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Abstract

Heterogeneity in Phillips Curve slopes among members of a monetary union can lead to downward biases to estimates of the union-wide slope in reduced form regressions. The intuition is that in a monetary union with heterogeneous regional Phillips Curve slopes, the central bank, aiming at stabilizing demand shocks, will react stronger to shocks in regions with steep slopes compared to shocks in regions with flat slopes. Using a simple New-Keynesian model of a monetary union that omitting controls for this heterogeneity, we show that reduced form estimates of the union-wide slope suffer from a substantial bias towards zero. Empirically, we show that controlling for slope heterogeneity in Euro Area data increases reduced form estimates of the slope in the period since 2009.

JEL-Codes: E240, E310, E580.

Keywords: Phillips curve, heterogeneity, monetary meeting.

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1 Introduction

The observed empirical flattening of the Phillips Curve slope in many developed countries in recent decades has raised the attention of researchers and policy makers. A leading explanation of this phenomenon is that monetary policy has become more successful at stabilizing the economy over the last decades Boivin & Giannoni (2006). This success relies on the endogenous response of monetary policy to movements in inflation or slack, thereby introducing a negative relationship between the two, while the Phillips Curve relationship implies a positive co-movement. A a result, as McLeay & Tenreyro (2019) point out, it becomes impossible to observe the Phillips Curve relationship when analyzing aggregate data, similarly to the futile attempt of trying to recover demand curves from equilibrium price realisations. This explanation has also been echoed by policy makers, see e.g. Bullard (2018).[1]

In the presence of this endogeneity problem, reduced form estimations of the Phillips Curve based on macro - aggregate - data will yield downward biased estimates of the true slope of the Phillips curve, with potential consequences for monetary policy. Still, such reduced form estimations remain quite prominent in the literature, see for example Ball & Mazumder (2019) or Eser et al. (2020). Recently, several studies have shown the value of analyses using regional data in a monetary union as a *solution* to an endogeneity problem when estimating the slope of the union-wide Phillips curve: the endogenous response of monetary policy to shocks to inflation or output (McLeay & Tenreyro, 2019; Bharadwaj & Dvorkin, 2020). Since regional demand shocks cannot be fully stabilized by the union's central bank, they can serve as an exogenous shock to the output gap that affects inflation only through the Phillips Curve relationship. Both of the above cited analyses assume that the monetary union consists of structurally *homogeneous* economies, also with respect to the slope of the Phillips Curve. The same holds for (Eser et al., 2020; Hazell et al., 2020). Under this strong assumption the conclusions for identification of the slope are correct.[2]

In reality, systematic Phillips curve slope heterogeneity may in fact be a characteristic of large currency areas like the Euro Area. For example, Amberger & Fendel (2017) estimate country-specific reduced form Phillips Curve slopes in the Euro Area

[1] Other explanations suggest that there are important non-linearities in price and wage setting that standard analyses do not take into account (Lindé & Trabandt, 2019) or that household inflation expectations can explain the missing deflation after the Great Recession (Coibion & Gorodnichenko, 2015). More recently, Lombardi et al. (2020) suggest that the falling unionisation in advanced economies has weakened the link between tight labor markets and wages and prices.

[2] Only Kapetanios et al. (2020) explicitly tackle cross-regional heterogeneity and take stock of how different (pooled) estimators perform in estimating Phillips Curve slopes using regional data. They do allude to the endogeneity problem outlined above. Their main objective however, is the modelling of common correlated effects, a separate problem from the one analyzed in this paper. Additionally, their approach contains no quantification and differentiation between different sources of endogeneity, but rather a comparison of different estimators on the same underlying (real world) data.

and find substantial heterogeneity. Imbs et al. (2011) give a potential explanation for this heterogeneity: substantial heterogeneity in the duration of nominal rigidities across industries leads to biased estimates of the Phillips Curve slope at the aggregate level. Cross-country heterogeneity in sectoral or firm structure could therefore drive slope heterogeneities across countries. The aim of this paper is to illustrate and isolate the effects that heterogeneous, regional Phillips Curve slopes have on estimating common monetary union slopes using aggregate and regional data. As we show in the empirical part, slope heterogeneity cannot fully explain changes in the slope of the Euro Area, but can explain a substantial portion. Moreover, we show how to correct for the existence of slope heterogeneity.[3]

