels 5, 6, 11, 21, 31 and 33. Firm survey responses are available from 2000Q1.

3.3.2 Comparing the Direct (Log) Deviation of Real Marginal Costs from it's Steady-State $\left(\phi_t - ln\left(\frac{\varepsilon-1}{\varepsilon}\right)\right)$ with Alternative Proxies

Figure 7 compares the direct (log) deviation of real marginal costs from it's steady-state value for each industrial aggregate with alternative proxies found in the literature - specifically the output gap ($y_t - \widetilde{y}_t$ where trend output ($\widetilde{y}_t$) is calculated using the Hodrick-Prescott filter), the unemployment recession gap ($urec_t$ defined as current unemployment rate less the minimum unemployment rate over the current and previous eleven quarters) and the deviation of real labour share of income (s_t), real unit labour costs ($rulc_t$) and the vacancy-to-unemployment ratio ($vacu_t$) from their respective steady-state values[22] [23]. Table 1 presents the corresponding correlation matrix across all potential proxies. Figure 8 compares the cross-correlogram between each of the (log) real marginal cost deviation proxies and lags/leads of π_t.

Figure 7: Comparing the Direct (Log) Deviation of Real Marginal Costs from it's Steady-State $(\phi_t - \overline{\phi})$ with Alternative Proxies



Note: Data is sourced from the enhanced Industrial Trends Survey (ITS) and ONS official statistics. Question 11 of the enhanced ITS which asks "excluding seasonal variations, what has been the trend over the past three months [...], with regard to average costs per unit of output", while question 8 asks "excluding seasonal variations, what has been the trend over the past three months [...], with regard to volume of output (i.e. production)". Note the enhanced ITS is missing firm responses from two-digit SIC07 levels 5, 6, 11, 21, 31 and 33. Firm survey responses are available from 2000Q1.

The purpose of this subsection is to demonstrate the wide variety (specifically, the discrepancies) across real marginal cost proxies found in the literature. In fact, the correlations across the proxies range from negatively correlated, to uncorrelated and strongly correlated. This is also reflected in the cross-correlograms with lags/leads of realised inflation

[22]Following existing literature, the steady state value is calculated as the mean of the (log) real marginal cost proxy, where the mean value for variable z_t is defined as $\overline{z}$.

[23]Data for these proxies is taken from ONS index of production, quarterly labour share of income index, quarterly nominal unit labour costs index, UNEM03 unemployment and VACS02 vacancies by industry

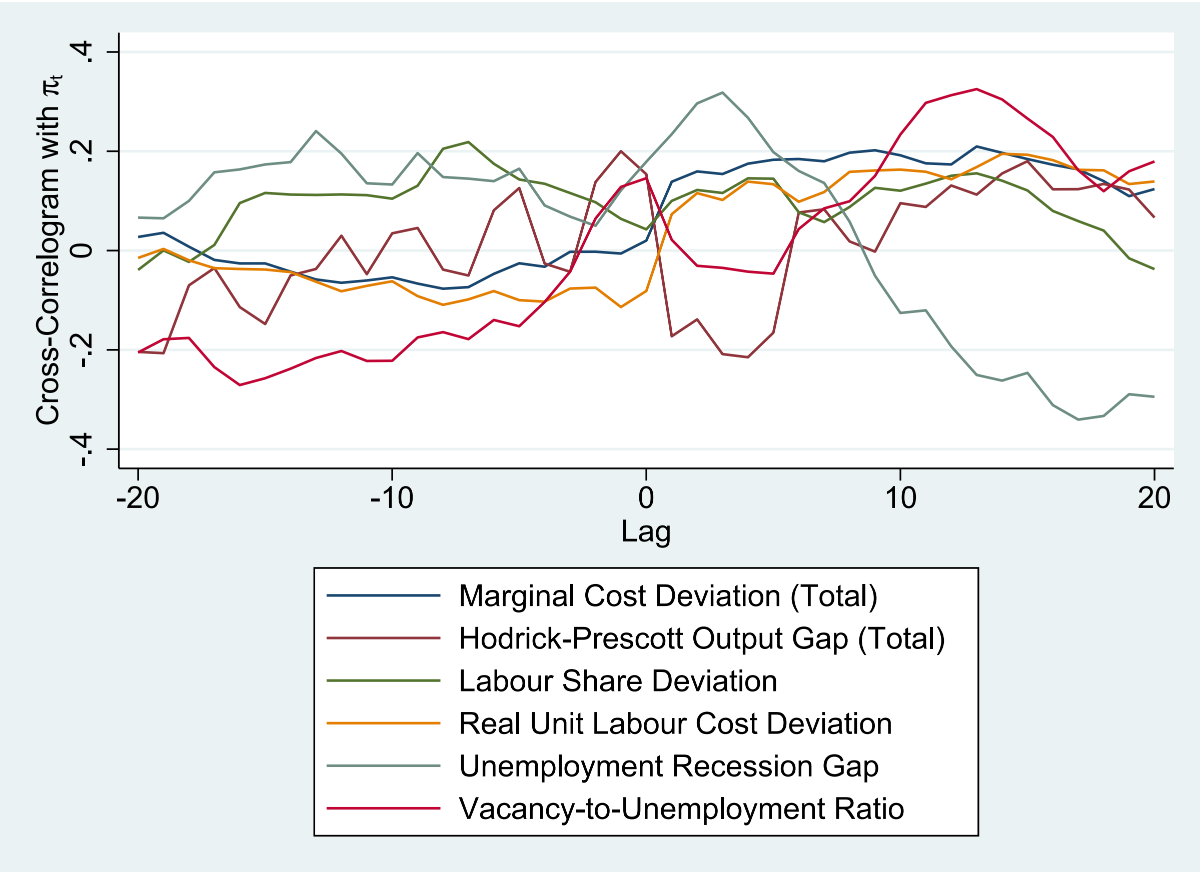
1[1]

Table 1: Comparison of the Deviation of (Log) Real Marginal Cost Proxies (Total Manufacturing)

	(1)					
	$\phi_t - \overline{\phi}$	$y_t - \widetilde{y}_t$	$s_t - \overline{s}$	$rulc_t - \overline{rulc}$	$urec_t$	$vacu_t - \overline{vacu}$
$\phi_t - \overline{\phi}$	1					
$y_t - \widetilde{y}_t$	-0.0273	1				
$s_t - \overline{s}$	0.635sym***	-0.269sym*	1			
$rulc_t - \overline{rulc}$	0.909sym***	-0.189	0.613sym***	1		
$urec_t$	-0.0850	-0.258sym*	0.292sym**	-0.192	1	
$vacu_t - \overline{vacu}$	0.386sym***	0.392sym***	0.0200	0.476sym***	-0.625sym***	1

Note: ϕ_t is the direct (log) real marginal cost measure derived in this paper, $y_t - \widetilde{y}_t$ is the output gap (using the Hodrick-Prescott filter), s_t is the real labour share of income, $rulc_t$ are real unit labour costs, $urec_t$ is the unemployment recession gap and $vacu_t$ is the vacancy-to-unemployment ratio. All data sourced from the *ITS* and ONS.

Figure 8: Cross-Correlogram between Deviation of (Log) Real Marginal Cost Proxies and Lags/Leads of π_t



Note: Data is sourced from the enhanced Industrial Trends Survey (ITS) and ONS official statistics. Question 11 of the enhanced ITS which asks “excluding seasonal variations, what has been the trend over the past three months [...], with regard to average costs per unit of output”, while question 8 asks “excluding seasonal variations, what has been the trend over the past three months [...], with regard to volume of output (i.e. production)”. Note the enhanced ITS is missing firm responses from two-digit SIC07 levels 5, 6, 11, 21, 31 and 33. Firm survey responses are available from 2000Q1.

- where no clear overall result can be derived. However, note that the direct measure $(\phi_t - \overline{\phi})$ introduced is highly correlated with the deviation of real unit labour costs from it’s steady-state. This further reinforces the strength of the new direct measure introduced in this paper, as it is closely aligned with an existing proxy which has found ready acceptance in the literature.

4 Results

4.1 Estimation Strategy

Following (among others) Galı and Gertler (1999), Jordi Galı et al. (2005), Jondeau and Le Bihan (2005), Brissimis and Magginas (2005), Fuhrer (2012), Nunes (2012) and Aristidou (2018), hybrid versions of Equation 15 and Equation 14 are estimated using Generalised Method of Moments (GMM) for the UK manufacturing sector from 2000Q1 to 2021Q3 - with the results presented in Table 2 to Table 7. Each table presents coefficient estimates (with standard errors in brackets), the number of observations, the Lag Truncation Parameter (LTP) for the Heteroskedasticity and Autocorrelation Consistent (HAC) Newey-West weighting matrix[24] and diagnostic tests. The instrument set, based on Galı and Gertler (1999) and later reinforced by Jordi Galı et al. (2005), includes four lags of realised inflation, one-period ahead expected inflation, the forcing variable[25], the output gap, wage inflation, consumer price inflation and the long-short interest rate spread[26]. In the case of Equation 14, λ_{t-1}, λ_{t-2}, $E_{t-1}\lambda_t$ and $E_{t-2}\lambda_{t-1}$ are also included as instruments. Note that each instrument is dated at period $t-1$ and earlier to allow for the possibility of serially correlated errors.

Reported diagnostic tests include the Arellano-Bond test for autocorrelation (m1 and m2), the Hansen J-Statistic and Shea Adjusted partial R^2. In all estimates presented, the Arellano-Bond test for autocorrelation rejects serial correlation. The purpose of these last two diagnostic tests is to determine if the instrument set is relevant (i.e. instruments are correlated with endogenous variables) and valid (i.e. instruments are uncorrelated with the errors). The Hansen J-Statistic tests the validity of the instruments. For all estimates presented, the p-value of the Hansen J-Statistic shows the overidentifying restrictions are not rejected (i.e. the null hypothesis that the instruments are uncorrelated with the

[24] The LTP is set to 3, which (following Greene (2018)) equals $T^{\frac{1}{3}}$ - where T is the sample size.

