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Is the Irish Phillips Curve Broken?

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Abstract: Contrary to the predictions of a traditional Phillips curve relationship, inflation in Ireland remained subdued in the decade following the 2008 financial crisis, despite improving labour market conditions. To examine this apparent puzzle, we test econometrically the relevance of the Phillips curve in Ireland. We find a significant role for domestic cyclical conditions. We investigate whether the Phillips curve may be non-linear and find some evidence that it is flatter when there are high excess capacities and turns steeper as economic slack is eliminated. However, forecasts from non-linear specifications do not systematically outperform forecasts from linear specifications.

I INTRODUCTION

Between 2012 and 2019, Ireland experienced a sustained expansion phase. Before the onset of the COVID-19 pandemic, the unemployment rate was approaching its pre-crisis level, wage pressure was building up and capacity constraints were becoming increasingly apparent. Yet inflation had remained low (Figure 1).

Persistently low inflation despite a closing output gap has cast doubt on the usefulness of the Phillips curve both in the US (Ball and Mazumder, 2011) and in the euro area (Onorante *et al.*, 2019; Berson *et al.*, 2018). This "missing inflation" puzzle led economists to reconsider the relationship between economic activity and inflation and the global nature of the drivers of inflation.

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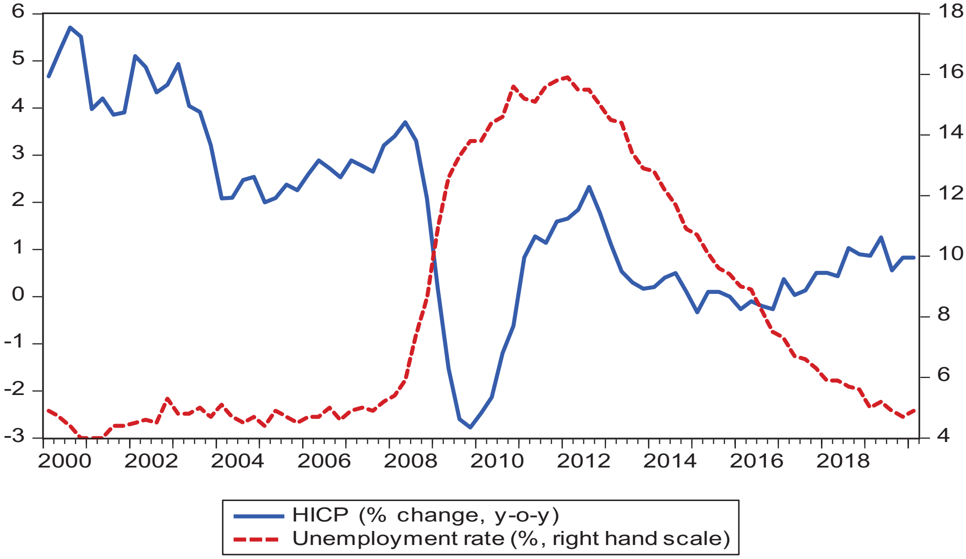
Figure 1: Unemployment rate and headline inflation in Ireland



Source: Central Statistics Office.

Low inflation despite considerable reductions in labour market slack could reflect different factors. The Phillips curve could be difficult to estimate owing to mismeasurements in the level of slack in the economy. The Phillips curve could be flattened (with inflation reacting less to the business cycle) or be non-linear (with different pricing behaviours at different stages of the economic cycle). Low inflation could also reflect low import prices. In a small open economy like Ireland, much of inflation is imported. A large literature on the Irish inflation process has failed to find a role for domestic demand (see Gerlach *et al.*, 2015, for a literature review) and sees inflation as largely determined by import prices.

We contribute to the empirical literature on the Phillips curve by examining the following questions:

i) Does inflation react to domestic cyclical conditions in a small, open economy like Ireland?
ii) Is inflation rather driven by external factors?
iii) Does the link between demand and prices vary depending on the state of the economy? Is there a role for non-linearities in the Irish Phillips curve?

Our contribution to the literature is threefold. Firstly, we provide robust evidence that domestic cyclical conditions drive Irish inflation. To the best of our knowledge, this article is the first to test systematically a large range of indicators of demand on different measures of inflation for Ireland. We consider several indicators of inflation: headline inflation (which reflects the price of tradable and non-tradable products), the price of services (which mostly reflects the price of non-tradable products) and inflation excluding food and energy. We find a significant role for domestic cyclical conditions on both the price of tradable products (which are expected to be mainly determined on international markets) and the price of non-tradable products (which are more likely driven by domestic factors). We also test indicators reflecting cyclical conditions in Ireland's main economic partners (the UK, the EU and the euro area). We do not find evidence that measures of domestic cyclical conditions are superseded by indicators of economic slack in Ireland's trading partners. This result is consistent with Mikolajun and Lodge (2016) and McCoy *et al.* (2019), who do not find evidence that measures of domestic cyclical conditions are superseded by global output gap variables in the euro area Phillips curve.

Secondly, we analyse the role of external price pressures in driving Irish inflation. We pay particular attention to imported inflation from the UK, Ireland's main trading partner. We test the impact of the euro-sterling exchange rate, Ireland's trade-weighted nominal exchange rate and the UK consumer and producer prices. Phillips curve specifications augmented with the bilateral euro-sterling exchange rate, in conjunction with an indicator of commodity prices, generate the most accurate pseudo out-of-sample forecasts. This result is consistent with Reddan and Rice (2017), who find that Irish consumer prices are predominantly affected by the euro-sterling exchange rate, rather than by the effective exchange rate. By contrast, specifications including UK producer or consumer prices do not outperform other models.

Thirdly, we examine non-linearities in the relationship between inflation and cyclical conditions. We test several approaches to ensure the robustness of our results. Threshold regressions suggest that the Phillips curve might be flatter when excess capacities are high and turn steeper as economic slack is eliminated. However, this finding is not robust to all indicators of cyclical conditions. In addition, non-linear specifications do not systematically outperform linear specifications.

The paper is organised as follows. Section II reviews the related literature. In Section III we estimate linear Phillips curve specifications to examine the respective role of domestic cyclical conditions and external drivers of inflation. In Section IV we analyse non-linearities in the Phillips curve and compare the performances of linear specifications with those of non-linear models. Section V concludes.

II LITERATURE REVIEW

This article relates to several strands of literature.

2.1 The Phillips Curve Breakdown

A recent strand of literature examines the apparent breakdown in the Phillips curve following the Great Recession. A possible explanation is the increasing role of external supply shocks, resulting in inflation becoming less sensitive to domestic developments (Gordon, 2013; Watson, 2014), or non-linearities in the relationship between inflation and real activity, implying that the Phillips curve coefficient on the output gap depends on the state of the business cycle (Ball and Mazumder, 2011). The apparent breakdown in the Phillips curve could also reflect difficulties in measuring labour market slack and identifying the measure of slack most appropriate in determining inflation dynamics (Yellen, 2014). The existence of more slack than suggested by the unemployment rate could explain subdued inflation. This could be the case if inflation were not only sensitive to the level of the unemployment rate but also to its composition, for example if short- and long-term unemployment exerted different pressures on prices (Kiley, 2015).

2.2 Existence of the Phillips Curve in Ireland

Few papers estimate a Phillips curve for Ireland (see Gerlach *et al.*, 2015, for a literature review). According to Gerlach *et al.* (2015), the scarcity of this literature reflects the long-held view that domestic demand had no role to play in the Irish inflation process.

Before Ireland's accession to the European Monetary Union (EMU), most of the literature saw Irish inflation as determined by external factors. In the 1960s and 1970s, when the Irish pound was linked to sterling, most studies of Irish inflation focused on the implications of the small open economy model, which posits that the long run rate of inflation in a small open economy is, under fixed exchange rates, effectively determined by the change in world prices. Geary (1976), based on a sample of annual data covering a period of 20 years, did not find a statistically significant relationship between domestic demand (as measured by the unemployment rate) and inflation. By contrast, he highlighted the role of the UK retail price index in driving Irish inflation, reflecting the maintenance of a fixed exchange rate with sterling until 1979 and the dominant role of the UK as a trading partner. In the same vein, Honohan and Flynn (1986), based on a sample covering both the parity link with sterling and the European Monetary System (EMS) adjustable peg regime, highlight the importance of foreign price movements in determining Irish inflation. Browne (1983) tests the small open economy price-taking hypothesis for Ireland and does not reject the null hypothesis that domestic exporters and importers have respectively no monopoly and no monopsony power in their respective markets. Hence, in a small open economy price-taker in trade, domestic excess demand is met at existing prices by imports while domestic excess supply is absorbed by exports.

Following the entry of the Irish pound into the EMS in 1979, more emphasis has been placed on domestic factors. Honohan and Lane (2003) investigate the domestic and external causes for high inflation in Ireland in the early 2000s. They argue that the depreciation of the euro against the dollar had been a major driver of inflation in Ireland in the early years of the euro. The depreciation raised import prices and improved wage competitiveness, thereby facilitating an increase in real wages. Persistently high inflation in Ireland after the euro had stopped depreciating reflected domestic factors (such as the continued rise in real wages and the relaxation in the budgetary position), in addition to delayed exchange rate passthrough.

Recent studies (Anthony, 2010 and Bermingham *et al.*, 2012) suggest the existence of a well-defined Phillips curve in Ireland following the accession to the EMU. Similarly, Gerlach *et al.* (2015), using annual data up to 2012, find that both the unemployment gap and import prices drive Irish inflation.

2.3 Non-Linearities in the Phillips Curve

Several theoretical models of price-setting behaviour suggest that the sensitivity of inflation to cyclical conditions may be non-linear (see Dupasquier and Ricketts, 1998, for a literature review).

Most of these models imply convexity, with inflation increasingly sensitive to excess demand. The capacity constraint model (Macklem, 1997) suggests that if aggregate demand increases during recessions – as a result possibly of expansionary monetary policy – firms would be able to satisfy additional demand by producing more without raising prices. By contrast, during times of expansion, firms produce closer to their capacity constraint and would raise prices.

Akerlof *et al.* (1996) suggest that workers are more reluctant to accept a decrease in their nominal wages than a decrease in their real wages, implying that in a low-inflation environment wages could adjust more slowly. Ball and Mankiw (1994) assume that, in the presence of menu costs, not all firms adjust their prices in response to a demand shock.

By contrast, the model of monopolistic competition suggests a concave relationship between inflation and demand. During boom times, firms might be reluctant to raise prices, with the aim of keeping out new competitors (Stiglitz, 1997).

The empirical literature examining non-linearities remains scarce for the euro area. Semmler and Gross (2017), using regime-switching Phillips curves, find a convex relationship, with prices reacting more strongly to a positive output gap than to a negative output gap. By contrast, Onorante *et al.* (2019) do not find evidence of non-linearities. To our knowledge, this paper is the first to investigate non-linearities in the Irish Phillips curve.

2.4 Global Drivers of Inflation

Another strand of literature suggests that domestic inflation is increasingly sensitive to the global output gap, which might not only play an indirect role on domestic inflation (via its effect on import prices and domestic output gaps) but also a direct one. One explanation is that globalisation has rendered domestic inflation less responsive to domestic capacity constraints, either because a sudden demand shock would bolster imports rather than increase prices, or because exposure to foreign competitors curtails increases in the price of domestic products (Guerrieri *et al.*, 2010). However, empirical evidence is mixed. Auer *et al.* (2017) argue that exposure to foreign competitors makes domestic inflation more sensitive to the global output gap and less sensitive to domestic cyclical conditions. By contrast, Mikolajun and Lodge (2016) do not find a direct effect of global slack on domestic inflation in advanced economies. Similarly, McCoy *et al.* (2019) do not find evidence that measures of domestic cyclical conditions are superseded by global output gap variables in the euro area. Ciccarelli and Mojon (2010) find that including a measure of global inflation improves national inflation forecasts for OECD countries. However, gains in forecasting accuracy are modest (Medel *et al.*, 2014).