The intuition behind the aggregate impact of regional slope heterogeneity is straightforward. In a monetary union, the central bank aims at stabilizing aggregate demand shocks, which are a mix of underlying regional demand shocks. Theoretical models show that in monetary unions, the central bank's effort to stabilize a region-specific demand shock is a function of that region's Phillips Curve slope (among other variables) (Brissimis & Skotida, 2008; Lee, 2009). The reason is that the Phillips Curve moderates the effect of output gap variations on inflation. As a result, the output gap in regions with flatter Phillips Curves is more volatile than in regions with steep Phillips Curves. When estimating the union-wide slope of the Phillips Curve, the variation of the output gap that is due to the region-specific deviation from the union-wide slope enters the error term and biases the output gap coefficient towards zero unless one controls for slope heterogeneity. Omitting controls for slope heterogeneity in reduced form estimations could spuriously suggest flattening slopes while in reality, regional slopes have only diverged.

The paper is structured as follows. Section 2 illustrates the endogeneity problem using a simple New Keynesian monetary union model, by contrasting regression results on simulated data for a union with homogeneous slopes with results for a union with heterogeneous slopes. It isolates the impact of slope heterogeneity on estimates of the union wide slope and presents modifications to the estimation strategy that allow identification of the slope. The simulations show that both aggregate (i.e. union-level) as well as panel regressions suffer from this bias. We then show how the estimation strategy proposed by Breitung & Salish (2020) provides a tailor-made solution.[4]

In section 3, we use Euro Area data to explore the degree to which the heterogeneity issue problem biases real world estimates of the slope of the Phillips Curve. We first

[3] Our analysis does not intend to disprove any of the aforementioned mechanisms driving changes in the structure of the economy. Indeed, any change in slope heterogeneity could be driven by regions being subject to the mechanisms described above to different degrees. Therefore, we see our analysis as complementary to the many structural explanations put forward in the literature.

[4] From an econometric perspective this problem is not new. With the mean group estimator, Pesaran et al. (1999) presented a solution to biases due to slope heterogeneity more than 20 years ago.

provide evidence on the degree of heterogeneity in the inflation-unemployment trade-off among Euro Area members by estimating country specific Phillips Multipliers following the methodology of Barnichon & Mesters (2021).[5] Equipped with a gauge of the existing degree of heterogeneity, we move on to estimate different reduced form specifications. By estimating reduced form regressions following the method proposed by Breitung & Salish (2020), we test whether the observed degree of heterogeneity is sufficiently large to bias unemployment coefficients when heterogeneity is uncontrolled for. This exercise shows that controlling for slope heterogeneity in Euro Area panel regressions of core inflation on unemployment (and other controls) can steepen the estimated slope by up to 37%. Additionally, the estimator detects increasing slope heterogeneity in Euro Area data over time, masking a stronger steepening of the slope since 2009 if heterogeneity is uncontrolled for.

Section 4 concludes.

2 Slope heterogeneity: a simulation approach

We start the analysis by discussing the bias due to slope heterogeneity in a controlled setting. To this purpose, we simulate data according to a simple New-Keynesian model of a monetary union that is composed of two regions that can only differ in their idiosyncratic slope of the Phillips Curve. Varying the parameter that determines slope heterogeneity allows us to illustrate its theoretical impact on reduced form estimates of the union-wide slope.