[25] Specifically, either the direct (log) deviation of real marginal costs from it's steady-state $\left(\phi_t - \overline{\phi}\right)$, the unemployment recession gap ($urec_t$) or the deviation of real labour share of income (s_t), real unit labour costs ($rulc_t$) and the vacancy-to-unemployment ratio ($vacu_t$) from their respective steady-state values.

[26] Additional data for the instruments is sourced from the ONS EARN03 average weekly earnings and D7BT CPI and the Bank of England

errors fails to be rejected). To examine the relevancy of the instrument set, the Shea Adjusted partial R^2 for each endogenous variable is supplied. This takes a value between zero and one - with values close to zero indicating weak instruments. The problem of weak instruments in estimating the NKPC has been identified by Mavroeidis et al. (2014), Abbas et al. (2016) and Aristidou (2018) among others. In none of the estimates presented are the Shea Adjusted partial R^2's close to zero, providing strong evidence that the instrument set is relevant.

Table 2 to Table 7 follow the same standard layout - columns one to six present estimates of the hybrid New Keynesian Phillips Curve, where the difference in each column is the forcing variable. Section A also presents coefficient estimates of the hybrid versions of Equation 15 and Equation 14 for the disaggregate primary and secondary manufacturing sectors.

4.2 Estimating the Standard New Keynesian Phillips Curve

Table 2: GMM Estimates of Equation 15 (Hybrid) (Total Manufacturing)

Inflation (Total), π_t^{total}	(1) Coeff./SE	(2) Coeff./SE	(3) Coeff./SE	(4) Coeff./SE	(5) Coeff./SE	(6) Coeff./SE
Expected Inflation (Total), $E_t\pi_{t+1}^{total}$	0.434***	0.287***	0.425***	0.402***	0.495***	0.356***
	(0.07)	(0.07)	(0.07)	(0.06)	(0.06)	(0.07)
Marginal Cost Deviation (Total), $\phi_t^{total} - \bar{\phi}^{total}$	0.028***					
	(0.00)					
Lag Inflation (Total), π_{t-1}^{total}	0.235***	0.286***	0.215***	0.264***	0.195***	0.257***
	(0.05)	(0.05)	(0.05)	(0.05)	(0.04)	(0.04)
Output Gap HP (Total), $y_t^{total} - \bar{y_t}^{total}$		-0.005				
		(0.03)				
Labour Share Deviation, $s_t - \bar{s}$			0.086***			
			(0.02)			
Real Unit Labour Cost Deviation, $ulc_t - \bar{ulc}$				0.023***		
				(0.01)		
Unemployment Recession Gap (All)					0.410***	
					(0.08)	
Vacancy-to-Unemployment Ratio						0.091
						(0.06)
Constant	0.003**	0.002*	0.001	0.002	-0.002	0.002
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Observations	81	81	81	81	81	77
Newey-West (LTP)	3	3	3	3	3	3
m1	0.69	0.47	0.59	0.66	0.54	0.38
m2	0.10	0.15	0.08	0.11	0.09	0.21
Hansen P-Value	0.85	0.82	0.85	0.87	0.90	0.92
Expected Inflation Shea Adj. Partial R^2	0.33	0.30	0.32	0.46	0.43	0.50
RMC Shea Adj. Partial R^2	0.92	0.12	0.78	0.93	0.94	0.91
Exp. Infl. ≤ 1	1.00	1.00	1.00	1.00	1.00	1.00

The instrument set includes four lags of realised inflation, one-period ahead expected inflation, the forcing variable, the output gap, wage inflation, consumer price inflation and the long-short interest rate spread. Reported diagnostic tests include the Arellano-Bond test for autocorrelation (m1 and m2), the Hansen J-Statistic and Shea Adjusted partial R^2. Lag truncation parameter is 3. *p<0.1 **p<0.05 ***p<0.01

Table 2 presents the GMM estimates of Equation 15 for the total manufacturing sector. In all specifications across each industrial sector, the coefficient on $E_t\pi_{t+1}$ is positive (as expected) and statistically significant (at the 1% level). There is some variability in the coefficient estimates. For example, in the total manufacturing sector the specifications using the output gap and vacancy-to-unemployment ratio having the smallest $E_t\pi_{t+1}$ coefficient estimates (both less than 0.36, and in the case of the former less than 0.3). Specifications using the direct (log) real marginal costs (introduced in this paper), the real labour share of income, the real unit labour cost and the unemployment recession gap all have $E_t\pi_{t+1}$ coefficient estimates exceeding 0.4. As expected, the forward-looking nature of inflation dynamics is confirmed since the coefficient on $E_t\pi_{t+1}$ dominates the π_{t-1} coefficient in each specification.

The model specification of interest in Table 2 is column one, where the forcing variable is defined using the direct (log) real marginal costs (ϕ_t) introduced in this paper. The coefficients estimates of $(\phi_t - \overline{\phi})$ are positive (as expected) and statistically significant (at the 1% level). The output gap coefficient is statistically insignificant - a result in line with existing literature which has found the output gap to be either statistically insignificant or statistically significant but negative (in contrast to what is expected). The only other specification where the forcing variable is statistically insignificant is the vacancy-to-unemployment ratio. Aside from column five (where the forcing variable is the unemployment recession gap), the coefficients on each forcing variable are all fairly low (being less than 0.1). Thus, the coefficients estimates of $(\phi_t - \overline{\phi})$ are consistent with accepted proxies commonly found in the literature. In fact, this coefficient estimate is similar to the model specification using real unit labour costs. This consistency with the proxy variable coefficient estimates further reinforces the reliability of the direct (log) real marginal costs (ϕ_t) introduced in this paper. Therefore, the key takeaway from Table 2 is that in the main specification of interest (column one which uses the direct (log) marginal costs introduced in this paper), the coefficient estimate is statistically significant, has the correct sign and is a plausible size.

4.3 Estimating a New Keynesian Phillips Curve with Asynchronous Adjustments to Firm Prices

Section 4.2 discussed the first key contribution (and it's success in standard NKPC estimates) - namely, the direct (log) real marginal costs measure derived from underlying survey microdata. Table 3 presents the coefficient estimates of Equation 14, the second key contribution of this paper to the literature - the introduction of asynchronous

Table 3: GMM Estimates of Equation 14 (Hybrid) (Total Manufacturing)

Inflation (Total), π_t^{total}	(1) Coeff./SE	(2) Coeff./SE	(3) Coeff./SE	(4) Coeff./SE	(5) Coeff./SE	(6) Coeff./SE
Expected Inflation (Total), $E_t\pi_{t+1}^{total}$	0.570***	0.380***	0.477***	0.540***	0.558***	0.389***
	(0.07)	(0.06)	(0.07)	(0.07)	(0.07)	(0.06)
Marginal Cost Deviation (Total), $\phi_t^{total} - \bar{\phi}^{total}$	0.058***					
	(0.01)					
Lag Inflation (Total), π_{t-1}^{total}	0.197***	0.250***	0.194***	0.211***	0.158***	0.225***
	(0.05)	(0.04)	(0.05)	(0.05)	(0.04)	(0.04)
Output Gap HP (Total), $y_t^{total} - \bar{y_t}^{total}$		-0.030				
		(0.06)				
Labour Share Deviation (Total), $s_t - \bar{s}$			0.154***			
			(0.05)			
Real Unit Labour Cost Deviation (Total), $ulc_t - \bar{ulc}$				0.053***		
				(0.01)		
Unemployment Recession Gap (All) (Total)					0.422**	
					(0.19)	
Vacancy-to-Unemployment Ratio (Total)						0.373***
						(0.11)
Constant	0.002**	0.002**	0.001	0.001	-0.000	0.002***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Observations	81	81	81	81	81	77
Newey-West (LTP)	3	3	3	3	3	3
m1	0.84	0.53	0.54	0.66	0.48	0.33
m2	0.13	0.16	0.12	0.13	0.14	0.26
Hansen P-Value	0.95	0.95	0.93	0.95	0.95	0.97
Expected Inflation Shea Adj. Partial R^2	0.30	0.37	0.33	0.35	0.46	0.51
RMC Shea Adj. Partial R^2	0.81	0.09	0.77	0.82	0.82	0.86
Exp. Infl. ≤ 1	1.00	1.00	1.00	1.00	1.00	1.00

The instrument set includes λ_{t-1}, λ_{t-2}, t-1λ_t and t-2λ_{t-1} and four lags of realised inflation, one-period ahead expected inflation, the forcing variable, the output gap, wage inflation, consumer price inflation and the long-short interest rate spread. Reported diagnostic tests include the Arellano-Bond test for autocorrelation (m1 and m2), the Hansen J-Statistic and Shea Adjusted partial R^2. Lag truncation parameter is 3. *p<0.1 **p<0.05 ***p<0.01

adjustments to firm prices in the underlying microfoundations of the New Keynesian Model (based on observed firm behaviour). The coefficient estimates on the adjusted one-period ahead inflation expectations ($\frac{\lambda_t^p(1-E_t\lambda_{t+1}^p)}{(1-\lambda_t^p)E_t\lambda_{t+1}^p}E_t\pi_{t+1}$) and adjusted forcing variable ($\frac{\lambda_t^p}{1-\lambda_t^p}$ times the forcing variable) are statistically significant, have the correct sign and plausible values. As before, the output gap is typically statistically insignificant. The results of column one in Table 3 again reinforce the success of using in the forcing variable the new direct (log) real marginal costs measure introduced in this paper. Estimates of the asynchronous NKPC show that the $E_t\pi_{t+1}$ coefficient dominates the π_{t-1} coefficient - again demonstrating forward-looking inflation dynamics in the asynchronous NKPC.