III DOES THE PHILLIPS CURVE EXIST IN IRELAND?

3.1 Measures of Cyclical Conditions

While assessing the cyclical position in real-time is difficult for any economy, several features of the Irish economy pose additional challenges (Casey, 2019). National Accounts figures are volatile owing to the activities of large foreign-owned multinational enterprises. Estimates of spare capacity in the Irish economy are thus subject to a high degree of volatility. We therefore consider a number of alternative indicators of cyclical conditions, presented below (see Table A.1 in the Annex for data details and stationarity tests).

3.1.1 Output Gap and Unemployment Gap

- **Unemployment gap:** difference between the unemployment rate and the non-accelerating wage rate of unemployment (NAWRU) estimated by the European Commission.
- **Output gaps and modified domestic demand gap**. Quantifying potential output, which is unobservable, and, by extension, the output gap, is subject to a significant margin of uncertainty (see Casey, 2019). Hence, we use a range of alternative estimation techniques and indicators as a robustness check. A first is a Hodrick-Prescott (HP) filter-based measure of the output gap, where the filter is applied to quarterly real GDP.[1] Along with this statistical measure, we

[1] The gap corresponds to the log difference between output and its trend estimate. To limit the "end-point problem" which, with some filters, may result in estimates that are highly biased at the ends of the sample, we extend historical data with forecasts from the European Commission.

test the output gap estimated by the European Commission based on a production function-type approach. Thirdly, we apply a HP filter to modified domestic demand (MDD), an indicator developed by the Central Statistics Office (CSO) that better reflects Irish domestic activity[2] than GDP.

3.1.2 Labour Market Indicators

The Irish unemployment rate sharply declined between 2012 and the outbreak of the COVID-19 pandemic. This drop coincided with a decrease in the Irish participation rate, which has sharply declined following the 2008 crisis, suggesting that the decline in the unemployment rate observed between 2012 and March 2020 may have overstated the improvement in labour market conditions. Hence, we test alternative indicators of labour supply.

- **The non-employment index (NEI).** The NEI developed for Ireland by Byrne and Conefrey (2017) distinguishes between short-term and long-term unemployed, discouraged workers and passive job seekers. The NEI is calculated as the weighted average of these different groups, with tailored weights reflecting each group's probability of transitioning to employment. We compute the index following the method developed in Byrne and Conefrey (2017), using data from the Irish Labour Force Survey (LFS) and the weights computed by the authors based on microdata from the LFS. We test both the impact of changes in the NEI and the level of the NEI gap, computed as the difference between the NEI and its long-term average.
- **Potential labour force.** The LFS provides indicators of the potential additional labour supply. PLS1 corresponds to unemployed persons plus discouraged workers as a percentage of the labour force plus discouraged workers. PLS2 includes unemployed persons plus potential additional labour force (which includes the persons available for work but not seeking a job and the persons seeking a job but not immediately available). We compute PLSs gaps as the difference between these indicators and their long-term averages.

We check whether **short- and long-term unemployment** exert different pressures on inflation. We use quarterly changes in the unemployment rate with a duration of up to one year and a duration over one year, respectively.

We test the impact of domestic **labour costs** for different economic sectors (by NACE code). Some services sectors, which experienced strong wage growth between 2016 and 2019, are dominated by multinational enterprises. Testing for

[2] Modified domestic demand is a measure of underlying economic activity. The rationale for distinguishing between measures of slack in the domestic sector and multinationals-driven sectors is that multinationals are expected to be operating at full capacity, whereas capacity constraints are more likely to be binding in the domestic sector.

the impact of sector-specific labour costs provides an indicator of how multinational firms could impact the aggregate price level.

3.1.3 Migration and Cyclical Conditions in Ireland's Economic Partners

The openness of the Irish labour market and the high mobility of labour may add to difficulties in discerning a stable relationship between unemployment and inflation. Between 2015 and 2019, net inward migration significantly supported the labour force. The additional labour supply prompted by migration can limit the wage pressures that may arise in a tightening labour market.

A number of studies dating back to the 1990s highlight an equilibrium unemployment gap between Ireland and the UK (see Gerlach *et al.*, 2015, for a literature review), whereby cross-border labour mobility ensures that the Irish unemployment rate adjusts to labour market conditions in the UK. However, Meyler (1999) concludes that this unemployment gap does not drive Irish inflation.

We could not directly test the unemployment gap between Ireland and the UK (or other trading partners), which is not stationary over our sample (see Table A.1 in the Annex). To account for fluctuations in the Irish labour force and cyclical conditions in Ireland's trading partners, we tested the following indicators:

- **Variation in unemployment rates** in Ireland and in its main economic partners (the UK, the euro area and the EU).
- **The UK, the EU and the euro area output gaps**, computed with two methods (the European Commission production function approach and a HP filter).

3.2 Baseline Specification

Following Gordon's triangle model (Gordon, 1988), inflation is modelled as a function of three sets of determinants: inertia, demand factors (reflecting the state of resource utilisation) and supply factors, such as changes in commodity prices. Our preferred specification[3] is the following:

$$\begin{aligned} \pi_t = \alpha + \textstyle\sum_{j=1}^{Max\ J=4} \rho_j \pi_{t-j} + \underset{j\in\{0;\,1\}}{\beta x_{t-j}} \\ + \textstyle\sum_{i=1}^{Max\ I=2} \sum_{l=0}^{Max\ L=4} \gamma_{i,l} \Delta z_{i,t-l} + \varepsilon_t \end{aligned} \tag{1}$$

[3] Other specifications were tested, including an accelerationist version of the Phillips curve with the sum of coefficients on lagged inflation constrained to unity. However, as the Wald test rejected the hypothesis of unity of the sum of coefficients on lagged inflation, we opted for a non-accelerationist specification.

Where π_t is the inflation rate, computed as the first difference in the logarithm of the HICP,[4] x is a measure of cyclical conditions,[5] introduced either contemporaneously or lagged, and z corresponds to an indicator of external price movements. International prices affect domestic prices directly, through the price of imported final consumption goods, and indirectly, through the price of imported intermediate goods. The lagged inflation term captures backward-looking inflation expectations[6] and other sources of persistence in price setting.

For each specification, the optimal lag order is selected based on the Akaike information criterion. Given our relatively short sample, we test up to two indicators of external prices and up to four lags for z. We estimate the models by OLS on quarterly data. The starting point of our sample (1999-2019) corresponds to the introduction of the euro, and hence, to a new regime for Irish inflation.

3.3 Linear Regressions

3.3.1 Headline Inflation

In this section, we examine the role of domestic cyclical conditions and external price pressures in driving Irish headline inflation. We start by selecting the indicators of external price pressures most relevant for headline inflation. In a second step, we test several indicators of demand, while controlling for two measures of external prices.

External drivers of inflation

In this paragraph, we focus on the impact of external price pressures on headline inflation. We test a number of indicators to capture such pressures (see Table A.1 in the Appendix for data sources and transformations).

A first set of indicators includes the euro-sterling exchange rate and three indicators of the nominal effective exchange rate of the euro against three different groups of trading partners. In addition to testing the euro effective exchange rate computed by the ECB for the whole euro area, we compute the nominal effective exchange rate of Ireland. For the sake of robustness, we consider several groups of trading partners (from five to 14 partners). Using tailored weights for the share of each partner country in Ireland's imports better reflects the structure of Ireland's trade, and in particular, Ireland's high reliance on imports from the UK.[7]

[4] HICP has been seasonally adjusted using the X-12 ARIMA procedure. We rely on seasonally adjusted quarter-on-quarter inflation rates. Although year-on-year inflation has no seasonal pattern, using year-on-year growth rates may introduce a moving average component to inflation and complicate econometric inference, with auto-correlated residuals.

[5] Stationary variables, such as the output gap, are introduced in levels. Non-stationary variables, such as the unemployment rate, are introduced in first differences.

[6] Time series for firms' and consumers' inflation expectations are not available for Ireland. In the absence of forward-looking indicators, the lagged inflation term is a proxy for backward-looking expectations.

[7] Weights assigned to the euro area, the UK and the US are respectively 27 per cent, 35 per cent and 15 per cent on average over the sample.

We also test other indicators of external price pressures, such as Ireland's import prices, crude oil prices (in euros and in US dollars), commodity prices (either excluding or including oil) and several indicators of global inflation, such as inflation in the euro area, in the EU and in the UK.

In the light of the UK's withdrawal from the EU, we pay particular attention to the impact of price pressure from the UK, a major economic partner for Ireland. According to Reddan and Rice (2017), imports from the UK dominate extra-euro area imports in Ireland in the categories contributing most to Irish consumer goods inflation (manufacturing and food). FitzGerald and Shortall (1998) highlight the role of UK-based retail firms in the Irish market. The price of these affiliate retail companies is often set by parent companies in the UK, suggesting that Irish consumer prices may be highly correlated to UK consumer or producer prices. We test the impact of producer prices in the UK to determine whether Irish prices are driven by production costs similar to those observed in the UK, owing to the close integration of the two economies.

To select the indicators most relevant for headline inflation, we estimate Phillips curve specifications augmented with two indicators of external price pressures (Equation 2).

Equation 2 relies on the Irish unemployment rate as indicator of cyclical conditions. Our findings are robust to using alternative indicators of economic slack, such as the output gap computed by the European Commission based on the production function approach.

In a first step, we test a single indicator of external price pressures (i = 1). We select the optimal lag order based on the Akaike information criterion for each model. Optimal lags for the dependent variable are the first and third lags.

$$\begin{aligned}\pi_t = \alpha + \textstyle\sum_{j=1}^{Max\ J=4} \rho_j \pi_{t-j} + \beta \Delta\ unemployment_t + \\ \textstyle\sum_{i=1}^{Max\ I=2} \sum_{l=0}^{Max\ L=4} \gamma_{i,\ l} \Delta z_{i,\ t-l} + \varepsilon_t\end{aligned} \tag{2}$$

In a second step, we add a second indicator of external price pressures and compare the pseudo-out-of-sample forecasting performance of different specifications with alternative indicators for z.

Most indicators are statistically significant. While the euro-sterling exchange rate is systematically significant, this is not the case for effective exchange rates of the euro area and Ireland. This result is consistent with Reddan and Rice (2017), who find that Irish consumer prices are predominantly exposed to the euro-sterling exchange rate, rather than to the effective exchange rate.

The Diebold-Mariano test suggests that a Phillips curve augmented with the euro-sterling exchange rate, in conjunction with an indicator of commodity prices, import prices, or lagged inflation in the euro area, generates more accurate forecasts than alternative specifications.[8]

Following Stock and Watson (2008), we calculate biweighted rolling estimates of the RMSE (BRMSE hereafter), based on a weighted centred 15-quarter window (Equation 3). Bigger weights are given to errors close to the centre of the window.

$$BRMSE(t) = \sqrt{\frac{\sum_{s=t-7}^{\tau+7} K\left(\frac{|s-t|}{8}\right)(\pi_{s+1} - \pi_{s+1|s})^2}{\sum_{s=t-7}^{\tau+7} K\left(\frac{|s-t||}{8}\right)}} \tag{3}$$

Where K is the biweight kernel:

$$K(x) = \frac{15}{16}(1-x^2)^2 I_{\{|x|<1\}} \tag{4}$$

The rationale for using *BRMSE* is the following. Our sample includes episodes of important volatility in the price of oil, the 2009 recession and the sovereign debt crisis, characterised by large fluctuations in the euro-sterling exchange rate. These events might have altered the link between external price pressures and domestic inflation. *BRMSE* highlights the forecasting performance at the centre of the window and, hence, the models yielding the lowest *BRMSE* for any specific event.