2.1 Monetary Union Model

The monetary union model is characterized by a set of equations. Inflation in country i at time t is described by the following equation:

$$\pi_{it} = \beta E_t \pi_{it+1} + \kappa_i x_{it} + u_{it} \tag{1}$$

where κ_i is the Phillips Curve slope of country i and defined as $\kappa_i = \kappa + \eta_i$. η_i is the country-specific deviation from the union-wide Phillips Curve slope κ. In our model, η_i is distributed symmetrically around zero, yielding an expected value of κ_i across all regions equal to the union-wide slope κ. To isolate the effects of slope heterogeneity, differing values of κ_i are the only source of cross-region heterogeneity in this model. The

[5] In the empirical part of the analysis, due to lacking data on the output gap at monthly or quarterly frequency, we use the unemployment rate instead. We rely on the relatively stable relationship between the two variables first documented by Okun (1962).

supply shock is defined as an AR(1) process of the form $u_{it} = \rho_u u_{it-1} + \epsilon_{it}$ with the random variable $\epsilon_{it} \sim N(0, \sigma_\epsilon^2)$. The region's output gap is denoted by x_{it} and develops according to a standard IS equation:

$$x_{it} = E_t x_{it+1} - \sigma \left(\bar{i}_t - E_t \pi_{it+1} \right) + r_{it} \tag{2}$$

where σ measures the intertemporal elasticity of substitution and $\bar{i}_t$ is the union-wide nominal interest rate. The demand shock is defined as an AR(1) process of the form $r_{it} = \rho_r r_{it-1} + \mu_{it}$ with the random variable $\mu_{it} \sim N(0, \sigma_\mu^2)$. The demand shocks across the different regions are independently distributed.

The aggregate variables are defined as

$$\bar{\pi}_t = \Sigma_{i=1}^N w_i \pi_{it} \tag{3}$$

$$\bar{x}_t = \Sigma_{i=1}^N w_i x_{it}, \tag{4}$$

where w_i is country i's relative size in the monetary union, with $\Sigma_{i=1}^N w_i = 1$. The model is closed by an interest rate rule on the union-level of the following form

$$\bar{i}_t = \lambda_\pi \bar{\pi}_t + \lambda_x \bar{x}_t, \tag{5}$$

where λ_π is the central bank's weight on inflation stabilization and λ_x the corresponding weight on output stabilization. The target inflation rate is set to 0.

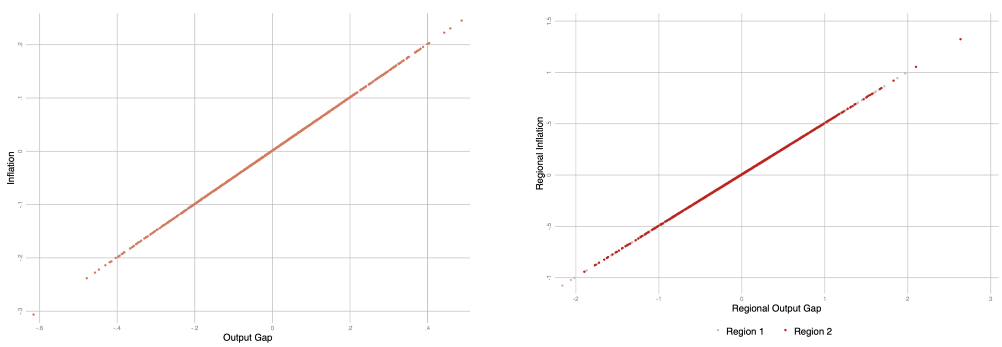
To isolate the endogeneity problems arising due to slope heterogeneity we simplify the model by switching off biases stemming from the relative size of cost-push shocks and from the persistence of both types of shocks, see McLeay & Tenreyro (2019). So we assume supply shocks are absent and shock persistence is zero. In the absence of persistence, the expected value for the subsequent period's inflation and output gap under rational expectations is always equal to its target, in this case zero for both variables. For simplicity, we assume that the monetary union is composed of two members of equal size ($w_1 = w_2 = 0.5$). Data is simulated for 200 periods. The other parameters are set to the following numerical values: $\sigma = 2, \lambda_\pi = 1.5, \lambda_x = 0.5, \sigma_{r_i}^2 = 0.7$. Note that the model abstracts from many important features of monetary unions, such as trade between members or common correlated shocks. However, the purpose of this paper is to isolate the impact of slope heterogeneity on the estimation of κ. It should be kept in mind that the bias that is demonstrated in what follows adds to the various biases that have been identified in the studies mentioned above.