How do the coefficient estimates from the standard NKPC compare to those from the NKPC with asynchronous adjustments to firm prices? In this comparison, note that the explanatory variables between the two models are different. In the standard New Keynesian Phillips Curve the explanatory variables are the one-period ahead inflation expectation ($E_t\pi_{t+1}$) and the forcing variable. However, with asynchronous adjustments to firm prices the explanatory variables now become the adjusted one-period ahead inflation expectation ($\frac{\lambda_t^p(1-E_t\lambda_{t+1}^p)}{(1-\lambda_t^p)E_t\lambda_{t+1}^p}E_t\pi_{t+1}$) and adjusted forcing variable ($\frac{\lambda_t^p}{1-\lambda_t^p}$ times the forcing variable). Comparing Table 3 with Table 2 it can be seen that the coefficient estimates from the NKPC with asynchronous adjustments to firm prices are higher than their standard counterparts - as expected. This reflects the better measurement of the NKPC by relaxing the assumption that a constant proportion of firms adjust prices each quarter. Incorporating asynchronous adjustments to firm prices directly captures the forward-looking nature of firms as they set their prices. This is particularly true in the case of (log) real marginal costs, which has become comparatively more important in explaining changes in realised inflation. This result also hold true for the specifications using marginal cost proxies - however, as these proxies contain noise or offer imprecise measurement they overcompensate for the forward-looking nature of firms. This again reinforces the importance of accurately measuring marginal costs, along the lines introduced in this paper. Thus, failing to properly account for the asynchronous adjustments to firm prices underestimates the two key drivers of inflation in the NKPC framework.

5 Conclusion

The purpose of this paper is twofold. First, to introduce asynchronous adjustments to firm prices into the microfoundations of the New Keynesian Model. This relaxes the (implicit) assumption that a constant proportion of firms adjust prices each period. This change is motivated by data presented in Section 3, which shows the variation in the proportion of firms adjusting their prices each quarter. As a result of altering the microfoundations, a new asynchronous NKPC is derived which directly incorporates the forward-looking nature of firms in its specification. This is an enhancement absent from standard NKPC specifications, which do not take into account that the proportion of firms adjusting prices each period can change (and thus do not properly reflect actual price setting behaviour of firms). Second, this paper introduces a new method of directly measuring marginal costs - which mitigates the need to rely on theoretically inconsistent or noisy proxies (such as the output gap). Furthermore, statistical tests presented in Section 3 confirm that this new direct marginal cost measure is a representative measure for all firms. The ability to directly measure marginal costs, ensures greater accuracy in estimating a key determinant of inflation.

Both of these innovations to the standard NKPC literature are possible due to a unique dataset of firm-level survey responses regarding changes to firm selling prices, output and average costs. Estimates of the standard NKPC using the direct measure of marginal costs as the forcing variable are successful - with coefficient estimates being statistically significant and correctly signed. Estimates of the asynchronous NKPC are also successful and indicate the importance of the forward-looking nature of firm price-setting behaviour. Furthermore, they show that expected inflation and the forcing variable have larger impacts on inflation than standard models realise. Results also show that (log) real marginal costs become comparatively more important in explaining inflation than in the standard NKPC. Finally, given the availability of data the methodology outlined in this paper can straightforwardly be applied to other countires in order to gain greater insights into inflation dynamics.

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A Disaggregated New Keynesian Phillips Curve Estimates

A subset of the time series literature examining the NKPC (for example Leith and Malley (2007) and Petrella and Santoro (2012)) estimate the NKPC at a sectoral level (as opposed to an aggregate level) so as to capture heterogeneity in price stickiness and mark-up over marginal cost. In addition, Abbas et al. (2016) argue that the NKPC fits the disaggregated data better than aggregated data - particularly, in estimating the forcing variable coefficient (which as discussed in Section 1 can be problematic). To examine this issue further, this appendix provides estimates of the standard and new asynchronous NKPC for the primary and secondary manufacturing sectors. Primary manufacturing is defined as mining and the wood, coke, rubber, base metals, machinery and other manufacturing subsectors[27] while secondary manufacturing is food, clothing, chemicals, computers, electrical equipment and transport equipment[28]. Total manufacturing is the sum of primary and secondary manufacturing. See Section E regarding this disaggregation choice.

Coefficient estimates of the hybrid versions of Equation 15 and Equation 14 for the disaggregate primary and secondary manufacturing sectors are presented in Table 4 to Table 7. In contrast to the arguments of Abbas et al. (2016), the forcing variable (in particular, the output gap) coefficients do not improve (i.e. become statistically significant and positive) compared to the total manufacturing sector. In fact, the key distinction between the coefficient estimates is the size of the $E_t\pi_{t+1}$ coefficient estimates. Irrespective of the model specification $\beta^{primary} > \beta^{total} > \beta^{secondary}$ - with $E_t\pi_{t+1}$ coefficient estimates in secondary manufacturing being noticeably small, while primary manufacturing $E_t\pi_{t+1}$ coefficient estimates are closer to the standard assumed value of 0.9 to 0.99. This is true in the case of both the standard and asynchronous NKPC specifications. These results confirm the success of the asynchronous NKPC specification and the direct measure of marginal costs in disaggregate sectoral estimates.

[27]Grouped SIC07 levels B, CC, CD, CG, CH CK and CM.

[28]Grouped SIC07 levels CA, CB, CE, CF , CI, CJ and CL

Table 4: GMM Estimates of Equation 15 (Hybrid) (Primary Manufacturing)

Inflation (Primary), $\pi_t^{primary}$	(1) Coeff./SE	(2) Coeff./SE	(3) Coeff./SE	(4) Coeff./SE	(5) Coeff./SE	(6) Coeff./SE	(7) Coeff./SE
Expected Inflation (Primary), $E_t\pi_{t+1}^{primary}$	0.395**	0.257*	0.257*	0.388***	0.409***	0.239	0.576***
	(0.15)	(0.14)	(0.14)	(0.14)	(0.14)	(0.16)	(0.13)
Marginal Cost Deviation (Primary), $\phi_t^{primary} - \bar{\phi}^{primary}$	0.030***						
	(0.01)						
Lag Inflation (Primary), $\pi_{t-1}^{primary}$	0.232***	0.237***	0.237***	0.212***	0.225***	0.235***	0.190***
	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.05)	(0.04)
Output Gap HP (Primary), $y_t^{primary} - \tilde{y_t}^{primary}$		0.047	0.047				
		(0.07)	(0.07)				
Labour Share Deviation, $s_t - \bar{s}$				0.137**			
				(0.06)			
Real Unit Labour Cost Deviation, $ulc_t - \bar{ulc}$					0.038***		
					(0.01)		
Unemployment Recession Gap (All)						0.624***	
						(0.16)	
Vacancy-to-Unemployment Ratio							0.120
							(0.09)
Constant	0.004***	0.003*	0.003*	0.003*	0.004*	0.001	0.002
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Observations	81	81	81	81	81	81	77
Newey-West (LTP)	3	3	3	3	3	3	3
m1	0.51	0.30	0.30	0.50	0.47	0.49	0.44
m2	0.11	0.15	0.15	0.08	0.11	0.09	0.19
Hansen P-Value	0.86	0.84	0.84	0.83	0.87	0.86	0.90
Expected Inflation Shea Adj. Partial R^2	0.19	0.18	0.18	0.17	0.22	0.19	0.49
RMC Shea Adj. Partial R^2	0.95	0.07	0.07	0.78	0.94	0.93	0.89
Exp. Infl. ≤ 1	1.00	1.00	1.00	1.00	1.00	1.00	1.00

The instrument set includes four lags of realised inflation, one-period ahead expected inflation, the forcing variable, the output gap, wage inflation, consumer price inflation and the long-short interest rate spread. Reported diagnostic tests include the Arellano-Bond test for autocorrelation (m1 and m2), the Hansen J-Statistic and Shea Adjusted partial R^2. Lag truncation parameter is 3. Primary manufacturing is mining and the wood, coke, rubber, base metals, machinery and other manufacturing subsectors (i.e.Grouped SIC07 levels B, CC, CD, CG, CH CK and CM). *p<0.1 **p<0.05 ***p<0.01

Table 5: GMM Estimates of Equation 15 (Hybrid) (Secondary Manufacturing)

Inflation (Secondary), $\pi_t^{secondary}$	(1) Coeff./SE	(2) Coeff./SE	(3) Coeff./SE	(4) Coeff./SE	(5) Coeff./SE	(6) Coeff./SE
Expected Inflation (Secondary), $E_t\pi_{t+1}^{secondary}$	0.145***	0.123***	0.176***	0.166***	0.178***	0.137***
	(0.02)	(0.02)	(0.03)	(0.02)	(0.02)	(0.02)
Marginal Cost Deviation (Secondary), $\phi_t^{secondary} - \bar{\phi}^{secondary}$	0.007***					
	(0.00)					
Lag Inflation (Secondary), $\pi_{t-1}^{secondary}$	0.523***	0.546***	0.484***	0.543***	0.479***	0.538***
	(0.03)	(0.04)	(0.04)	(0.03)	(0.04)	(0.04)
Output Gap HP (Secondary), $y_t^{secondary} - \tilde{y_t}^{secondary}$		-0.004				
		(0.01)				
Labour Share Deviation, $s_t - \bar{s}$			0.029***			
			(0.01)			
Real Unit Labour Cost Deviation, $ulc_t - \bar{ulc}$				0.004***		
				(0.00)		
Unemployment Recession Gap (All)					0.024	
					(0.03)	
Vacancy-to-Unemployment Ratio						0.004
						(0.01)
Constant	0.001***	0.001***	0.001***	0.001***	0.001**	0.001***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Observations	81	81	81	81	81	77
Newey-West (LTP)	3	3	3	3	3	3
m1	0.19	0.39	0.20	0.21	0.43	0.41
m2	0.65	0.92	0.69	0.81	0.99	0.92
Hansen P-Value	0.89	0.89	0.87	0.89	0.86	0.92
Expected Inflation Shea Adj. Partial R^2	0.13	0.15	0.06	0.18	0.37	0.28
RMC Shea Adj. Partial R^2	0.86	0.25	0.66	0.87	0.93	0.92
Exp. Infl. ≤ 1	1.00	1.00	1.00	1.00	1.00	1.00