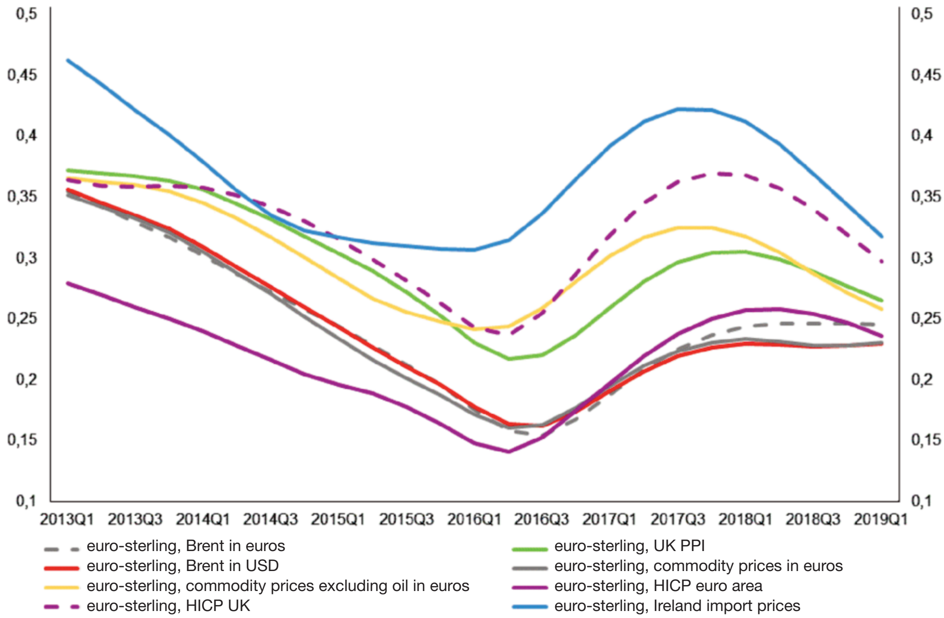
Until mid-2016, the best performing model included the euro-sterling exchange rate and inflation in the euro area (Figure 2). The correlation between inflation in the euro area and in Ireland decreased thereafter, as inflation remained more subdued in Ireland. Reduced inflation correlation likely reflects Ireland's high reliance on imports from the UK and the passthrough of lower import prices following the depreciation of sterling from mid-2016 onwards.

Since 2016, models yielding the lowest BRMSE include the euro-sterling exchange rate, in conjunction with an indicator of commodity prices. Models including a broad index of commodity prices (including agricultural products, minerals, metals and fuel) do not yield lower BRMSEs than models solely based on Brent crude oil prices. Specifications based on UK producer or consumer prices do not outperform other models.

Figure 3 shows the BRMSE obtained while using three different indicators for the exchange rate: i) the euro-sterling exchange rate; ii) the euro area nominal effective exchange rate, computed against a group of 12 trading partners, and iii) the euro effective exchange rate with tailored weights for Ireland, computed against

[8] Models are estimated on 40-quarter rolling windows and forecast errors are computed over 34 observations.

Figure 2: BRMSE for Phillips Curve Specifications With Different Indicators of External Price Pressures



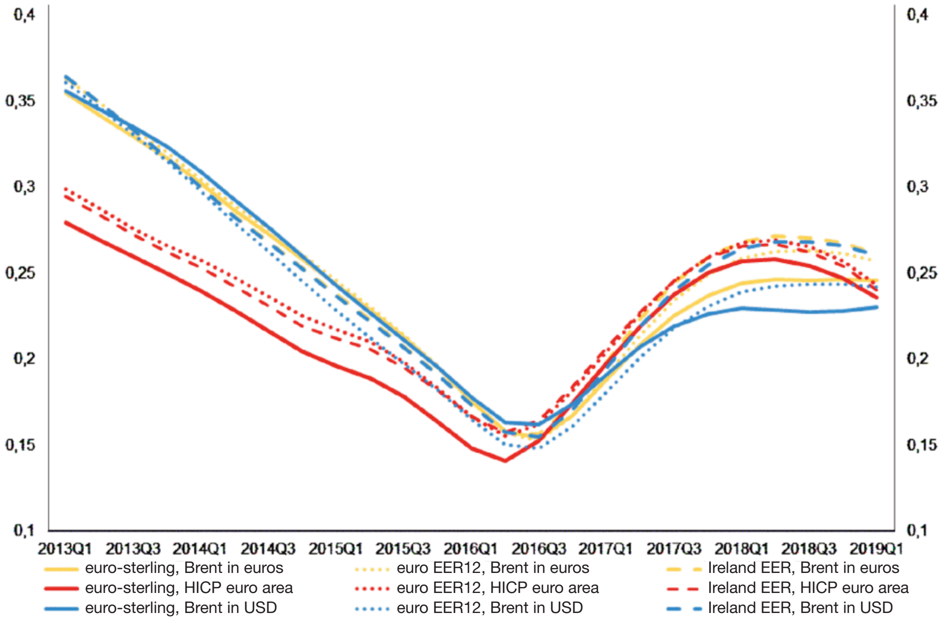
Source: Author's analysis.
Note: The date on the time axis represents the end of the 15-quarter rolling window. Models are estimated on 40-quarter rolling windows, based on Equation 2. BRMSE are computed for one-quarter-ahead forecasts.

a group of 14 trading partners. Overall, using the bilateral euro-sterling exchange rate yields lower BRMSEs.[9]

Domestic cyclical conditions
In this paragraph, we examine the role of domestic cyclical conditions in driving Irish headline inflation. We test several indicators of demand, while controlling for two measures of external prices (Equation 5): quarterly changes in the euro-sterling exchange rate (reflecting Ireland's reliance on goods imported from the UK) and quarterly changes in oil prices (in euros),[10] which reflect fluctuations in the prices of internationally-traded goods. These two indicators have been selected in light of the results from the previous paragraph.

[9] As a robustness check, we also run the regressions on year-on-year changes in HICP and its regressors and obtain similar conclusions. The optimal lag order is slightly different: we select the first and second lags of inflation for year-on-year inflation vs the first and third lags for quarterly changes in HICP.
[10] Results are similar when oil prices are in USD.

Figure 3: Comparing the BRMSE for Phillips Curve Specifications With Different Exchange Rate Indicators



Source: Author's analysis.
Note: The date on the time axis represents the end of the 15-quarter rolling window. Models are estimated on 40-quarter rolling windows, based on Equation 2. BRMSE are computed for one-quarter-ahead forecasts.

We also tested a dummy for the last three quarters of 2009, characterised by negative inflation, falling output and surging unemployment. The rationale for testing a dummy is that the severe economic downturn could have lowered expectations of future inflation which are not captured in the backward-looking expectations (proxied by lags) included in Equation 5 – possibly biasing our results. However, the dummy is not statistically significant.

$$\pi_t = \alpha + \sum_{j=1}^{Max\ J=4} \rho_j \pi_{t-j} + \underset{j \in \{0;\, 1\}}{\beta y_{t-j}} + \gamma \Delta brent_t + \delta \Delta sterling_t + \varepsilon_t \quad (5)$$

A large number of indicators of cyclical conditions are statistically significant[11] (Table 1), such as the output gap, changes in the unemployment rate, changes in the potential labour supply indicator (PLS1) from the LFS and changes in the

[11] Table 1 only reports the specifications for which the indicator of cyclical conditions was statistically significant.

non-employment index. Output gap indicators have similar coefficients, regardless of the computation method (production function approach vs H-P filter). Changes in the unemployment rate and in the potential labour supply indicator (PLS1) have similar coefficients, whereas coefficients are larger for changes in short-term unemployment and changes in the non-employment index.

Inflation is very persistent, as indicated by high and statistically significant coefficients of lagged inflation. Estimates of the slope of the Phillips curve depend on the indicator of cyclical conditions. For instance, estimation results suggest that a 1pp increase in the output gap, implying less slack in the economy, is associated with a 0.03 per cent increase in inflation (Models 1 and 2 in Table 1). This value is consistent with the literature. Semmler and Gross (2017) find a coefficient of 0.03 for Ireland on monthly data for a sample covering 1999 to 2016.

Our findings are also robust to using a longer estimation sample. Using CSO data for headline CPI, which are available on a longer sample than the HICP computed by Eurostat, we estimate Model 1 on the Q4 1990-Q4 2019 sample. The coefficient for the output gap is statistically significant and of the same size.

To determine the indicator of cyclical conditions most relevant for inflation, we compute the Root Mean Square Errors (RMSEs) for one-quarter-ahead ($h = 1$) and four-quarter-ahead forecasts ($h = 4$). The RMSE corresponds to Equation 6, where $\pi^h_{t+h|t}$ is the pseudo out-of-sample forecast of π_{t+h}.

$$RMSE(t_1, t_2) = \sqrt{\frac{1}{t_2 - t_1 + 1} \Sigma_{t=t_1}^{t_2} (\pi^h_{t+h} - \pi^h_{t+h|t})^2} \tag{6}$$

The model yielding the lowest RMSE varies depending on the estimation sample. As a robustness check, we compute RMSEs based on rolling estimation windows of different lengths (Table 1). All Phillips curves specifications yield lower RMSEs than an autoregressive (AR) benchmark model for one-quarter-ahead forecasts.[12] Most Phillips curve specifications also yield lower RMSEs than the AR benchmark for four-quarter ahead forecasts. Exceptions are Models 1 and 2, which rely on the Irish output gap computed using the production function approach.[13]

[12] The appropriate lag length for the AR model was selected using the Akaike information criterion.

[13] Our findings are robust to estimating Phillips curve specifications on year-on-year changes in headline HICP. The optimal lag order is slightly different: we select the first and second lags of inflation for year-on-year inflation vs the first and third lags for quarterly changes in HICP. Hence, we compare Phillips curve specifications to an AR2 benchmark model for year-on-year inflation. For one-quarter-ahead forecasts, Phillips curve specifications systematically yield lower RMSEs than the AR2 benchmark. However, for four-quarter-ahead forecasts, the AR2 benchmark yields lower RMSEs than most Phillips curve specifications. Only Models 5, 6 and 8 outperform the AR2 benchmark.

Table 1: Linear Estimates for Headline HICP (Q2 1999-Q4 2019)

Model	*AR*	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*
constant	0.07	0.02	0.02	0.03	0.02	0.02	0.03	0.02	0.01
	(0.05)	(0.04)	(0.04)	(0.03)	(0.04)	(0.05)	(0.04)	(0.04)	(0.05)
π_{t-1}	0.56***	0.57***	0.56***	0.59***	0.56***	0.55***	0.55***	0.56***	0.56***
	(0.09)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)
π_{t-3}	0.26***	0.25***	0.24***	0.26***	0.31***	0.31***	0.27***	0.30***	0.34***
	(0.09)	(0.08)	(0.08)	(0.08)	(0.08)	(0.07)	(0.07)	(0.08)	(0.08)
$\Delta sterling_t$		–0.03**	–0.03**	–0.03***	–0.03**	–0.02*	–0.03***	–0.03**	–0.03**
		(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
$\Delta brent_t$		0.01***	0.01***	0.01***	0.01***	0.01***	0.01***	0.01***	0.01***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
output gap IE_t		0.03*							
		(0.02)							
output gap IE_{t-1}			0.03*						
			(0.02)						
output gap HP IE_{t-1}				0.02*					
				(0.01)					
$\Delta URIE_t$					–0.11*				
					(0.07)				
ΔNEI_{t-1}						–0.24***			
						(0.09)			
NEI gap_t							–0.01**		
							(0.00)		
$\Delta PLS1_t$								–0.11*	
								(0.06)	
$\Delta UR < 1$ *year* IE_t									–0.19**
									(0.09)

Table 1: Linear Estimates for Headline HICP (Q2 1999-Q4 2019) (Contd.)

Model	*AR*	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*
Observations	83	83	83	83	83	83	83	83	83
R^2	0.55	0.72	0.72	0.72	0.72	0.74	0.73	0.72	0.73
Adjusted R^2	0.54	0.71	0.70	0.70	0.70	0.72	0.71	0.70	0.71
Estimation window:					RMSE one-quarter ahead				
50 quarters	0.31	0.23	0.22	0.22	0.21	0.24	0.21	0.23	0.22
60 quarters	0.32	0.25	0.24	0.22	0.21	0.24	0.21	0.22	0.22
65 quarters	0.32	0.23	0.23	0.23	0.21	0.24	0.21	0.21	0.23
					RMSE four-quarter ahead				
50 quarters	0.82	0.89	0.71	0.69	0.72	0.74	0.64	0.99	0.66
60 quarters	0.62	0.89	0.86	0.58	0.61	0.63	0.61	0.64	0.57
65 quarters	0.67	0.90	0.87	0.55	0.51	0.50	0.52	0.51	0.49

Source: Central Statistics Office.