2.2 Identification Under Homogeneous Slopes

Before introducing slope heterogeneity this section evaluates the identification problem under the assumptions described above as well as slope *homogeneity*: $\kappa_i = \kappa = 0.5$ for all i. The model is then simulated for the two regions. The purpose of this section is to provide a benchmark scenario in which identification of the slope is guaranteed in order to illustrate the contrast with results obtained under heterogeneous slopes.

Due to the absence of cost-push shocks the identification is straight-forward. Demand shocks will affect output and inflation in the same direction, so that the central bank does not face a trade-off. Co-movement between inflation and output is determined entirely by the Phillips Curve relationship. Figure 1a clearly shows the positive relationship between the output gap and inflation in the aggregate simulated data. A regression of the union-wide inflation rate on the output gap identifies the slope of the Phillips Curve, as column 1 in Table 1 shows. Under these circumstances using regional data provides no added value. The regressions provide the same results, irrespective of the inclusion of period fixed effects as columns 2 and 3 in Table 1 show. Any of the three regressions identify the union-wide slope of the Phillips Curve.

Figure 1: Inflation and Output Gap in Simulations: Homogeneous Slopes



(a) Aggregate Data

(b) Regional Data

2.3 Identification Under Heterogeneous Slopes

Next, we introduce slope heterogeneity. The union wide (average) slope remains at $\kappa = 0.5$ but we set $\eta_1 = 0.3$ and $\eta_2 = -0.3$. The aim of this exercise is to identify the union-wide slope κ under slope heterogeneity. Figures 2a and 2b show the aggregate and regional data for the simulated monetary union with slope heterogeneity. The picture looks very different from Figure 1. Clearly, the aggregate relationship in Figure 2a is blurry, showing that aggregate output gap and inflation are not helpful to identify the

Table 1: Regression Results on Simulated Data

	Homogeneous Slopes			Heterogeneous Slopes				
	(1) Aggregate OLS	(2) Pooled OLS	(3) Mean Group	(4) Aggregate OLS	(5) Pooled OLS	(6) Pooled OLS	(7) Mean Group	(8) Augmented GLS
$\bar{x}$	0.500***			0.009				
	(0.000)			(0.044)				
x		0.500***	0.500***		0.375***	0.429***	0.500*	0.500***
		(0.000)	(0.000)		(0.021)	(0.006)	(0.300)	(0.000)
z								-2.075***
								(0.000)
Constant	0.000	0.000	-0.000	0.001	0.008	0.220***	-0.000***	-0.000**
	(0.000)	(0.000)	(0.000)	(0.009)	(0.008)	(0.049)	(0.000)	(0.000)
Period Effects	No	No	CCE	No	No	PFE	CCE	No
Observations	200	400	400	200	400	400	400	400
R^2	1.000	1.000		0.000	0.655	0.968		

Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
Note: (1) and (4) regress aggregate inflation ($\bar{\pi}$) on the aggregate output gap ($\bar{x}$). (2) and (5) are pooled OLS regressions of regional inflation (π) on regional output gap (x). (3) and (7) are Mean Group regressions of regional inflation on regional output gap and common correlated effects (CCE), i.e. monthly average values of all regressors and the independent variable across all countries. (6) is an OLS regression of regional inflation on regional output gap and period fixed effects. (8) is a FGLS regression of regional inflation on regional output gap and an augmenting regressor (z) proposed by Breitung & Salish (2020).

union's Phillips Curve slope. By contrast, the regional data in Figure 2b clearly trace out the two regional Phillips Curve slopes.