The instrument set includes four lags of realised inflation, one-period ahead expected inflation, the forcing variable, the output gap, wage inflation, consumer price inflation and the long-short interest rate spread. Reported diagnostic tests include the Arellano-Bond test for autocorrelation (m1 and m2), the Hansen J-Statistic and Shea Adjusted partial R^2. Lag truncation parameter is 3. Secondary manufacturing is food, clothing, chemicals, computers, electrical equipment and transport equipment (i.e. Grouped SIC07 levels CA, CB, CE, CF , CI, CJ and CL). *p<0.1 **p<0.05 ***p<0.01

Table 6: GMM Estimates of Equation 14 (Hybrid) (Primary Manufacturing)

Inflation (Primary), $\pi_t^{primary}$	(1) Coeff./SE	(2) Coeff./SE	(3) Coeff./SE	(4) Coeff./SE	(5) Coeff./SE	(6) Coeff./SE
Expected Inflation (Primary), $E_t\pi_{t+1}^{primary}$	0.761***	0.511***	0.795***	0.890***	0.817***	0.774***
	(0.13)	(0.14)	(0.10)	(0.11)	(0.09)	(0.10)
Marginal Cost Deviation (Primary), $\phi_t^{primary} - \bar{\phi}^{primary}$	0.047***					
	(0.02)					
Lag Inflation (Primary), $\pi_{t-1}^{primary}$	0.141***	0.105**	0.124***	0.102**	0.091**	0.086**
	(0.04)	(0.05)	(0.04)	(0.04)	(0.04)	(0.03)
Output Gap HP (Primary), $y_t^{primary} - \tilde{y_t}^{primary}$		0.251***				
		(0.07)				
Labour Share Deviation (Primary), $s_t - \bar{s}$			0.235**			
			(0.09)			
Real Unit Labour Cost Deviation (Primary), $ulc_t - \bar{ulc}$				0.081***		
				(0.02)		
Unemployment Recession Gap (All) (Primary)					0.526*	
					(0.30)	
Vacancy-to-Unemployment Ratio (Primary)						0.525***
						(0.19)
Constant	0.002	0.002	-0.000	0.000	-0.001	0.001
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Observations	81	81	81	81	81	77
Newey-West (LTP)	3	3	3	3	3	3
m1	0.52	0.10	0.54	0.47	0.38	0.32
m2	0.14	0.25	0.11	0.14	0.14	0.29
Hansen P-Value	0.95	0.95	0.95	0.95	0.94	0.97
Expected Inflation Shea Adj. Partial R^2	0.08	0.06	0.04	0.03	0.06	0.35
RMC Shea Adj. Partial R^2	0.73	0.04	0.66	0.72	0.76	0.68
Exp. Infl. ≤ 1	0.97	1.00	0.98	0.83	0.98	0.99

The instrument set includes λ_{t-1}, λ_{t-2}, t-1λ_t and t-2λ_{t-1} and four lags of realised inflation, one-period ahead expected inflation, the forcing variable, the output gap, wage inflation, consumer price inflation and the long-short interest rate spread. Reported diagnostic tests include the Arellano-Bond test for autocorrelation (m1 and m2), the Hansen J-Statistic and Shea Adjusted partial R^2. Lag truncation parameter is 3. Primary manufacturing is mining and the wood, coke, rubber, base metals, machinery and other manufacturing subsectors (i.e.Grouped SIC07 levels B, CC, CD, CG, CH CK and CM). *p<0.1 **p<0.05 ***p<0.01

Table 7: GMM Estimates of Equation 14 (Hybrid) (Secondary Manufacturing)

Inflation (Secondary), $\pi_t^{secondary}$	(1) Coeff./SE	(2) Coeff./SE	(3) Coeff./SE	(4) Coeff./SE	(5) Coeff./SE	(6) Coeff./SE
Expected Inflation (Secondary), $E_t\pi_{t+1}^{secondary}$	0.174***	0.133***	0.202***	0.182***	0.180***	0.135***
	(0.02)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)
Marginal Cost Deviation (Secondary), $\phi_t^{secondary} - \bar{\phi}^{secondary}$	0.016***					
	(0.00)					
Lag Inflation (Secondary), $\pi_{t-1}^{secondary}$	0.500***	0.521***	0.454***	0.520***	0.450***	0.541***
	(0.03)	(0.04)	(0.03)	(0.04)	(0.05)	(0.04)
Output Gap HP (Secondary), $y_t^{secondary} - \tilde{y_t}^{secondary}$		0.000				
		(0.02)				
Labour Share Deviation (Secondary), $s_t - \bar{s}$			0.069***			
			(0.01)			
Real Unit Labour Cost Deviation (Secondary), $ulc_t - \bar{ulc}$				0.007***		
				(0.00)		
Unemployment Recession Gap (All) (Secondary)					0.090	
					(0.06)	
Vacancy-to-Unemployment Ratio (Secondary)						0.007
						(0.02)
Constant	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Observations	81	81	81	81	81	77
Newey-West (LTP)	3	3	3	3	3	3
m1	0.08	0.31	0.06	0.12	0.21	0.25
m2	0.88	0.72	0.82	0.92	0.68	0.91
Hansen P-Value	0.96	0.96	0.95	0.95	0.94	0.95
Expected Inflation Shea Adj. Partial R^2	0.17	0.23	0.24	0.23	0.43	0.39
RMC Shea Adj. Partial R^2	0.75	0.32	0.74	0.81	0.69	0.88
Exp. Infl. ≤ 1	1.00	1.00	1.00	1.00	1.00	1.00

The instrument set includes λ_{t-1}, λ_{t-2}, t-1λ_t and t-2λ_{t-1} and four lags of realised inflation, one-period ahead expected inflation, the forcing variable, the output gap, wage inflation, consumer price inflation and the long-short interest rate spread. Reported diagnostic tests include the Arellano-Bond test for autocorrelation (m1 and m2), the Hansen J-Statistic and Shea Adjusted partial R^2. Lag truncation parameter is 3. Secondary manufacturing is food, clothing, chemicals, computers, electrical equipment and transport equipment (i.e. Grouped SIC07 levels CA, CB, CE, CF , CI, CJ and CL). *p<0.1 **p<0.05 ***p<0.01

B Mathematical Appendix

B.1 Deriving Equation 3

Note the intermediate goods firm maximisation problem (Equation 2) can be rewritten as Equation 34.

$$maxP_t\left(\int_0^1 Y_t(i)^{\frac{\varepsilon-1}{\varepsilon}}di\right)^{\frac{\varepsilon}{\varepsilon-1}} - \int_0^1 P_t(i)Y_t(i)di \tag{18}$$

where the constraint (Equation 1) is substituted directly into the maximisation problem. Differentiating with respect to $Y_t(i)$ yields:

$$P_t(i) = P_t\left(\int_0^1 Y_t(i)^{\frac{\varepsilon-1}{\varepsilon}}di\right)^{\frac{1}{\varepsilon-1}} Y_t(i)^{-\frac{1}{\varepsilon}} \tag{19}$$

This also holds true for good j:

$$P_t(j) = P_t\left(\int_0^1 Y_t(j)^{\frac{\varepsilon-1}{\varepsilon}}dj\right)^{\frac{1}{\varepsilon-1}} Y_t(j)^{-\frac{1}{\varepsilon}} \tag{20}$$

Then:

$$\frac{P_t(i)}{P_t(j)} = \frac{P_t(\int_0^1 Y_t(i)^{\frac{\varepsilon-1}{\varepsilon}}di)^{\frac{1}{\varepsilon-1}}Y_t(i)^{-\frac{1}{\varepsilon}}}{P_t(\int_0^1 Y_t(j)^{\frac{\varepsilon-1}{\varepsilon}}dj)^{\frac{1}{\varepsilon-1}}Y_t(j)^{-\frac{1}{\varepsilon}}} \tag{21}$$

which can be rewritten as Equation 22:

$$P_tY_t^{\frac{1}{\varepsilon}}Y_t(j)^{-\frac{1}{\varepsilon}}P_t(i) = P_tY_t^{\frac{1}{\varepsilon}}Y_t(i)^{-\frac{1}{\varepsilon}}P_t(j) \tag{22}$$

by noting that Equation 1 can be rewritten as:

$$Y_t^{\frac{1}{\varepsilon}} = \left(\int_0^1 Y_t(i)^{\frac{\varepsilon-1}{\varepsilon}}di\right)^{\frac{1}{\varepsilon-1}} \tag{23}$$

Multiply the LHS and RHS of Equation 22 by $Y_t(j)Y_t(i)^{\frac{1}{\varepsilon}}$, integrate out good j and note that Equation 1 can be rewritten as:

$$Y_t^{\frac{\varepsilon-1}{\varepsilon}} = \int_0^1 Y_t(i)^{\frac{\varepsilon-1}{\varepsilon}}di \tag{24}$$

to obtain Equation 25:

$$\int_0^1 P_t(j)Y_t(j)dj = P_t(i)Y_t(i)^{\frac{1}{\varepsilon}}Y_t^{\frac{-1}{\varepsilon}} \tag{25}$$

To remove the integral from Equation 25, first note that:

$$\begin{aligned}
\int_0^1 P_t(j)Y_t(j)dj &= \int_0^1 P_t\left(\int_0^1 Y_t(j)^{\frac{\varepsilon-1}{\varepsilon}}di\right)^{\frac{1}{\varepsilon-1}} Y_t(j)^{\frac{\varepsilon-1}{\varepsilon}}dj \\
&= \int_0^1 P_t Y_t^{\frac{1}{\varepsilon}} Y_t(j)^{\frac{\varepsilon-1}{\varepsilon}}dj \\
&= P_t Y_t^{\frac{1}{\varepsilon}} \int_0^1 Y_t(j)^{\frac{\varepsilon-1}{\varepsilon}}dj \\
&= P_t Y_t^{\frac{1}{\varepsilon}} Y_t^{\frac{\varepsilon-1}{\varepsilon}} \\
&= P_t Y_t
\end{aligned} \tag{26}$$

Substituting into Equation 25 yields Equation 27:

$$P_tY_t = P_t(i)Y_t(i)^{\frac{1}{\varepsilon}}Y_t^{\frac{\varepsilon-1}{\varepsilon}} \tag{27}$$

Multiplying the LHS and RHS of Equation 27 by $Y_t^{\frac{1-\varepsilon}{\varepsilon}}$, then take LHS and RHS to the power ε and a small minor algebraic manipulation yields Equation 3.