Notes: *, ** and *** denote statistical significance at 10 per cent, 5 per cent and 1 per cent levels respectively. RMSE for one-quarter and four-quarter ahead forecasts are computed on rolling estimation windows of up to 65 quarters. Grey shaded cells highlight the lowest RMSE. Standard errors are reported in parentheses.

We examine whether Phillips curve specifications provide more accurate forecasts than the benchmark AR model for one-quarter ahead forecasts. We perform pairwise Clark-West tests (Clark and West, 2007) to assess whether additional parameters (such as external price pressures and cyclical conditions) improve the accuracy of the forecast, compared to the more parsimonious AR benchmark.[14] We test the null hypothesis that the AR benchmark performs as well as a Phillips curve model. The first column in Table A.2 in the Appendix shows that the null hypothesis is systematically rejected, suggesting that all Phillips curve specifications yield more accurate forecasts than the AR model.

RMSEs yielded by different Phillips curve specifications are close, suggesting similar forecasting performances (Table 1). We perform the Diebold-Mariano test[15] (Diebold and Mariano, 1995) to assess whether differences in forecasting performances are statistically significant (see Appendix, Table A.2). The null hypothesis is that the benchmark Phillips curve specification (in columns) performs at least as well as alternative Phillips curve models (in rows). We cannot reject the null hypothesis that Models 2, 3, 4 and 5 perform at least as well as alternative models. By contrast, Models 3 and 5 (which rely, respectively, on the Irish output gap computed with a statistical filter and changes in the non-employment index) outperform Models 1, 6 and 7.

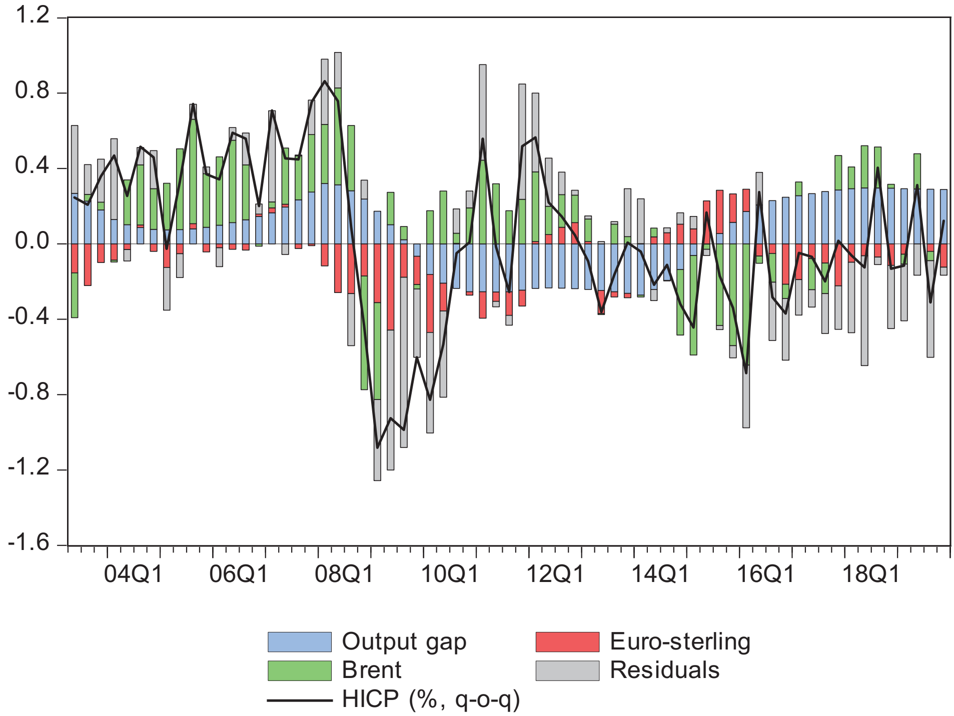
We compute the contributions of the main drivers of headline inflation in terms of deviations from their historical averages. We compare two specifications. Figure 4 shows results obtained with the output gap (Model 1 in Table 1), while Figure 5 relies on the non-employment index (Model 5 in Table 1).

At the onset of the 2008 financial crisis, inflation was above its historical average, bolstered by buoyant demand, as the economy grew above its potential during the early 2000s construction boom (Figure 4). From 2009 to 2012, inflation was dampened by the increasing level of economic slack. The drag from domestic demand was partly offset by high oil prices between 2008 and 2011. From 2010 to 2014, part of inflation was unexplained by these three drivers (output gap, the exchange rate and oil prices). The positive contribution from the residuals illustrates the "missing disinflation" episode when inflation fell by less than suggested by the high level of slack. The relative importance of the drivers of inflation has changed throughout the sample. The drag from economic slack dominated the picture between 2009 and 2015, until spare capacity was absorbed. Low import prices contributed to low inflation between 2014 and 2017, as oil prices decreased and the depreciation of sterling after 2016 made imports from the UK cheaper. Between 2017 and 2019, the negative contributions from the residuals illustrates the "missing inflation" puzzle: inflation remained subdued despite the tightening of the labour market observed before the outbreak of the COVID-19 pandemic.

[14] As the Diebold-Mariano test is not suited to situations where the competing forecasts are obtained using nested models, we use the Clark-West test instead.

[15] We focus on one-sided tests to detect forecast superiority. Given the small size of the sample, we use the small-sample bias correction to the Diebold-Mariano test proposed by Harvey *et al.* (1997).

Figure 4: Contributions of the Output Gap, the Exchange Rate and Oil Prices to Headline Inflation (%, Q-on-Q)



Source: Author's analysis.

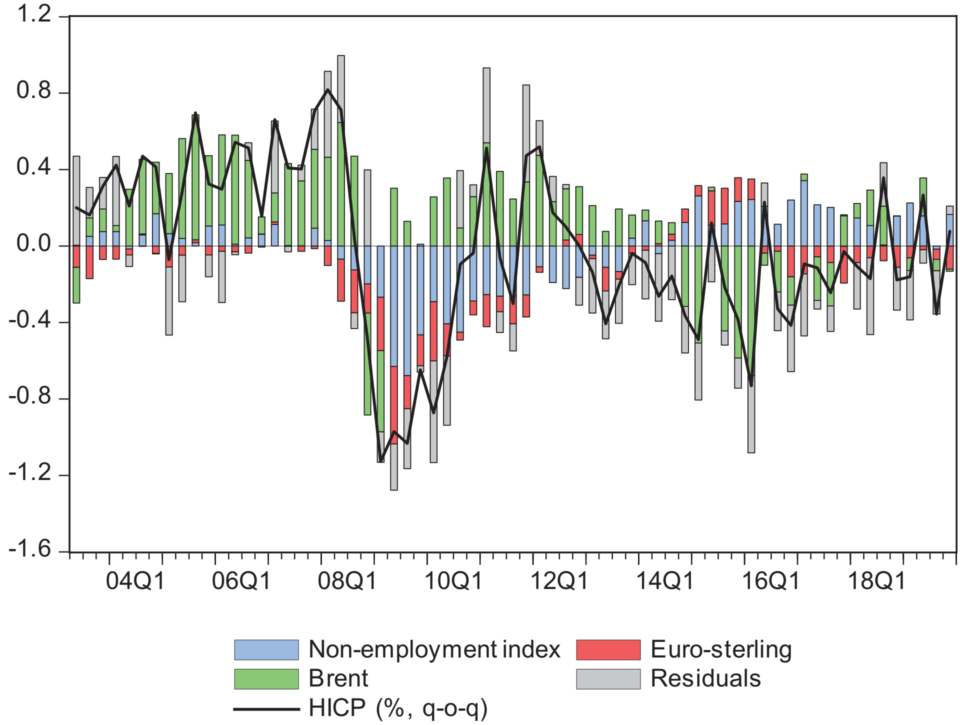
Figure 5 shows that the negative contributions of the residuals during the 2008-2010 downturn is much smaller when using the non-employment index as indicator of economic slack. Similarly, the negative contribution from the residuals between 2017 and 2019 is more limited with Model 5, suggesting that the "missing inflation" puzzle might partly reflect difficulties in measuring the level of economic slack.

Overall, our results are subject to two caveats: first, difficulties in measuring the level of economic slack and second, methodological issues in the computation of the Irish HICP. The price of non-energy industrial goods has been on a declining trend since 2007, which partly reflects difficulties in measuring changes in quality in specific goods (Keating and Murtagh, 2018).

Cyclical conditions in Ireland's trading partners

In this paragraph, we test whether adding an indicator reflecting cyclical conditions in Ireland's main trading partners might improve the fit of the linear Phillips curve

Figure 5: Contributions of the Non-Employment Index, the Exchange Rate and Oil Prices to Headline Inflation (%, Q-on-Q)



Source: Author's analysis.

(Equation 7). We test one additional indicator of cyclical conditions at a time and check variance inflation factors to limit the risk of multicollinearity. We test changes in unemployment rates in the UK, the EU and the euro area, as well as the UK, the EU and the euro area output gaps.

$$\pi_t = \alpha + \sum_{j=1}^{Max\ J=4} \rho_j \pi_{t-j} + \beta_d\, domestic\ slack_{\substack{t-j \\ j\in\{0;\ 1\}}} + \beta_f foreign\ slack_{\substack{t-j \\ j\in\{0;\ 1\}}} + \gamma \Delta brent_t + \delta \Delta sterling_t + \varepsilon_t \qquad (7)$$

In most cases, the additional indicator is not statistically significant. This finding is consistent with Mikolajun and Lodge (2016) and McCoy *et al.* (2019), who do not find evidence that measures of domestic cyclical conditions are superseded by global output gap variables for forecasting inflation in the euro area.

3.3.2 Robustness Check

The price of services

As a robustness check, we focus on the price of non-tradable products, proxied by the services component of HICP. As most services are produced domestically and intensive in labour, inflation in services might better illustrate the relationship between domestic demand and inflation.[16] In Ireland, the price of services is mainly driven by rents and accommodation and restaurant services. Hence, our specifications for HICP services include the first and third lags of the dependent variable (selected based on the Akaike information criterion), an indicator of cyclical conditions and lagged changes in house prices, which are highly correlated to rents. Neither the bilateral euro-sterling exchange rate nor commodity prices are statistically significant for services, whereas indicators of domestic cyclical conditions are significant.[17]

Core inflation

The analysis in Section 3.3.1 and Figure 4 suggests that the subdued inflation observed between 2014 and 2019 was driven primarily by declining oil prices and the depreciation of sterling following the June 2016 UK referendum on Brexit.

In this paragraph, we estimate Equation 5 on HICP excluding food and energy. Oil prices are not statistically significant for core inflation, whereas the exchange rate remains statistically significant, although with a different optimal lag order (see Table 2). Most indicators of domestic cyclical conditions are statistically significant for core inflation too.

Most Phillips curve specifications for core inflation yield similar or lower RMSEs than the AR benchmark model for one-quarter-ahead forecasts. Compared to models estimated on headline inflation, R^2 tends to be lower and RMSEs higher for core inflation.

IV TIME-VARIATION AND NON-LINEARITIES

The linear Phillips curves with a constant slope estimated in Section III illustrate the average relationship between cyclical conditions and inflation. However, the slope could have changed over time, which may explain why inflation had remained subdued between 2014 and 2019 despite the economic recovery. The Phillips curve could also be non-linear, with different sensitivity of inflation to different positions in the economic cycle.