2.3.1 Aggregate Data

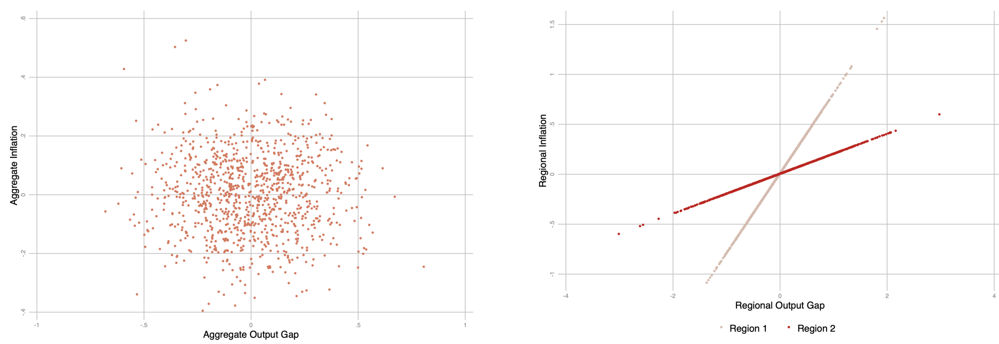
However, the relevant question for our analysis is whether the union-wide slope will be identified in reduced form regressions using aggregate or regional data. Column 4 in Table 1 presents the result for the regression using average - aggregate - data. As already suggested, by Figure 2a the slope is virtually zero and insignificant. The only difference in the data between columns 1 and 4 in Table 1 is slope heterogeneity. The bias can also be clearly linked analytically to slope heterogeneity. In column 4 the following regression was estimated

$$\bar{\pi}_t = \alpha + \kappa \bar{x}_t + v_t, \tag{6}$$

We denote the estimate of κ in equation 6 by $\hat{\kappa}$. Then, it is easy to show that bias of $\hat{\kappa}$ depends on the correlation between $\bar{x}_t$ and $\Sigma_{i=1}^{N} w_i \eta_i x_{it}$. The estimator for $\hat{\kappa}$ can be written as

$$\hat{\kappa} = \frac{Cov(\bar{\pi}_t, \bar{x}_t)}{Var(\bar{x}_t)} = \kappa + \delta_{agg}, \tag{7}$$

Figure 2: Inflation and Output Gap in Simulations: Heterogeneous Slopes



(a) Aggregate Data

(b) Regional Data

where δ_{agg} is the coefficient in an OLS regression of the omitted variable $\Sigma_{i=1}^{N} w_i \eta_i x_{it}$ on $\bar{x}$.

To shed more light on the bias, we estimate coefficient $\hat{\kappa}$ in the aggregate Phillips Curve regression for 200 simulations with 500 periods each. The average value of $\hat{\kappa}$ from these simulations is -0.023, with a standard deviation of 0.024. That is, the average bias is -0.523 which implies a strong *negative* correlation between $\bar{x}_t$ and $\Sigma_{i=1}^{N} w_i \eta_i x_{it}$.[6] .

How slope heterogeneity leads to this negative correlation and downward bias can be illustrated as follows. If a positive demand shock hits region 1, raising its output gap, the central bank will partly offset that shock by raising the policy rate. As a side effect, the output gap in region 2 will go down. Vice versa, a positive demand shock to region 2 will be partly offset by the central bank, with a negative impact on the output gap in region 1. However, due to the steeper Phillips curve slope in region 1, the central bank will offset the region 1 shock to a larger degree than the region 2 shock, despite the equal weight both regions have in the interest rate rule (Equation 5).[7] This has multiple consequences. First, region 2 experiences more volatile output gaps and inflation deviations than region 1. Therefore, the aggregate output gap is dominated by shocks to region 2. Second, the own shock effect is stronger for region 2, while the negative spillover effect from region 1 to region 2 is stronger than vice versa. In the end, it leads to a negative correlation between the output gap in region 1 and the aggregate output gap and a positive correlation between the output gap in region 2 and the aggregate output gap. The omitted variable $\Sigma_{i=1}^{N} w_i \eta_i x_{it}$ is the weighted average of the two regional output gaps, with a positive weight for the output gap in region 1 and a negative weight for the output

[6] In Appendix A we formally derive the bias. In this case, the theoretical value of $\hat{\kappa}$ is 0.022 and of the bias is -0.478.