B.2 Deriving Equation 4

To derive the aggregate price level, recall that:

$$P_tY_t = \int_0^1 P_t(i)Y_t(i)di \tag{28}$$

Substituting in Equation 3, this becomes:

$$\int_0^1 P_t(i)\left(\frac{P_t(i)}{P_t}\right)^{-\varepsilon} Y_tdi = P_t^{\varepsilon}Y_t \int_0^1 P_t(i)P_t(i)^{-\varepsilon}di \tag{29}$$

Minor algebraic adjustment yields Equation 4.

B.3 Deriving Equation 6

Note the aggregate price level (Equation 4) can be rewritten as:

$$P_t^{1-\varepsilon} = \left(\int_0^1 P_t(i)^{1-\varepsilon} di\right) \tag{30}$$

Combining this with Equation 5 yields:

$$P_t = (\lambda_t^p Q_t^{1-\varepsilon} + (1-\lambda_t^p)P_{t-1}^{1-\varepsilon})^{\frac{1}{1-\varepsilon}} \tag{31}$$

Taking the LHS and RHS to the power $(1-\varepsilon)$ yields Equation 6.

B.4 Deriving Equation 7

Divide LHS and RHS of Equation 6 by $P_{t-1}^{1-\varepsilon}$ to obtain Equation 32.

$$\left(\frac{P_t}{P_{t-1}}\right)^{1-\varepsilon} = \lambda_t^p \left(\frac{Q_t}{P_{t-1}}\right)^{1-\varepsilon} + (1-\lambda_t^p) \tag{32}$$

Log-linearising Equation 32 around the zero-inflation steady-state[29] yields:

$$\begin{aligned} \Pi^{1-\varepsilon} + (1-\varepsilon)\Pi^{-\varepsilon}(\Pi)(log(\Pi_t) - log(\Pi)) = {} & ((1-\lambda_t^p) + \lambda_t^p(\frac{Q}{P})^{1-\varepsilon}) \\ & + (1-\varepsilon)(\lambda_t^p)(\frac{Q}{P})^{-\varepsilon}\frac{1}{P}Q(log(Q_t) - log(Q)) \\ & - (1-\varepsilon)(\lambda_t^p)(\frac{Q}{P})^{-\varepsilon}\frac{Q}{P^2}P(log(P_{t-1}) - log(P)) \end{aligned} \tag{33}$$

Collection of like terms and cleaning yields Equation 7.

B.5 Deriving Equation 13

Substitute Equation 11 and Equation 12 into Equation 10 to obtain Equation 34

$$\begin{aligned} & max\left(\left(Q_t\left(\frac{Q_t}{P_t}\right)^{-\varepsilon}C_t - \Psi_t\left(\left(\frac{Q_t}{P_t}\right)^{-\varepsilon}C_t\right)\right)\right. \\ & \left. + E_t\sum_{k=1}^{\infty}\left(\prod_{j=1}^{k}(1-\lambda_{t+j}^p)\right)B_{t,t+k}^k\left(Q_t\left(\frac{Q_t}{P_{t+k}}\right)^{-\varepsilon}C_{t+k} - \Psi_{t+k}\left(\left(\frac{Q_t}{P_{t+k}}\right)^{-\varepsilon}C_{t+k}\right)\right)\right) \end{aligned} \tag{34}$$

[29] Zero-inflation steady-state denoted by no subscripts.

where $B_{t,t+k} = \beta^k \left(\frac{C_{t+k}}{C_t}\right)^{-\sigma} \frac{P_t}{P_{t+k}}$. Differentiate Equation 34 with respect to Q_t and collection of terms yields Equation 35.

$$Y_{t|t}(i)\left((1-\varepsilon)+\varepsilon\frac{1}{Q_t}\psi_{t|t}(i)\right)+E_t\sum_{k=1}^{\infty}\left(\prod_{j=1}^{k}(1-\lambda^p_{t+j})\right)B^k_{t,t+k}Y_{t+k|t}(i)\left((1-\varepsilon)+\varepsilon\frac{1}{Q_t}\psi_{t+k|t}(i)\right)=0 \tag{35}$$

where $\psi_{t|t}(i) = \Psi_t'(Y_{t|t}(i))$ and $\psi_{t+k|t}(i) = \Psi_{t+k}'(Y_{t+k|t}(i))$ are the (nominal) marginal costs. Multiply the LHS and RHS of Equation 35 by Q_t, divide by $(1-\varepsilon)$ and collect like terms to obtain Equation 36.

$$\begin{aligned} &Y_{t|t}(i)Q_t + E_t\sum_{k=1}^{\infty}\left(\prod_{j=1}^{k}(1-\lambda^p_{t+j})\right)B^k_{t,t+k}Y_{t+k|t}(i)Q_t \\ &\quad = \frac{\varepsilon}{\varepsilon-1}Y_{t|t}(i)\psi_{t|t}(i) + \frac{\varepsilon}{\varepsilon-1}E_t\sum_{k=1}^{\infty}\left(\prod_{j=1}^{k}(1-\lambda^p_{t+j})\right)B^k_{t,t+k}Y_{t+k|t}(i)\psi_{t+k|t}(i) \end{aligned} \tag{36}$$

Substitute expressions for $Y_{t|t}(i)$ and $B^k_{t,t+k}$ into Equation 36, note that $\left(\frac{C_t}{C_t}\right)^{-\sigma}\frac{P_t}{P_t} = 1$ and collect like terms to derive Equation 37.

$$\begin{aligned} &Q_t^{1-\varepsilon}C_t^{\sigma}P_t\left(C_t^{1-\sigma}P_t^{\varepsilon-1} + E_t\sum_{k=1}^{\infty}\left(\prod_{j=1}^{k}(1-\lambda^p_{t+j})\right)\beta^k C_{t+k}^{1-\sigma}P_{t+k}^{\varepsilon-1}\right) \\ &\quad = Q_t^{-\varepsilon}C_t^{\sigma}P_t\frac{\varepsilon}{\varepsilon-1}\left(C_t^{1-\sigma}P_t^{\varepsilon-1}\psi_{t|t}(i) + E_t\sum_{k=1}^{\infty}\left(\prod_{j=1}^{k}(1-\lambda^p_{t+j})\right)\beta^k C_{t+k}^{1-\sigma}P_{t+k}^{\varepsilon-1}\psi_{t+k|t}(i)\right) \end{aligned} \tag{37}$$

Multiply the LHS and RHS of Equation 37 by Q_t^{ε} and collect like terms to obtain Equation 13.

B.6 Deriving Equation 14

Divide Equation 13 by P_{t-1} and minor algebraic manipulation to obtain Equation 38.

$$\begin{aligned} &\frac{Q_t}{P_{t-1}}\left(C_t^{1-\sigma}P_t^{\varepsilon-1} + E_t\sum_{k=1}^{\infty}\left(\prod_{j=1}^{k}(1-\lambda^p_{t+j})\right)\beta^k C_{t+k}^{1-\sigma}P_{t+k}^{\varepsilon-1}\right) \\ &\quad = \frac{\varepsilon}{\varepsilon-1}\left(C_t^{1-\sigma}P_t^{\varepsilon}\Phi_{t|t} + E_t\sum_{k=1}^{\infty}\left(\prod_{j=1}^{k}(1-\lambda^p_{t+j})\right)\beta^k C_{t+k}^{1-\sigma}P_{t+k}^{\varepsilon}\Phi_{t+k|t}\right)\frac{1}{P_{t-1}} \end{aligned} \tag{38}$$

Taking the first order Taylor Expansion of $\frac{Q_t}{P_{t-1}}$ and collecting terms yields Equation 39.

$$\begin{aligned} q_t = &-ln\left(\frac{\varepsilon-1}{\varepsilon}\right) \\ &+\frac{1}{1+E_t\sum_{k=1}^{\infty}\prod_{j=1}^{k}(1-\lambda_{t+j}^{p})\beta^k}\left((\phi_{t|t}+p_t)+E_t\sum_{k=1}^{\infty}\left(\prod_{j=1}^{k}(1-\lambda_{t+j}^{p})\right)\beta^k(\phi_{t+k|t}+p_{t+k})\right) \end{aligned} \tag{39}$$

In general, (nominal) marginal costs are defined per Equation 40.

$$\psi = \frac{\Delta VC_t}{\Delta Y_t} = \frac{W_t}{\Gamma_t} \tag{40}$$

where ΔVC_t and ΔY_t are the change in variable costs and output between period $t-1$ and t (respectively). The second equality arises using the substitution $\Delta VC_t = W_t \Delta L_t$, where W_t is the wage rate and ΔL_t is the change in labour between periods $t-1$ and t, and noting that the (nominal) marginal product of labour is $\Gamma_t = \frac{\Delta Y_t}{\Delta L_t}$. Thus, (nominal) marginal costs are defined as the ratio of the (nominal) cost of labour (W_t) to the (nominal) marginal product of labour (Γ_t). Real marginal cost (Φ_t) is defined in Equation 41, as the ratio of the (nominal) cost of labour (W_t) to the (nominal) marginal gain ($\Gamma_t P_t$).