[16] Methodological issues in the computation of the Irish HICP strengthen the case for focusing on services. Hence, we do not focus on core inflation, which includes non-energy industrial goods, but rather on the services component, which is immune from these methodological difficulties.

[17] Results available upon request.

Table 2: Linear Estimates for HICP Excluding Food and Energy (Q4 2000-Q4 2019)

Model	*AR*	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*
constant	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.03
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
π_{t-1}	0.51***	0.44***	0.45***	0.50***	0.47***	0.51***	0.47***	0.47***	0.48***	0.50***	0.50***
	(0.10)	(0.10)	(0.10)	(0.10)	(0.10)	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)
π_{t-3}	0.34***	0.32***	0.31***	0.35***	0.37***	0.35***	0.37***	0.34***	0.37***	0.35***	0.39***
	(0.10)	(0.10)	(0.10)	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)
$\Delta sterling_{t-1}$		–0.03*	–0.03**	–0.03**	–0.02*	–0.02	–0.02*	–0.03**	–0.02	–0.02*	–0.02
		(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
$output\ gap\ IE_t$		0.03*									
		(0.02)									
$output\ gap\ IE_{t-1}$			0.03*								
			(0.02)								
$output\ gap\ HP\ IE_{t-1}$				0.01							
				(0.01)							
$\Delta UR\ IE_t$					–0.12*						
					(0.07)						
ΔNEI_t						–0.18**					
						(0.09)					
ΔNEI_{t-1}							–0.20***				
							(0.09)				
$NEI\ gap_t$								–0.01**			
								(0.00)			
$\Delta\ PLS1_t$									–0.12*		
									(0.06)		
$\Delta\ PLS2_t$										–0.09*	
										(0.05)	
$\Delta\ UR < 1\ year\ IE_t$											–0.19**
											(0.09)

Table 2: Linear Estimates for HICP Excluding Food and Energy (Q4 2000-Q4 2019) (Contd.)

Model	*AR*	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*
Observations	77	77	77	77	77	77	77	77	77	77	77
R^2	0.63	0.67	0.67	0.65	0.67	0.67	0.68	0.67	0.67	0.67	0.67
Adjusted R^2	0.62	0.65	0.65	0.63	0.65	0.65	0.66	0.65	0.65	0.65	0.65
Estimation window:	*RMSE one-quarter ahead*										
50 quarters	0.26	0.30	0.30	0.28	0.26	0.28	0.26	0.26	0.27	0.29	0.27
60 quarters	0.23	0.22	0.22	0.23	0.22	0.23	0.22	0.20	0.22	0.26	0.22
65 quarters	0.20	0.22	0.22	0.20	0.18	0.18	0.21	0.18	0.20	0.24	0.19

Source: Central Statistics Office.

Notes: *, ** and *** denote statistical significance at 10 per cent, 5 per cent and 1 per cent levels respectively. RMSE for one-quarter and four-quarter ahead forecasts are computed on rolling estimation windows of up to 65 quarters. Grey shaded cells highlight the lowest RMSE. Standard errors are reported in parentheses. HICP excluding food and energy is available from December 1999 onwards. Hence, the estimation sample for core inflation is slightly shorter than for headline HICP.

In this section, we investigate time-variation and non-linearities in the relationship between cyclical conditions and inflation. We use different approaches to ensure the robustness of our results.

4.1 Rolling Linear Regressions

Based on the specifications presented in Section III, we estimate rolling linear regressions to illustrate possible changes in the relationship between cyclical conditions and inflation. We use CPI data from the CSO to avail of a longer sample (1990-2019). Models are estimated over 65-quarter rolling windows, which we consider a sufficiently long sample to provide robust coefficients.

Figure 6 shows the results for the specification including the Irish output gap estimated using the production function approach (Model 1 in Table 1). The coefficient of the output gap is slightly lower at the end of the estimation sample and not statistically significant. This seemingly reduced sensitivity of headline inflation to economic conditions is observed in other advanced economies (e.g. Ball and Mazumder, 2011). Possible causes include better-anchored inflation expectations, increased globalisation and global competition (which may have made inflation less responsive to domestic demand), lower and less volatile inflation (which may have induced less frequent price changes by firms), and increased volatility of supply shocks relative to demand shocks (see Occhino, 2019 for a literature review).

Inflation persistence has slightly increased at the end of the sample. Higher persistence suggests that following a prolonged period of subdued inflation and weak demand, it will take a longer period of strong demand to pass through to prices. By contrast, the coefficients on oil prices and the exchange rate have remained stable. Figure 7 shows similar results for core inflation. Overall, results are sensitive to the size of the estimation window and the indicator of cyclical conditions. Hence, this exercise does not provide conclusive evidence of a decrease in the sensitivity of inflation to economic conditions in recent years.

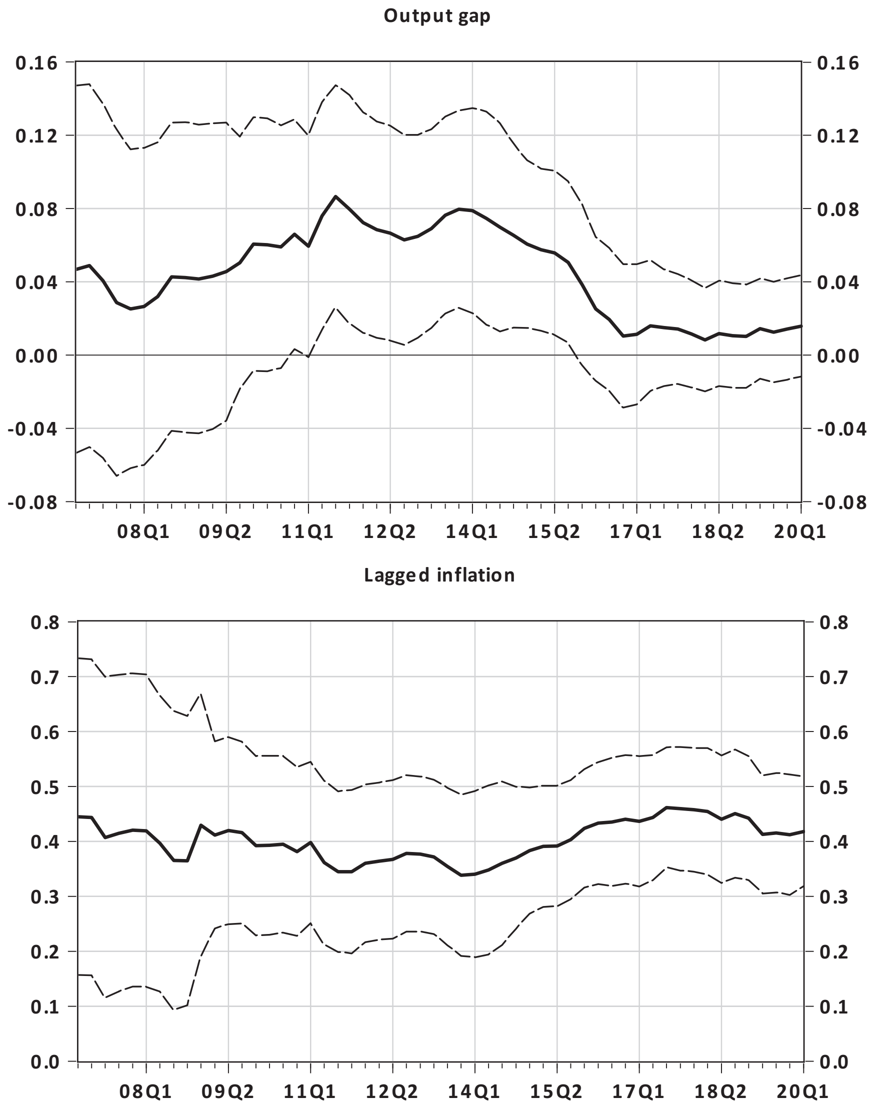
4.2 Testing for Non-Linearities with Cubic Splines

The average quarterly growth rate of HICP has sharply decreased in Ireland, from 0.8 per cent on average between 1999 and 2008 to 0.1 per cent over the decade following the financial crisis (Figure 8). The existence of different regimes of inflation suggests that non-linear modelling may be appropriate to analyse inflation in Ireland.

In this section, we use a cubic B-spline model to test the hypothesis of non-linearity in the relationship between inflation and economic slack.

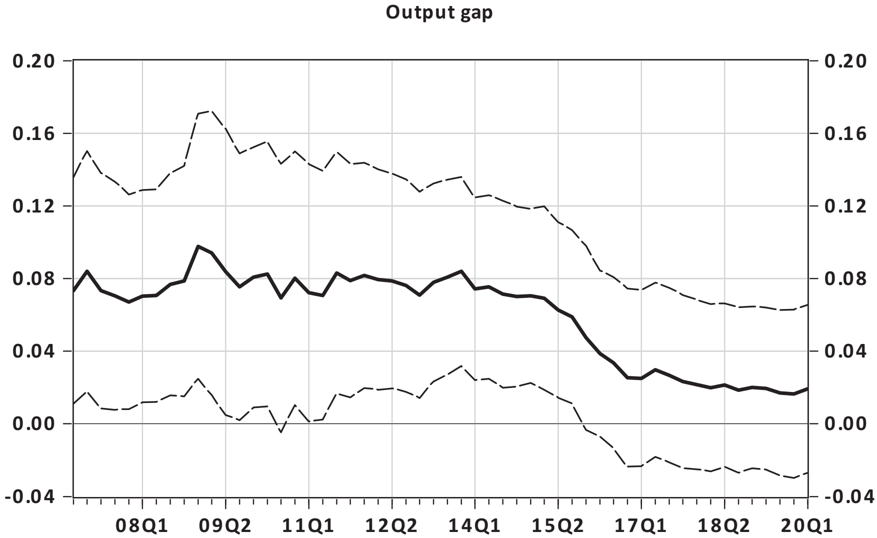
Given $\{(x_i, y_i): i = 1,\ldots,n\}$ with y the inflation rate and x the output gap, we model y_i as a function of x_i using a cubic B-spline model. We introduce k interior knots on the x-axis located at $t_1, t_2,\ldots,t_k$.

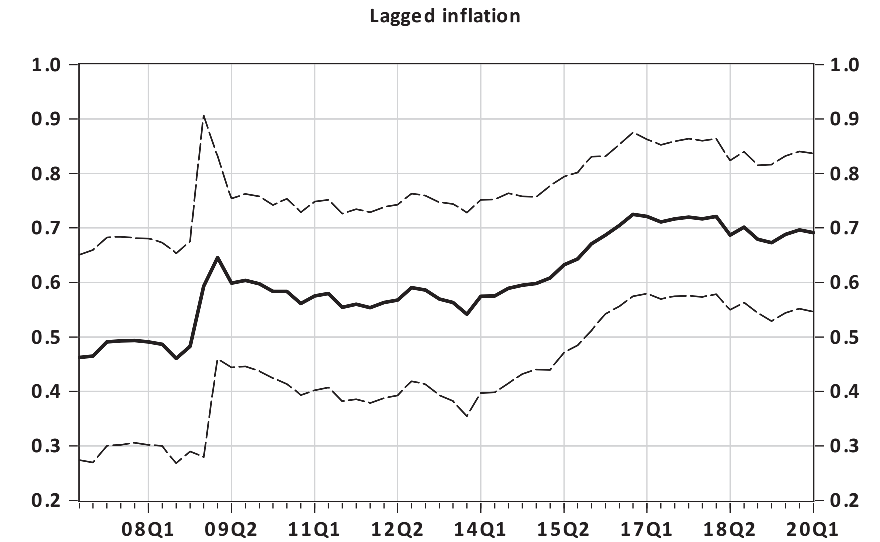
Figure 6: Rolling Linear Regressions (CPI)



Source: Author's analysis.
Note: Rolling regressions with a constant number of 65 observations, starting from Q4 1990. The solid line represents the point estimate. Dotted lines represent the +/-2 standard errors confidence bands.