$$\Phi_t = \frac{W_t}{\Gamma_t P_t} \tag{41}$$

Taking the (natural) log of Equation 41 yields Equation 42.

$$\phi_t = (w_t - \gamma_t) - p_t \tag{42}$$

where $\phi_t = ln(\Phi_t)$, $w_t = ln(W_t)$ and $\gamma_t = ln(\Gamma_t)$. To derive an explicit form for γ_t, consider the average production function $Y_t = A_t N_t^{1-\alpha}$ (where A_t is technology and N_t is labour). Then Equation 43 defines the marginal cost of labour.

$$\Gamma_t = \frac{\partial Y_t}{\partial N_t} = (1-\alpha)A_t N_t^{-\alpha} \tag{43}$$

Taking the (natural) of Equation 43 yields Equation 44.

$$\gamma_t = ln(1-\alpha) + a_t - \alpha n_t \tag{44}$$

where $n_t = ln(N_t)$. Substitute Equation 44 into Equation 42 to obtain Equation 45.

$$\phi_t = (w_t - ln(1-\alpha) - a_t + \alpha n_t) - p_t \tag{45}$$

Market clearing and equilibrium imply Equation 46.

$$n_t = \frac{y_t - a_t}{1-\alpha} \tag{46}$$

Substituting Equation 46 into Equation 45 and collect terms yields the economy's average real marginal cost (Equation 47).

$$\phi_t = (w_t - ln(1-\alpha) - \frac{a_t - \alpha y_t}{1-\alpha}) - p_t \tag{47}$$

Accordingly, Equation 48 defines the economy's average real marginal cost in $t+k$.

$$\phi_{t+k} = (w_{t+k} - ln(1-\alpha) - \frac{a_{t+k} - \alpha y_{t+k}}{1-\alpha}) - p_{t+k} \tag{48}$$

The firm's real marginal cost in $t+k$ is defined in Equation 49.

$$\phi_{t+k|t}(i) = (w_{t+k} - ln(1-\alpha) - \frac{a_{t+k} - \alpha y_{t+k|t}(i)}{1-\alpha}) - p_{t+k} \tag{49}$$

Subtracting Equation 48 from Equation 49 and collecting terms yields Equation 50 - an expression for individual firms' marginal cost as a function of the economy's average real marginal cost.

$$\phi_{t+k|t}(i) = \phi_{t+k} + \frac{\alpha}{1-\alpha}(y_{t+k|t}(i) - y_{t+k}) \tag{50}$$

Taking the (natural) log of the market-clearing condition $Y_{t+k|t} = \left(\frac{P_{t+k|t}}{P_{t+k}}\right)^{-\varepsilon} Y_{t+k}$ yields $y_{t+k|t} = -\varepsilon(p_{t+k|t} - p_{t+k}) + y_{t+k}$, which is substituted into Equation 50 and after collecting terms yields Equation 51.

$$\phi_{t+k|t}(i) = \phi_{t+k} - \varepsilon\frac{\alpha}{1-\alpha}(q_t - p_{t+k}) \tag{51}$$

Equation 51 is substituted into Equation 39 which after collecting terms and adding and subtracting $\left(1-\frac{1-\alpha}{1-\alpha(1-\varepsilon)}p_{t-1}\right)$ yields Equation 52.

$$\begin{aligned}
&q_t - p_{t-1} = \\
&\tfrac{1}{1+E_t\sum_{k=1}^{\infty}\left(\prod_{j=1}^{k}(1-\lambda^p_{t+j})\right)\beta^k}\tfrac{1-\alpha}{1-\alpha(1-\varepsilon)}\left(\left(\phi_t - ln\left(\tfrac{\varepsilon-1}{\varepsilon}\right)\right)+E_t\sum_{k=1}^{\infty}\left(\prod_{j=1}^{k}(1-\lambda^p_{t+j})\right)\beta^k\left(\phi_{t+k}-ln\left(\tfrac{\varepsilon-1}{\varepsilon}\right)\right)\right) \\
&+\tfrac{1}{1+E_t\sum_{k=1}^{\infty}\left(\prod_{j=1}^{k}(1-\lambda^p_{t+j})\right)\beta^k}\left((p_t-p_{t-1})+E_t\sum_{k=1}^{\infty}\left(\prod_{j=1}^{k}(1-\lambda^p_{t+j})\right)\beta^k(p_{t+k}-p_{t-1})\right)
\end{aligned} \tag{52}$$

For tractability assume $E_t\lambda^p_{t+1} = E_t\lambda^p_{t+2} = E_t\lambda^p_{t+3} = ... = E_t\lambda^p_{t+j} = ...$ as $j \to \infty$. Then $E_t\sum_{k=1}^{\infty}\left(\prod_{j=1}^{k}(1-\lambda^p_{t+j})\right)\beta^k = E_t\sum_{k=1}^{\infty}((1-\lambda^p_{t+1})\beta)^k = E_t\sum_{k=0}^{\infty}((1-\lambda^p_{t+1})\beta)^k - 1 = \frac{1}{1-(1-E_t\lambda^p_{t+1})\beta} - 1 = \frac{(1-E_t\lambda^p_{t+1})\beta}{1-(1-E_t\lambda^p_{t+1})\beta}$. Thus Equation 52 becomes Equation 53.

$$\begin{aligned}
q_t - p_{t-1} = (1-(1-E_t\lambda^p_{t+1})\beta)\frac{1-\alpha}{1-\alpha(1-\varepsilon)}E_t\sum_{k=0}^{\infty}((1-\lambda^p_{t+1})\beta)^k\left(\phi_{t+k}-ln\left(\frac{\varepsilon-1}{\varepsilon}\right)\right) \\
+(1-(1-E_t\lambda^p_{t+1})\beta)E_t\sum_{k=0}^{\infty}((1-\lambda^p_{t+1})\beta)^k(p_{t+k}-p_{t-1})
\end{aligned} \tag{53}$$

Note the second component on the RHS of Equation 53 can be written as $E_t\sum_{k=0}^{\infty}((1-\lambda^p_{t+1})\beta)^k\pi_{t+k}$, by successively adding and subtracting lagged values of p_{t+k} $\forall k$. This is substituted into Equation 53, which is then rewritten as Equation 54.

$$\begin{aligned}
q_t - p_{t-1} = (1-(1-E_t\lambda^p_{t+1})\beta)\frac{1-\alpha}{1-\alpha(1-\varepsilon)}\left(E_t\sum_{k=1}^{\infty}((1-\lambda^p_{t+1})\beta)^k\left(\phi_{t+k}-ln\left(\frac{\varepsilon-1}{\varepsilon}\right)\right)\right) \\
+E_t\sum_{k=1}^{\infty}((1-\lambda^p_{t+1})\beta)^k\pi_{t+k}+(1-(1-E_t\lambda^p_{t+1})\beta)\frac{1-\alpha}{1-\alpha(1-\varepsilon)}\left(\phi_t-ln\left(\frac{\varepsilon-1}{\varepsilon}\right)\right)+\pi_t
\end{aligned} \tag{54}$$

By noting the first two components on the RHS of Equation 54 can be rewritten as $(1-E_t\lambda^p_{t+1})\beta E_t(q_{t+1}-p_t)$ and manipulating Equation 7, Equation 14 is obtained.

C Converting Old Classifications into SIC07

C.1 Conversion in the ITS

SIC80 is the primary means of recording industrial classification in the ITS. Using Stata code provided by Jennifer Smith (University of Warwick)[30], the 4 digit SIC80 is converted to 2 digit SIC92 - which in turn is converted to 2 digit SIC07[31].

There are a number of instances where the 4 digit SIC80 has not been correctly recorded - these need correcting before conversion to 2 digit SIC92. Some corrections are solved by examining the database directly. For example, firms which have SIC80 recorded as 1.1 are also recorded as having industrial classification 4196 (bread and flour confectionery). Thus, instances where SIC80 is recorded as 1.1 is corrected to 4196. Some corrections are solved thanks to the conversion process. For example, some firms are recorded with industrial classification 247 - which could be 2471, 2478 or 2479 in the 4 digit SIC80. However, each of these 4 digit classifications is converted to the same 2 digit SIC92 (26 manufacture of other non-metallic mineral products). Unfortunately, some corrections cannot be solved. For example, some firms are recorded with industrial classification 223 - which could be 2234 or 2235 in the 4 digit SIC80, both of which have different conversions to 2 digit SIC92. However, only 0.67% of survey responses cannot be corrected to allow an accurate conversion to 2 digit SIC92.

Thus, the 4 digit SIC80 in the ITS is converted to 2 digit SIC92 which is then converted to 2 digit SIC07. The 2 digit SIC07 levels in the ITS are:

- 7 Mining of metal ores
- 8 Other mining and quarrying
- 9 Mining support service activities
- 10 Manufacture of food products
- 12 Manufacture of tobacco products

[30]Available from: https://warwick.ac.uk/fac/soc/economics/staff/jcsmith/sicmapping/

[31]Converting the 2 digit SIC92 to 2 digit SIC07 relies on the fact that SIC03 is essentially identical to SIC92 at the 3-digit aggregation level and above. I have used SIC03 as a proxy for SIC92.

- 13 Manufacture of textiles
- 14 Manufacture of wearing apparel
- 15 Manufacture of leather and related products
- 16 Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
- 17 Manufacture of paper and paper products
- 18 Printing and reproduction of recorded media
- 19 Manufacture of coke and refined petroleum products
- 20 Manufacture of chemicals and chemical products
- 22 Manufacture of rubber and plastic products
- 23 Manufacture of other non-metallic mineral products
- 24 Manufacture of basic metals
- 25 Manufacture of fabricated metal products, except machinery and equipment
- 26 Manufacture of computer, electronic and optical products
- 27 Manufacture of electrical equipment
- 28 Manufacture of machinery and equipment (not elsewhere classified)
- 29 Manufacture of motor vehicles, trailers and semi-trailers
- 30 Manufacture of other transport equipment
- 32 Other manufacturing
- 43 Specialised construction activities
- 46 Wholesale trade, except of motor vehicles and motorcycles
- 70 Activities of head offices; management consultancy activities
- 86 Human health activities

Alternatively, the grouped SIC07 levels in the ITS are:

- B Mining and quarrying[32]
- CA Manufacture of food products, beverages and tobacco[33]
- CB Manufacture of textiles, wearing apparel and leather products[34]
- CC Manufacture of wood and paper products, and printing[35]
- CD Manufacture of coke, and refined petroleum products[36]
- CE Manufacture of chemicals and chemical products[37]
- CG Manufacture of rubber and plastic products, and other non-metallic mineral products[38]
- CH Manufacture of basic metals and metal products[39]
- CI Manufacture of computer, electronic and optical products[40]
- CJ Manufacture of electrical equipment[41]
- CK Manufacture of machinery and equipment not elsewhere classified[42]
- CL Manufacture of transport equipment[43]

[32] Consists of 7 (mining of metal ores), 8 (other mining and quarrying) and 9 (mining support service activities).

[33] Consists of 10 (manufacture of food products), 11 (manufacture of beverages) and 12 (manufacture of tobacco products). Note there are no firms with SIC07 11 in the ITS.

[34] Consists of 13 (manufacture of textiles), 14 (manufacture of wearing apparel) and 15 (manufacture of leather and related products).

[35] Consists of 16 (manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials), 17 (manufacture of paper and paper products) and 18 (printing and reproduction of recorded media).

[36] Consists of 19 (manufacture of coke and refined petroleum products).

[37] Consists of 20 (manufacture of chemicals and chemical products).

[38] Consists of 22 (manufacture of rubber and plastic products) and 23 (manufacture of other non-metallic mineral products).

[39] Consists of 24 (manufacture of basic metals) and 25 (manufacture of fabricated metal products, except machinery and equipment).

[40] Consists of 26 (manufacture of computer, electronic and optical products).

[41] Consists of 27 (manufacture of electrical equipment).

[42] Consists of 28 (manufacture of machinery and equipment (not elsewhere classified)).

[43] Consists of 29 (manufacture of motor vehicles, trailers and semi-trailers) and 30 (manufacture of other transport equipment).

- CM Other manufacturing[44]
- F Construction[45]
- G Wholesale and retail trade and repair of motor vehicles and motorcycles[46]
- MA Legal, accounting, management, architecture, engineering, technical testing activities[47]
- QA Human health activities[48]

C.2 Conversion in the SSS

SIC92 is the primary means of recording industrial classification in the SSS. As with the ITS, the SIC92 is converted to 2 digit SIC07. In contrast to the SIC80 in the ITS there are no inconsistencies in the recording of SIC92 in the SSS which need correcting. Thus, the 4 digit SIC92 in the SSS are converted to 2 digit SIC07. The 2 digit SIC07 levels in the SSS are:

- 49 Land transport and transport via pipelines
- 50 Water transport
- 51 Air transport
- 52 Warehousing and support activities for transportation
- 53 Postal and courier activities
- 56 Food and beverage service activities
- 62 Computer programming, consultancy and related activities
- 68 Real estate activities

[44] Consists of 31 (manufacture of furniture), 32 (other manufacturing) and 33 (repair and installation of machinery and equipment). Note there are no firms with SIC07 31 or 33 in the ITS.

[45] Consists of 41 (construction of buildings), 42 (civil engineering) and 43 (specialised construction activities). Note there are no firms with SIC07 41 or 42 in the ITS.

[46] In this instance corresponds with 46 (wholesale trade, except of motor vehicles and motorcycles).

[47] In this instance corresponds with 70 (activities of head offices; management consultancy activities).

[48] In this instance corresponds with 86 (human health activities).

- 70 Activities of head offices; management consultancy activities
- 77 Rental and leasing activities
- 86 Human health activities
- 90 Creative, arts and entertainment activities
- 96 Other personal service activities

Alternatively, the grouped SIC07 levels in the SSS are:

- H Transportation and storage[49]
- I Accommodation and food service activities[50]
- JC IT and other information service activities[51]
- L Real estate activities[52]
- MA Legal, accounting, management, architecture, engineering, technical testing activities[53]
- N Administrative and support service activities[54]
- QA Human health activities[55]
- R Arts, entrainment and recreation[56]

[49]Consists of 49 (land transport and transport via pipelines), 50 (water transport), 51 (air transport), 52 (warehousing and support activities for transportation) and 53 (postal and courier activities).

[50]Consists of 55 (accommodation) and 56 (food and beverage service activities). Note there are no firms with SIC07 55 in the SSS.

[51]Consists of 62 (computer programming, consultancy and related activities) and 63 (information service activities). Note there are no firms with SIC07 63 in the SSS.

[52]Consists of 68 (real estate activities).

[53]Consists of 69 (legal and accounting activities), 70 (activities of head offices; management consultancy activities) and 71 (architectural and engineering activities; technical testing and analysis). Note there are no firms with SIC07 69 or 71 in the SSS.

[54]Consists of 77 (rental and leasing activities), 78 (employment activities), 79 (travel agency, tour operator and other reservation service and related activities), 80 (security and investigation activities), 81 (services to buildings and landscape activities) and 82 (office administrative, office support and other business support activities). Note there are no firms with SIC07 78, 79, 80, 81 or 82 in the SSS.

[55]Consists of 86 (human health activities).

[56]Consists of 90 (creative, arts and entertainment activities), 91 (libraries, archives, museums and other cultural activities), 92 (gambling and betting activities) and 93 (sports activities and amusement and recreation activities). Note there are no firms with SIC07 91, 92 or 93 in the SSS.

- S Other service activities[57]

C.3 Conversion in the DTS

SIC07 is the primary means of recording industrial classification in the DTS. Thus, no conversion is needed. The 2 digit SIC07 levels in the DTS are:

- 45 Wholesale and retail trade and repair of motor vehicles and motorcycles
- 46 Wholesale trade, except of motor vehicles and motorcycles
- 47 Retail trade, except of motor vehicles and motorcycles

Alternatively, the grouped SIC07 level in the DTS is:

- G Wholesale and retail trade and repair of motor vehicles and motorcycles

D Minor Cleaning of CBI Dataset

Before utilising the CBI dataset, some cleaning techniques are employed. First, firms without a unique identification number are dropped from the sample. For reasons of anonymity, each firm that participates in at least one survey is provided with a unique identification number by the CBI so their responses can be tracked through subsequent survey waves. However, within the dataset a number of survey responses are not paired with a unique identification number. While it could be the case that these survey responses are all generated by one firm there is no guarantee this is true. Therefore, in order to ensure the highest level of accuracy possible all survey responses without a corresponding unique identification number are dropped.

Second, firm responses recorded as N/A are designated as missing responses. For the trichotomous style question regarding what happened to prices/output/average costs in the previous quarter firms can reply up, same, down or N/A. Recording these N/A answers as missing ensures calculating the percentages of firm responses to the survey questions are more accurate.

[57]Consists of 94 (activities of membership organisations), 95 (repair of computers and personal and household goods) and 96 (other personal service activities). Note there are no firms with SIC07 94 or 95 in the SSS.

E Potential Price Indices to be Constructed using CBI Survey Data

The CBI dataset provides (qualitative) price movement data for manufacturing (SIC07 group C), services (SIC07 group H to S) and distributive trades (SIC07 G). Since the CBI also provides industrial classification data, multiple price indices can be constructed based on different aggregations of industrial subtypes. Existing empirical literature, provides an insight into possible classifications. For example, according to Klenow and Malin (2010) service firms changes prices less frequently than manufacturing firms. What follows primarily applies to manufacturing firms (i.e. firms which complete the ITS)

According to Bils and Klenow (2004) and Klenow and Malin (2010) firms which face greater competition should (in theory) display greater flexibility in their prices[58]. The Herfindahl–Hirschman index (HHI) is a measure of market concentration used to assess market competitiveness. A HHI less than 1,500 indicates an unconcentrated industry, a HHI between 1,500 and 2,500 indicates the industry is moderately concentrated, while industries with a HHI above 2,500 are highly concentrated. The Department for Business, Innovation and Skills analysis of key sectors (by SIC2007) measures the HHI at the 5 digit SIC07 level for 2006 to 2015. However, due to the necessary conversion of SIC80 and SIC92 to SIC07 for the ITS and SSS (respectively), the CBI dataset only contains 2 digit SIC07 data. Therefore, an aggregated 2 digit HHI using weights based on 5 digit total employment level (available from the ONS Business Register and Employment Survey dataset)[59] [60]. Unconcentrated 2-digit SIC07 levels in the manufacturing sector include 10, 13, 14, 16, 17, 18, 19, 20, 22, 25, 27 and 32. Moderately concentrated 2-digit SIC07 levels in the manufacturing sector include 15, 23, 26, 28 and 29. Heavily concentrated 2-digit SIC07 levels in the manufacturing sector include 12, 24 and 30.

Durable goods are more flexible with respect to prices than non-durables (Klenow and Malin, 2010). The United States Census Bureau Manufacturers' Shipments, Inventories and Orders lists a set of industries which produce durable goods. At the 2 digit SIC07

[58] Conversely, firms facing lesser competition have stickier prices.

[59] While data is available for SIC07 47, SIC07 49 and SIC07 70 this isn't sufficient to yield significant insights into constructing price indices from the SSS or DTS.

[60] Note the aggregate HHI is constructed using the 2015 5-digit HHI and 2015 5-digit total employment level

level these are 16, 23, 24, 25, 26, 27, 28, 29, 30 and 32.