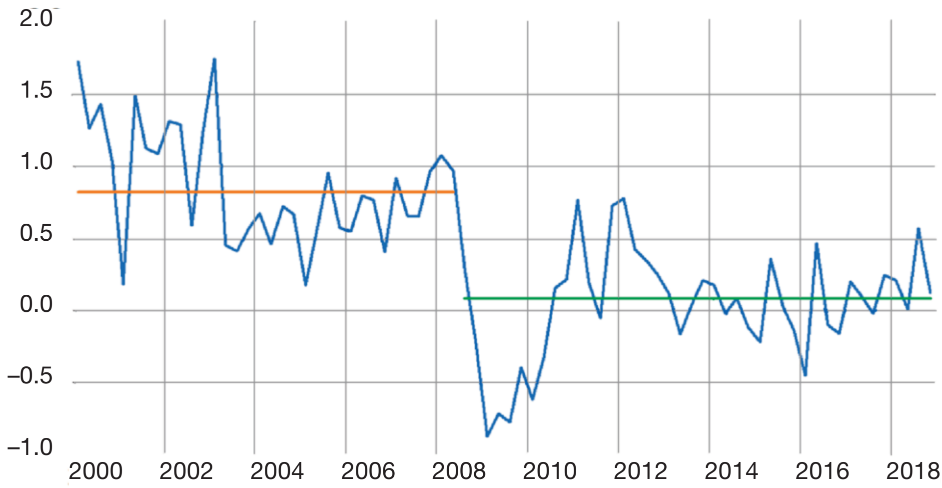
Figure 7: Rolling Linear Regressions (CPI excluding Food and Energy)





Source: Author's analysis.
Note: Rolling regressions with a constant number of 65 observations, starting from Q4 1990. The solid line represents the point estimate. Dotted lines represent the +/-2 standard errors confidence bands.

Figure 8: Quarterly Growth Rate of HICP (%)



Source: Eurostat and author's calculations.
Note: Solid lines represent the average inflation rates between 1999 and 2008 and between 2009 and 2018.

Dupont and Plummer (2005) show how to select a model of the expected value of y given x that is linear before t_1 and after t_k, consists of piecewise cubic polynomials between adjacent knots, and is continuous and smooth at each knot, with continuous first and second derivatives.

B-splines are defined by their order m and number of interior knots N. The order m of the B-spline polynomial corresponds to $m = n + 1$, with n the spline degree. Hence, for a cubic B-spline, $m = 4$. We use the 'quantile' knot sequence, where the interior knots ($N = 3$) are given by the quantiles from the empirical distribution of x, the output gap. In addition, two external knots correspond to the boundary of the distribution of x. Quantile knots guarantee that an equal number of sample observations lie in each interval.

A B-spline of degree n is a parametric curve composed of a linear combination of basis B-splines $B_{i,n}(x)$ of degree n given by $B(x) = \sum_{i=0}^{N+n} \beta_i B_{i,n}(x), x \in [t_0, t_{N+1}]$. For each of the augmented knots t_i, we recursively define a set of real-valued functions $B_{i,j}$ (for $j = 0, 1,\ldots, n$, n being the degree of the B-spline basis) as follows:

$$B_{i,0}(x) = \begin{cases} 1 \ if \ t_i \leq x \leq t_{i+1} \\ 0 \ otherwise \end{cases}$$

For a cubic B-spline of order 4 with 3 interior knots, there are $K = N + m = 7$ basis functions, denoted $B_{0,3},\ldots, B_{6,3}$ with $\sum_{i=0}^{N+n} B_{i,n}(x) = 0$.

We estimate Equation 8 and perform a Wald test on the control points β_i.

$$y = \alpha + \sum_{i=0}^{6} \beta_i B_{i,3}(x) + \varepsilon_t \tag{8}$$

We reject the null hypothesis that the control points are not statistically different from zero, suggesting the existence of non-linearities in the relationship between inflation and economic slack. We obtain similar results for core inflation and inflation in the price of services.

4.3 Regime Switching Regressions

4.3.1 Headline HICP

In this section, we analyse the relationship between headline inflation and its three sets of determinants with Markov-switching dynamic regressions.

Equations are estimated using a standard Expectation-Maximisation (EM) algorithm. Transition probabilities are assumed to be constant. The initial regime probabilities are set to the ergodic (steady state) values implied by the Markov transition matrix. The error variance is allowed to switch regimes to allow for heteroscedasticity.

In a first step, we allowed all coefficients to be time-varying, with non-linearities arising from discrete changes in regime. However, the Wald test did not reject the hypothesis of equality of the coefficients of oil prices, the exchange rate and lagged inflation across regimes. We subsequently set these regressors as non-switching.

Estimation results (Table 3) suggest the existence of a regime (Regime 1) under which the output gap has no impact on inflation, corresponding to a flat Phillips curve, whereas under Regime 2, the Phillips curve is steeper than the linear model. Under Regime 2, the coefficient of the output gap is thrice larger than the coefficient estimated based on a linear specification. Assuming that a Markov-switching process better captures inflation, the linear specification would tend to overestimate inflation when the economy is experiencing Regime 1. However, this finding is not robust to all indicators of cyclical conditions. For all indicators except the Irish output gap (computed based on the production function approach), the Wald test does not reject the null hypothesis of equality of the coefficient of slack across regimes. Moreover, results are sensitive to the measure of the output gap, whose quantification is subject to a significant margin of uncertainty. While we find evidence of non-linearities when relying on the output gap estimated by the European Commission based on a production function-type approach, the Wald test does not reject the null hypothesis of equality of the coefficient of the output gap across regimes when testing alternative, Hodrick-Prescott filter-based measures of the output gap. Hence, evidence of non-linearities is limited and dependent on using a specific indicator of cyclical conditions.

4.3.2 Core HICP and HICP Services

As a robustness check, we estimated Markov-switching regressions for core inflation and HICP services. We found similar results. For most indicators of cyclical conditions except the Irish output gap (computed based on the production function approach) and changes in the potential labour force, we cannot reject the Wald test null hypothesis of equality of the coefficient of economic slack across regimes. Table 3 shows the estimates of Markov-switching regressions for a few specifications. Overall, the coefficient under Regime 2 is much larger than under Regime 1. Under Regime 2, the coefficients of the output gap and of changes in the potential labour force are about twice as large as the respective coefficients from linear specifications.

Overall, Markov-switching regressions suggest the existence of different regimes of core and headline inflation for a couple of indicators of cyclical conditions. Results should nevertheless be interpreted with caution given the small size of the sample.

We compare the forecasting performances of linear and Markov-switching regressions. We produce dynamic pseudo-out-of-sample forecasts for HICP, conditional on the actual data for the exogenous variables. We perform the Diebold-Mariano test to assess whether differences in forecasting accuracy are statistically significant. Table 4 shows that in most cases, non-linear specifications yield more accurate forecasts than linear specifications.

4.4 Threshold Effects

While Section 4.3 focuses on non-linearities that might arise from discrete changes in regime where the sample separation into regimes is not observed, this section focuses on the role of potential threshold effects, where slack needs to fall below or rise above a certain critical level before driving significant movements in inflation. We test two approaches, which can fit both convex and concave relationships between inflation and cyclical conditions.

4.4.1 Dummy Variables

Dummy regressions provide a simple way to test whether the relationship between inflation and a demand variable (such as the output gap) may change according to whether the gap lies above or below a particular value. We use arbitrarily-defined thresholds (x) for different indicators of cyclical conditions (y), using an indicator function $\mathbb{1}(.)$ which takes the value 1 if the expression is true and 0 otherwise (Equation 9).

$$\pi_t = \alpha + \rho_1 \pi_{t-1} + \rho_3 \pi_{t-3} + \beta_1 y_{t-j} \mathbb{1}\, y_{t-j} > x + \beta_2 y_{t-j} \mathbb{1}\, y_{t-j} \leq x \quad j \in \{0; 1\} \\ + \delta \Delta brent_t + \chi \Delta sterling_t \tag{9}$$

Table 3: Parameters Estimates: Linear vs Markov-Switching (MS) Specifications (Q2 1999-Q4 2019) and Wald Test for Equality of Coefficients Across Regimes

	Cyclical conditions	*Slack*	
HICP			
Linear model	*output gap* IE_t	0.03*	(0.02)
MS Regime 1		0.03	(0.04)
MS Regime 2		0.09**	(0.04)
Wald test p-value		0.01	
HICP excluding energy and food			
Linear model	*output gap* IE_t	0.03*	(0.02)
MS Regime 1		0.01	(0.02)
MS Regime 2		0.08***	(0.02)
Wald test p-value		0.04	
Linear model	$\Delta\ PLS_t$	–0.12*	(0.06)
MS Regime 1		0.03	(0.11)
MS Regime 2		–0.21***	(0.07)
Wald test p-value		0.09	
HICP services			
Linear model	*output gap* IE_{t-1}	0.05**	(0.02)
MS Regime 1		0.04**	(0.02)
MS Regime 2		0.29***	(0.03)
Wald test p-value		0.04	

Source: Author's analysis.
Notes: *, ** and *** denote statistical significance at 10 per cent, 5 per cent and 1 per cent levels, respectively. Non-switching regressors are not reported. Grey shaded cells highlight situations in which the null hypothesis of equality of coefficients across regimes is rejected at the 10 per cent level. Standard errors are reported in parentheses.

The value of the thresholds depends on the indicator of cyclical conditions. For the output gap, we set the dummy variable to 1 when the gap is positive, 0 otherwise. Our results should be interpreted with caution given the small size of the sample: situations where the output gap is positive correspond to between 35 and 40 observations, depending on the indicator.

Coefficients on dummy variables are only significant for the Irish output gap (computed based on the production function approach). Table 5 shows that the output gap only affects inflation significantly when it is positive (β_1), suggesting that in the presence of a large amount of slack, prices change more slowly than in periods of expansion, making the Phillips curve convex. This result concurs with Semmler and Gross (2017). Using regime-switching Phillips curves, the authors find a convex relationship, with prices reacting more strongly to a positive output gap than to a negative output gap in the euro area.

Table 4: Diebold-Mariano Test (p-values): Linear vs Markov-Switching Specifications

Indicator of demand	*Rolling estimation window* 60 quarters	65 quarters
	HICP	
output gap IE_{t-1}	0.01	0.01
	HICP excluding food and energy	
output gap IE_t	0.01	0.02
Δ PLS_t	0.00	0.01
	HICP services	
output gap IE_{t-1}	0.01	0.01

Source: Author's analysis.
Note: The null hypothesis is that forecasts generated by linear specifications are at least as accurate as forecasts from Markov-switching specifications. The alternative hypothesis is that Markov-switching specifications yield more accurate forecasts. Grey shaded cells highlight situations in which the null hypothesis is rejected at the 10 per cent level. Models are estimated on two rolling windows (60 and 65 quarters), which are relatively large to benefit from a sufficient number of observations.

Table 5: Parameters Estimates: Linear vs Dummy Regressions (Q2 1999-Q3 2019)

y	*Model*	β	β_1	β_2	R^2	*Adj.* R^2
			HICP			
output gap IE_{t-1}	Linear	0.03*			0.72	0.70
		(0.02)				
	Dummy		0.06*	0.01	0.73	0.70
			(0.03)	(0.04)		
			HICP services			
output gap IE_{t-1}	Linear	0.05**			0.61	0.59
		(0.02)				
	Dummy		0.10**	0.01	0.62	0.59
			(0.04)	(0.04)		

Source: Author's analysis.
Note: *, ** and *** denote statistical significance at 10 per cent, 5 per cent and 1 per cent levels, respectively. Standard errors are reported in parentheses.