Cyclical goods change prices more frequently than non-cyclical goods (Klenow and Malin, 2010). Following Klenow and Malin (2010), the cyclical nature of each industrial subsector in the ITS is based on the coefficient obtained from regressing the grouped SIC07 level GVA growth on the industrial sector GVA growth. The results are presented in Table 8 for the ITS. In the manufacturing sector there is evidence of cyclicality for SIC07 level 13, 14, 15, 16, 18, 22, 23, 27, 28 and 29.

Table 8: Cyclicality (Index of Production)

2-Digit SIC07 Level	Coefficient
10	0.326***
13	2.842***
14	2.067***
15	2.038***
16	2.252***
17	0.339***
18	1.149***
19	0.519***
20	0.278***
22	1.339***
23	2.027***
24	0.657***
25	0.973***
26	0.968***
27	1.056***
28	1.449***
29	5.718***
30	0.903***
32	0.837***

Note: 10 Manufacture of food products; 12 Manufacture of tobacco products; 13 Manufacture of textiles; 14 Manufacture of wearing apparel; 15 Manufacture of leather and related products; 16 Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials; 17 Manufacture of paper and paper products; 18 Printing and reproduction of recorded media; 19 Manufacture of coke and refined petroleum products; 20 Manufacture of chemicals and chemical products; 22 Manufacture of rubber and plastic products; 23 Manufacture of other non-metallic mineral products; 24 Manufacture of basic metals; 25 Manufacture of fabricated metal products, except machinery and equipment; 26 Manufacture of computer, electronic and optical products; 27 Manufacture of electrical equipment; 28 Manufacture of machinery and equipment (not elsewhere classified); 29 Manufacture of motor vehicles, trailers and semi-trailers; 30 Manufacture of other transport equipment; 32 Other manufacturing.

Small firms exhibit stickier prices than large firms (Klenow and Malin, 2010). The ONS activity, size and location dataset provides the number of firms in the Inter-Departmental Business Register (IDBR) by SIC07 and the standard employment sizebands[61]. Using the ONS 2021 returns[62] 2 digit SIC07 level industries in the manufacturing sector which are populated primarily by large firms are 19 and 23. Conversely, 2-digit SIC07 level industries in the manufacturing sector which are populated primarily by micro, small and medium firms are 10, 12, 13, 14, 15, 16, 17, 18, 19, 20, 22, 23, 24, 25, 26, 27, 28, 29, 30 and 32.

Another potential classification is provided by the ONS, which aggregates grouped SIC07 levels B, CC, CD, CG, CH CK and CM into one classification called primary manufacturing[63]. In other words, primary manufacturing consists of mining and the wood, coke, rubber, base metals, machinery and other manufacturing subsectors. Conversely, secondary manufacturing aggregated grouped SIC07 levels are CA, CB, CE, CF , CI, CJ and CL[64]. In other words, secondary manufacturing consists of food, clothing, chemicals, computers, electrical equipment and transport equipment.

In order to examine this further and to provide an empirical justification for any aggregation of the manufacturing sector, a set of binary variables ($Z_{j,t}$) are created taking a value of 1 if industry j is concentrated, durable goods industry, cyclical, large or primary and zero otherwise[65]. Table 9 provides the Spearman correlation for these binary variables.

Denote $\lambda^p_{j,t}$ as the proportion of firms in each 2-digit SIC07 level (j) which update their price each quarter (t). Table 10 presents the results of regressing $\lambda_{j,t}$ on the binary classification variables. Results from Table 10 indicate that only the binary variable for primary manufacturing is statistically significant.

Accordingly, based on the results from Table 10 five price indices (including the corresponding flexible price indices) are created: total manufacturing price index, primary manufacturing price index, secondary manufacturing price index, service price index and

[61] The standard employment sizebands are: micro 0-9 employees, small 10-49 employees, medium 50-249 employees and large 250 or more employees.

[62] Which are effectively the same as 2017 - the first year of this ONS dataset.

[63] In terms of 2-digit SIC07 levels this is 7, 8, 9, 16, 17, 18, 19, 22, 23, 24, 25, 28 and 32.

[64] In terms of 2-digit SIC07 levels this is 10, 12, 13, 14, 15, 20, 26, 27, 29 and 30.

[65] For example, concentration is 1 if the 2-digit SIC07 level is moderately or heavily concentrated and 0 if unconcentrated.

Table 9: Spearman Correlation Coefficient

	Concentration	Durability	Cyclical	Large	Primary
Concentration	1				
Durability	0.535	1			
Cyclical	0.162	0.126	1		
Large	0.498	0.187	0.011	1	
Primary	-0.096	0.206	0.033	0.307	1

Note: Concentrated is 1 if industry j is concentrated (0 otherwise), Durability is 1 if industry j is in a durable goods industry (0 otherwise), Cyclical is 1 if industry j is cyclical (0 otherwise), Large is 1 if industry j is large (0 otherwise) and Primary is 1 if industry j is primary manufacturing (0 otherwise).

Table 10: $\lambda_{j,t}$ and Industrial Classifications

	(1)	(2)	(3)	(4)	(5)
	Coeff./SE	Coeff./SE	Coeff./SE	Coeff./SE	Coeff./SE
$\lambda_{j,t}$					
Concentration	-0.045		-0.037		-0.039
	(0.04)		(0.02)		(0.03)
Durable	0.007				
	(0.03)				
Cyclical	0.029			0.026	0.028
	(0.03)			(0.03)	(0.03)
Large	0.028	0.016		0.016	
	(0.03)	(0.03)		(0.03)	
Primary	0.045	0.053	0.051**	0.055*	0.052**
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Constant	0.298***	0.297***	0.313***	0.283***	0.298***
	(0.02)	(0.02)	(0.01)	(0.02)	(0.02)
Observations	1661	1661	1661	1661	1661
Industries	19	19	19	19	19

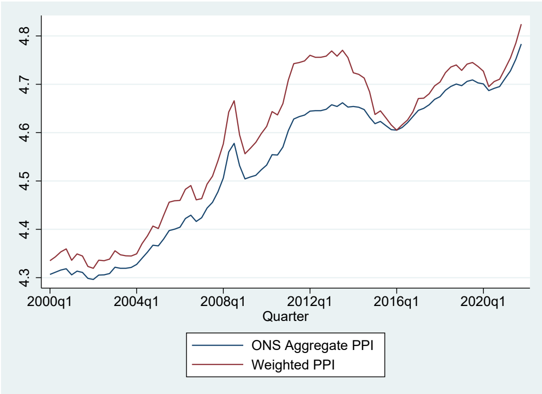
Concentrated is 1 if industry j is concentrated (0 otherwise), Durability is 1 if industry j is in a durable goods industry (0 otherwise), Cyclical is 1 if industry j is cyclical (0 otherwise), Large is 1 if industry j is large (0 otherwise) and Primary is 1 if industry j is primary manufacturing (0 otherwise). *p<0.1 **p<0.05 ***p<0.01

distributive trades price index.

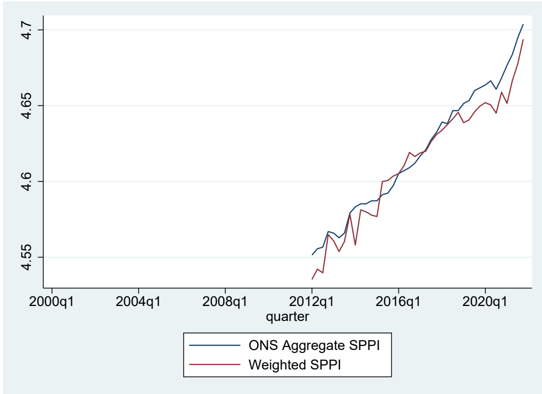
F Comparing Weighted and Unweighted Price Indices

Figure 9a and Figure 9b compares the ONS aggregate price index for manufacturing and services with the weighted versions used in this technical note (respectively). Note since the SSS only has firm responses from two-digit SIC07 levels 49, 50, 51, 52, 53, 56, 62, 68, 70, 77, 86, 90 and 96, only these sectors are included in the weighted services aggregate price level. Figure 9c and Figure 9d present the corresponding output index graphs. In each case, the weighted index (consisting only of industries recorded in the CBI dataset) corresponds closely with the ONS aggregate series.

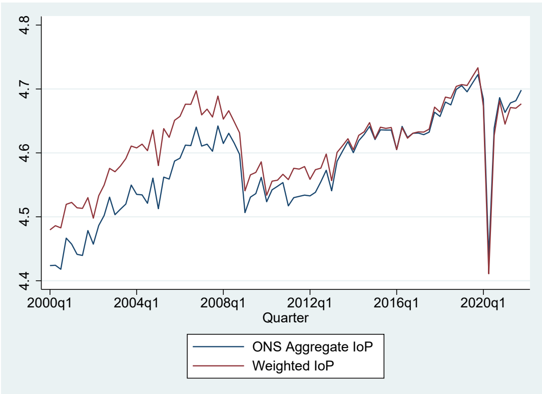
Figure 9: Comparing Weighted and Unweighted Indices



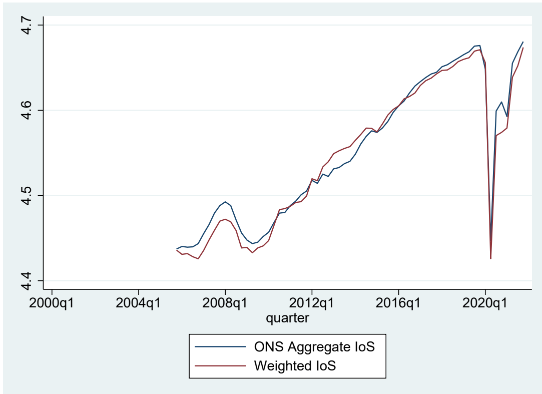
(a) Manufacturing PPI Comparison



(b) Services SPPI Comparison



(c) Manufacturing IoP Comparison



(d) Services IoS Comparison

Note: Base is 2016Q1.