We find similar results for services when estimating Equation 10. On average across specifications, the coefficient of the output gap is three times larger than the coefficient estimated based on a linear specification for both headline inflation and the price of services. Hence, linear models would tend to overpredict (respectively, underestimate) inflation during times of pronounced economic slack (respectively, periods of expansion), as such models would neglect the convexity in the Phillips curve relationship.

$$\pi_t = \alpha + \rho_1 \pi_{t-1} + \rho_3 \pi_{t-3} + \beta_1 \underset{j\in\{0;\,1\}}{y_{t-j}} \mathbb{1}\, y_{t-j} > x + \beta_2 \underset{j\in\{0;\,1\}}{y_{t-j}}\, \mathbb{1}\, y_{t-j} \leq x \\ + \chi\Delta\ \textit{house prices}_{t-3} \tag{10}$$

Overall, results are dependent on the indicator of cyclical conditions. Hence, we find limited evidence of non-linearities in the Irish Phillips curve for a few indicators of cyclical conditions. These results concur with the findings outlined in Section 4.3.

4.4.2 Threshold Regressions

After testing dummy variables with arbitrarily-defined thresholds, we examine whether non-linearities might occur when the indicator of cyclical conditions y crosses an unknown threshold. We use the threshold regression model, which is a form of nonlinear regression featuring piecewise linear specifications and regime switching that occurs when an observed variable (the indicator of cyclical conditions, y) crosses an unknown threshold.

Assuming an observable threshold variable q_t and strictly increasing threshold values ($\gamma_1 < \gamma_2 < \ldots < \gamma_m$) such that we are in regime j if $\gamma_j \leq q_t < \gamma_{j+1}$, we estimate the following single threshold, two-regime model for headline inflation:

$$\pi_t = \alpha + \rho\pi_{t-1} + \beta_1 \underset{j\in\{0;\,1\}}{y_{t-j}} + \delta\Delta\ \textit{brent}_t + \chi\Delta \textit{sterling}_t$$

if $$\gamma_1 \leq q_t < \gamma_2$$

and $$\pi_t = \alpha + \rho\pi_{t-1} + \beta_2 \underset{j\in\{0;\,1\}}{y_{t-j}} + \delta\Delta \textit{brent}_t + \chi\Delta \textit{sterling}_t \quad \text{otherwise} \tag{11}$$

We assume that the slope of the Phillips curve can change according to whether the indicator of cyclical conditions lies between or outside the threshold values. If the indicator of cyclical conditions is between the lower threshold γ_1 and the upper threshold γ_1, then the coefficient β_1 measures the slope of the Phillips curve in this interior region. If the indicator of cyclical conditions lies below the lower threshold or above the upper threshold, the coefficient β_2 measures the slope of the Phillips curve in either exterior region.

The parameters and the threshold values γ are estimated by non-linear least squares. The Wald test null hypothesis of equality of coefficients across regimes is only rejected for β. Hence, the coefficient on cyclical indicators, β, is regime-specific, whereas other coefficients are invariant. In other words, we assume that the other exogenous variables do not produce threshold effects on inflation. The threshold variable q corresponds to the lagged indicator of demand, y.

Table 6: Parameters Estimates: Linear vs Discrete Threshold Regressions (Q2 1999-Q4 2019)

Cyclical conditions	*Model*	*Threshold (q)*	β		R^2	*Adj.* R^2
			HICP			
output gap IE_{t-1}	Linear		0.03*	(0.02)	0.72	0.72
	$y < q$	–2.0	0.01	(0.03)	0.74	0.72
	$y \geq q$		0.05***	(0.02)		
			HICP excluding food and energy			
output gap IE_{t-1}	Linear		0.03*	(0.02)	0.67	0.65
	$y < q$	–2.0	0.02	(0.04)	0.64	0.62
	$y \geq q$		0.04*	(0.02)		
			HICP services			
output gap IE_{t-1}	Linear		0.05**	(0.02)	0.61	0.59
	$y < q$	–2.2	0.05	(0.04)	0.60	0.57
	$y \geq q$		0.12***	(0.03)		

Source: Author's analysis.
Note: *, ** and *** denote statistical significance at 10 per cent, 5 per cent and 1 per cent levels respectively.

Table 6 shows that the output gap only affects inflation in a statistically significant way beyond a certain level. For instance, the second line shows that the output gap does not have a significant impact on inflation when it is highly negative.

The existence of non-linearities may lead to a more sudden rise in inflation than suggested by a linear Phillips curve as inflation becomes more sensitive to slack beyond a certain threshold. Hence, a linear model may over-predict inflation at times of recession and underestimate it during times of expansion.

Overall, threshold regressions suggest that the Phillips curve may be flatter in times when excess capacities are high and turn steeper as slack is eliminated. However, results are not robust to all indicators of cyclical conditions and should be interpreted with caution given the small size of the sample. These findings concur with the results outlined in Sections 4.3 and 4.2.1.

We compare the forecasting performance of linear Phillips curve specifications to that of threshold regressions. We produce dynamic pseudo-out-of-sample forecasts for inflation, conditional on the actual data for the exogenous variables.

The Diebold-Mariano test (Table 7) suggests that threshold regressions do not yield more accurate forecasts than linear specifications.

Overall, we do not find compelling evidence of non-linearities in the Irish Phillips curve. The identification of non-linearities depends on using a specific indicator of cyclical conditions, i.e. the output gap estimated based on a production function approach. The quantification of the output gap being fraught with uncertainty, the lack of robustness of our results to alternative measures of economic slack does not make a strong case for the existence of non-linearities. Moreover, non-linear specifications do not systematically out-perform the forecasting performances of linear regressions.

Table 7: Diebold-Mariano Test (P-Values) Linear vs Threshold Regressions

	Rolling estimation window (quarters)			
Cyclical conditions	*50*	*60*	*65*	*70*
	HICP			
output gap IE_{t-1}	0.42	0.51	0.48	0.10
	HICP excluding food and energy			
output gap IE_{t-1}	0.63	0.51	0.83	0.63
	HICP services			
output gap IE_{t-1}	0.20	0.49	0.10	0.94

Source: Author's analysis.
Note: The null hypothesis is that forecasts generated by linear specifications are at least as accurate as forecasts from threshold regressions. Models are estimated on 50, 60, 65 and 70-quarter rolling windows.

4.5 Mixed Evidence of Non-Linearities

In the paragraphs above, we investigated whether the Phillips curve might be non-linear. We tested several approaches for the sake of robustness and found limited evidence of non-linearities for a couple of indicators of cyclical conditions. Markov-switching regressions suggest the existence of a regime under which the output gap has no impact on inflation, corresponding to a flat Phillips curve, whereas under Regime 2, the Phillips curve is steeper than suggested by the linear model. Hence, the linear specification would underestimate inflation when the economy is experiencing Regime 2. Threshold regressions suggest that the Phillips curve might be flatter when excess capacities are high and turn steeper as economic slack is eliminated.

However, our results are subject to several caveats. Firstly, the identification of non-linearities is not robust to all indicators of cyclical conditions. Regarding headline inflation, we could only identify non-linearities when using a specific measure of the output gap. As the output gap is notoriously difficult to quantify, this lack of robustness does not make a strong case in favour of non-linear specifications. Secondly, when comparing the forecasting performances of linear vs Markov-switching or threshold regressions, forecasts from non-linear specifications do not systematically outperform forecasts from linear specifications.

Overall, we do not find a strong case for using non-linear Phillips curves. Linear specifications are robust to a larger number of indicators of cyclical conditions, and hence look more reliable.

V CONCLUSION

Persistently low inflation despite considerable reductions in economic slack in the decade following the Great Recession has cast doubt on the relevance of the Phillips curve relationship. This "missing inflation" puzzle has stirred debates on the measurements of economic slack and on possible non-linearities in the Phillips curve.

We find that the Phillips curve relationship between inflation and cyclical conditions remains valid in Ireland. This finding is robust to different measures of demand and inflation. While all Phillips curve specifications perform better than a simple AR benchmark for one-quarter ahead forecasts, the forecasting performances of Phillips curves based on alternative measures of cyclical conditions are close.

We show that import prices play a significant role in driving Irish inflation and explain part of the subdued inflation observed between 2012 and 2019. We compare the forecasting performances of Phillips curves augmented with alternative indicators of external prices and find that the best-performing model includes the euro-sterling exchange rate, in conjunction with an indicator of commodity prices. This result confirms the high exposure of Irish consumer prices to price developments in the UK.

We test the hypothesis that the relationship between inflation and slack may be convex, with inflation becoming increasingly sensitive to cyclical conditions as economic slack decreases. Results are highly sensitive to the indicator of cyclical conditions. We find limited evidence of non-linearities for a couple of indicators of economic slack. However, the identification of non-linearities mainly depends on using a specific, production-function based measure of the output gap. Furthermore, non-linear specifications do not systematically out-perform the forecasting performances of linear regressions. Overall, we do not find strong evidence of non-linearities in the Irish Phillips curve. Linear specifications, which are robust to a larger number of indicators of cyclical conditions, look more reliable.

The analysis in this paper can be further extended by considering other types of non-linearities. For instance, regime dependence on variables other than economic slack could be considered. In addition, the empirical relevance of some of the theories that imply convexity in the Phillips curve (see Semmler and Gross, 2017, for a literature review) could also be tested for Ireland.

REFERENCES

Akerlof, G., W. Dickens and G. Perry, 1996. "The Macroeconomics of Low Inflation", Brookings Papers on Economic Activity 27 (1), 1-76. https://ideas.repec.org/a/bin/bpeajo/v27y1996i1996-1p1-76.html.

Anthony, L., 2010. "Understanding Ireland's Economic Crisis: Prospects for Recovery", Blackhall, Dublin, Ch. *The Phillips Curve and the wage inflation process in Ireland*, 159-179.

Auer, R., C. Borio and A. Filardo, 2017. "The Globalisation of Inflation: The Growing Importance of Global Value Chains", BIS Working Papers 602, Bank for International Settlements. https://www.bis.org/publ/work602.htm.

Ball, L. and N. Mankiw, 1994. "Asymmetric Price Adjustment and Economic Fluctuations", *Economic Journal* 104 (423), 247-261. https://ideas.repec.org/a/ecj/econjl/v104y1994i423p247-61.html.

Ball, L. and S. Mazumder, 2011. "Inflation Dynamics and the Great Recession", Brookings Papers on Economic Activity 42 (1 Spring), 337-405.

Bermingham, C., D. Coates, J. Larkin, D. O'Brien and G. O'Reilly, 2012. "Explaining Irish Inflation During the Financial Crisis", Central Bank of Ireland. Research technical paper 9/RT/12. https://ideas.repec.org/p/cbi/wpaper/09-rt-12.html.

Berson, C., L. de Charsonville, P. Diev, V. Faubert, L. Ferrara, S. Guilloux-Nefussi, Y. Kalantzis, A. Lalliard, J. Matheron and M. Mogliani, 2018. "Does the Phillips Curve Still Exist?" *Rue de la Banque* (56). https://ideas.repec.org/a/bfr/rueban/201856.html.

Browne, F.X., 1983. "Price Setting Behaviour for Traded Goods: The Irish Case," *Applied economics*, 15(2) 153-163. https://www.tandfonline.com/doi/abs/10.1080/00036848300000026?journalCode=raec20.

Byrne, S. and T. Conefrey, 2017. "A Non-employment Index for Ireland", Central Bank of Ireland Economic Letter Series. https://www.centralbank.ie/news-media/press-releases/economic-letter-non-employment-index-for-ireland.

Casey, E., 2019. "Inside the 'Upside Down': Estimating Ireland's Output Gap", *The Economic and Social Review*, Vol. 50, No. 1, Spring 2019, pp. 5-34. https://www.esr.ie/article/view/1117.

Ciccarelli, M. and B. Mojon, 2010. "Global Inflation", *The Review of Economics and Statistics* 92 (3), 524-535. https://ideas.repec.org/p/fip/fedhwp/wp-08-05.html.

Clark, T. and K. West, 2007. "Approximately Normal Tests for Equal Predictive Accuracy in Nested Models", *Journal of Econometrics*, 2007.

Diebold, F. and R. Mariano, 1995. "Comparing Predictive Accuracy", *Journal of Business & Economic Statistics* 13 (3), 253-263.

Dupasquier, C. and N. Ricketts, 1998. "Non-Linearities in the Output-Inflation Relationship: Some Empirical Results for Canada", Staff Working Papers 98-14, Bank of Canada.

Dupont, W. and W. Plummer, 2005. "Using Stata 9 to Model Complex Nonlinear Relationships with Restricted Cubic Splines", Researchgate, January 2005.

FitzGerald, J. and F. Shortall, 1998. "Pricing to market, exchange rate changes and the transmission of inflation", *The Economic and Social Review*.

Geary, P., 1976. "World Prices and the Inflationary Process in a Small Open Economy – The Case of Ireland", *The Economic and Social Review*, 7, 391-400.

Gerlach, S., R. Lydon and R. Stuart, 2015. "Unemployment and Inflation in Ireland: 1926-2012", CEPR Discussion Papers 10567, C.E.P.R. Discussion Papers.

Gordon, R., 1988. "U.S. Inflation, Labor's Share, and the Natural Rate of Unemployment", NBER Working Papers 2585, National Bureau of Economic Research.

Gordon, R., 2013. "The Phillips Curve is Alive and Well: Inflation and the NAIRU during the Slow Recovery", NBER Working Papers 19390, National Bureau of Economic Research, Inc. https://ideas.repec.org/p/nbr/nberwo/19390.html.

Guerrieri, L., C. Gust and D. Lopez-Salido, 2010. “International Competition and Inflation: A New Keynesian Perspective”, *American Economic Journal*: Macroeconomics 2 (4), 247-280.

Harvey, D., S. Leybourne and P. Newbold, 1997. “Testing the Equality of Prediction Mean Squared Errors”, *International Journal of Forecasting* 13 (2), 281-29.

Honohan, P. and J. Flynn, 1986. “Irish Inflation in EMS”, *The Economic and Social Review*, 17, 175-191.

Honohan, P. and P. Lane, 2003. “Divergent Inflation Rates in EMU”, *Economic Policy*, Vol. 18, No. 37, pp. 357-394. http://hdl.handle.net/10.1111/1468-0327.00110_1.

Keating, J. and M. Murtagh, 2018. “Quality adjustment in the Irish CPI”. In: CSO meeting of the group of experts on consumer prices indices.

Kiley, M., 2015. “An evaluation of the inflationary pressure associated with short- and long-term unemployment”, Economics Letters 137 (C), 5-9.

Macklem, T., 1997. “Capacity Constraints, Price Adjustment, and Monetary Policy”, *Bank of Canada Review 1997* (Spring), 39-56. https://ideas.repec.org/a/bca/bcarev/v1997y1997ispring97p39-56.html.

McCoy, E., M. Salto and V. Zdarek, 2019. “Do Global Factors Spell the End of the Phillips Curve?”, *Quarterly Report on the Euro Area (QREA)* 18 (1), 23-36.

Medel, C., M. Pedersen and P. Pincheira, 2014. “The Elusive Predictive Ability of Global Inflation”, Working Papers Central Bank of Chile 725, Central Bank of Chile.

Meyler, A., 1999. “The Non-accelerating Inflation Rate of Unemployment (NAIRU) in a Small Open Economy: The Irish Context”, MPRA Paper 11363, University Library of Munich, Germany. https://ideas.repec.org/p/pra/mprapa/11363.html.

Mikolajun, I. and D. Lodge, 2016. “Advanced Economy Inflation: The Role of Global Factors”, Working Paper Series 1948, European Central Bank.

Occhino, F., 2019. “The flattening of the Phillips Curve: policy implications depend on the cause”, *Federal Reserve Bank of Cleveland Economic commentary*, Number 2019-11. https://www.clevelandfed.org/newsroom-and-events/publications/economic-commentary/2019-economic-commentaries/ec-201911-flattening-phillips-curve.aspx.

Onorante, L., S. Saber and L. Moretti, 2019. “Phillips Curves in the Euro Area”, Working Paper Series 2295, European Central Bank. https://ideas.repec.org/p/ecb/ecbwps/20192295.html.

Reddan, P. and J. Rice, 2017. “Exchange Rate Pass-Through to Domestic Prices”, Economic Letters 08/EL/17, Central Bank of Ireland. https://ideas.repec.org/p/cbi/ecolet/08-el-17.html.

Semmler, W. and M. Gross, 2017. “Mind the Output Gap: the Disconnect of Growth and Inflation During Recessions and Convex Phillips Curves in the Euro Area”, Working Paper Series 2004, European Central Bank. https://ideas.repec.org/p/ecb/ecbwps/20172004.html.

Stiglitz, J., 1997. “Reflections on the Natural Rate Hypothesis”, *Journal of Economic Perspectives* 11 (1), 3-10. https://ideas.repec.org/a/aea/jecper/v11y1997i1p3-10.html.

Stock, J. and M. Watson, 2008. “Phillips Curve Inflation Forecasts”, Conference Series.

Watson, M., 2014. “Inflation Persistence, the NAIRU, and the Great Recession”, *American Economic Review* 104 (5), 31-36. https://ideas.repec.org/a/aea/aecrev/v104y2014i5p31-36.html.

Yellen, J., 2014. “Labor Market Dynamics and Monetary Policy”, speech at the Federal Reserve Bank of Kansas City economic symposium, Jackson Hole, Wyoming, August 22 2014, speech 815, board of governors of the Federal Reserve System.

APPENDIX

Table A.1: Data Sources and Transformations

Variable	*Source*	*ADF p-value Test for unit root in level*	*ADF p-value Test for unit root in first difference*	*Frequency*	*Transformation applied to the original data*
HICP					
Headline HICP IE	Eurostat	0.10	0.00	monthly	Transformed into quarterly data (average); seasonal adjustment with Census 12.
Headline HICP EU	Eurostat	0.63	0.00	monthly	
Headline HICP EA	Eurostat	0.53	0.00	monthly	
Headline HICP UK	Eurostat	0.94	0.00	monthly	
HICP ex. food and energy IE	Eurostat	0.87	0.06	monthly	
Cyclical conditions					
Output gap IE	Ameco	0.02		annual	Converted into quarterly data by linear interpolation.
Output gap UK	Ameco	0.12	0.06	annual	
Output gap EU	Ameco	0.06		annual	
Output gap EA	Ameco	0.04		annual	
Output gap IE HP	Eurostat	0.00		quarterly	GDP data retrieved from Eurostat filtered with the Hodrick-Prescott filter. To limit the "end-point problem" which may result in estimates that are highly biased at the ends of the sample, we extend historical data with forecasts from the European Commission.
Output gap UK HP	Eurostat	0.01		quarterly	
Output gap EA HP	Eurostat	0.00		quarterly	
Output gap EU HP	Eurostat	0.00		quarterly	

Table A.1: Data Sources and Transformations (Contd)

Variable	*Source*	*ADF p-value Test for unit root in level*	*ADF p-value Test for unit root in first difference*	*Frequency*	*Transformation applied to the original data*
Modified domestic demand gap Ireland	CSO	0.12	0.00	quarterly	Modified domestic demand retrieved from CSO filtered with the Hodrick-Prescott filter.
Unemployment rate IE	CSO	0.39	0.09	quarterly	
Unemployment rate<1 year IE	CSO	0.53	0.02	quarterly	Seasonal adjustment with Census 12.
Unemployment rate UK	Eurostat	0.69	0.00	quarterly	
Unemployment rate EA	Eurostat	0.16	0.02	quarterly	
Unemployment rate EU	Eurostat	0.52	0.02	quarterly	
Unemployment gap (IE-UK)	Eurostat	0.19	0.45	quarterly	Difference between the Irish and British unemployment rates.
Unemployment gap (IE-EU)	Eurostat	0.29	0.17	quarterly	Difference between the Irish and EU unemployment rates.
Non-Employment Index IE	CSO	0.17	0.00		Following Byrne and Conefrey (2017), the NEI is computed as a weighted average of the shares of different groups of the working age population (e.g. discouraged workers, part-time underemployed…), where the weights for each cohort corresponds to that group's average transition probability to employment over the period 1998-2016. Byrne and Conefrey (2017) compute these probabilities based on microdata from the LFS. The NEI is calculated as a percentage of the working age population.

Table A.1: Data Sources and Transformations (Contd)

Variable	*Source*	*ADF p-value Test for unit root in level*	*ADF p-value Test for unit root in first difference*	*Frequency*	*Transformation applied to the original data*
NEI gap	CSO	0.06		quarterly	Difference between the NEI and its long-term average.
PLS	CSO	0.29	0.06	quarterly	Seasonal adjustment with Census 12.
IE Labour cost sector B to S	Eurostat			quarterly	
External drivers of inflation					
Oil prices (Brent) in euro	ECB, FRED	0.35	0.00	quarterly	Crude oil prices in USD retrieved from FRED and converted in euros with the exchange rate retrieved from the ECB.
Euro-sterling exchange rate	ECB	0.53	0.00	quarterly	
NEER12	ECB	0.31	0.00	quarterly	Nominal effective exchange rate of the euro against a group of trading partners (respectively, 12, 19 and 42 currencies).
NEER19	ECB	0.19	0.00	quarterly	
NEER42	ECB	0.12	0.00	quarterly	
IE nominal effective exchange rate (14 trading partners)	ECB	0.74	0.04	quarterly	Calculated using bilateral exchange rates retrieved from the ECB and moving trade weights, computed on the basis of the share of each partner country in Ireland's total imports of manufactured goods. The group of partner countries includes, besides the euro area, the UK, the US, Canada, the Czech Republic, Denmark, Norway, Poland, Sweden, Switzerland, China, Japan, Singapore and South Korea.

Table A.1: Data Sources and Transformations (Contd)

Variable	*Source*	*ADF p-value Test for unit root in level*	*ADF p-value Test for unit root in first difference*	*Frequency*	*Transformation applied to the original data*
IE nominal effective exchange rate (5 trading partners)	ECB	0.22	0.00	quarterly	The group of partner countries includes, besides the euro area, the UK, the US, Switzerland and China.
Import prices IE	CSO	0.62	0.00	quarterly	Deflator computed as the ratio of imports at current prices over imports at constant prices.
UK PPI (manufacturing)	ONS	0.97	0.00	monthly	Transformed into quarterly data (average).
Primary commodity prices in USD (including agriculture, wood, minerals, metals, fuel products)	EC	0.25	0.00	quarterly	Converted into euros using the euro-dollar exchange rate (retrieved from the ECB).
Primary commodity prices in USD excluding fuels	EC	0.47	0.00	quarterly	

Source: Author's analysis.
Note: A p-value below 0.10 for the augmented Dickey Fuller (ADF) test indicates that the null hypothesis of presence of a unit root is rejected at the 10 per cent level.

Table A.2: Diebold-Mariano and Clark-West Tests (P-Values) for Linear Models (Headline HICP)

	Clark-West	*Diebold-Mariano*						
		Benchmark model						
Model	*AR*	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*
(1)	0.00		0.81	0.94	0.77	0.85	0.15	0.47
(2)	0.00	0.19		0.86	0.73	0.81	0.12	0.37
(3)	0.00	0.06	0.14		0.66	0.71	0.06	0.13
(4)	0.00	0.22	0.27	0.34		0.50	0.13	0.23
(5)	0.00	0.15	0.19	0.29	0.50		0.09	0.06
(6)	0.00	0.84	0.88	0.94	0.87	0.91		0.68
(7)	0.00	0.53	0.63	0.87	0.77	0.94	0.32	
(8)	0.00	0.29	0.33	0.42	0.56	0.64	0.23	0.17

Source: Author's analysis.
Note: Models are estimated on 50-quarter rolling windows. Forecast errors are computed over 34 observations. Grey shaded cells highlight situations in which the null hypothesis is rejected at the 10 per cent level for the following hypotheses: the AR model performs as well as a Phillips curve model (Clark-West test); the benchmark Phillips curve specification (in columns) performs at least as well as the alternative Phillips curve models in rows (Diebold-Mariano test). For instance, a p-value of 0.06 indicates that we reject the null hypothesis that Model 1 performs as well as Model 3.