[7] Brissimis & Skotida (2008) and Lee (2009) have already shown this asymmetric stabilization in more complex models of monetary unions with cross-region heterogeneity.

gap in region 2. Both parts contribute to the negative correlation between the omitted variable and the aggregate output gap and to the resulting negative bias.[8]

2.3.2 Regional Data

As McLeay & Tenreyro (2019) have shown, under persistent shocks and the existence of cost-push shocks regional data in a monetary union can alleviate the biases to the estimated Phillips Curve slope. We now turn to the question whether the use of regional data can also alleviate the bias due to Phillips curve slope heterogeneity. The raw data in Figure 2b already suggested that cross-regional heterogeneity is clearly detectable. However, the aim of this analysis is to find out whether in reduced form regressions using regional data we can identify the union wide slope κ. In column 5 in Table 1 we report results from the following pooled regression of regional inflation on the regional output gap

$$\pi_{it} = \alpha + \kappa x_{it} + e_{it} \tag{8}$$

where e_{it} is the error term. The regression yields a coefficient of the output gap of 0.375. This is much closer to the true union-wide slope of 0.5 than when using aggregate data, but nonetheless shows a significant downward bias. To understand the source of this bias, in the absence of supply shocks we can write the error term as:

$$e_{it} = \eta_i x_{it} \tag{9}$$

Clearly, the regressor in equation 8 and the error term are correlated as they both contain x_{it}. Analogous to the aggregate case, the overall correlation is negative due to the region with $\eta_i < 0$ which experiences larger variations in the output gap, resulting in a downward bias of $\hat{\kappa}$. However, some of the variation in the regional output gaps x_{it} is being stabilized by the central bank, blurring the Phillips Curve relationship (McLeay & Tenreyro, 2019). Period-fixed effects, or equivalently, regressions in terms of deviations from the union-wide aggregate, can control for this union-wide reaction of the interest rate to regional output gap fluctuations. Defining the regional deviation of a regional variable from its union-wide aggregate as $\tilde{y}_{it} = y_{it} - \bar{y}_t$, we estimate the following regression in column 6 of Table 1:

8 The size of each region's economy, measured by w_i, plays a similar role as the region's Phillips Curve slope. A larger relative size of the economy also leads to less variation in the output gap as any shock to output in a big region will, everything else being equal, have larger effects on aggregate inflation than demand shocks in small regions. However, in order to illustrate the issue of slope heterogeneity, this mechanism is switched off in the model by assuming equally sized regions.

$$\tilde{\pi}_{it} = \alpha + \kappa \tilde{x}_{it} + h_{it} \tag{10}$$

The output gap coefficient now rises to 0.429 with a remaining bias equal to -0.071. Controlling for the endogenous response of monetary policy to regional output gap fluctuations has thus decreased the bias to $\hat{\kappa}$. The error term becomes

$$h_{it} = \eta_i x_{it} - \kappa \bar{x}_t \tag{11}$$

while the resulting bias - now exclusively due to slope heterogeneity - can be retrieved by estimating the following regression:

$$\eta_i x_{it} - \kappa \bar{x}_t = \delta_{reg} \tilde{x}_{it} + \gamma_{it}. \tag{12}$$

In 200 separate simulations of 500 periods each, δ_{reg} has a mean value of -0.0775 with a standard deviation of 0.0039. Accordingly, $\hat{\kappa}$ has a mean value of 0.422. The intuition goes as follows and is closely related to the endogeneity in the aggregate data. Note that the omitted variable, $\eta_i x_{it} - \kappa \bar{x}_t$, measures the region's slope-dependent idiosyncratic deviation from the aggregate inflation rate. This inflation deviation is positively correlated to the total region-specific deviation from aggregate output and here the reasoning resembles that in the aggregate case: The steeper the regional Phillips Curve, i.e. the larger η_i, the smaller the regional deviation from aggregate output will be because the central bank will not allow that region's demand shocks to play out their full effect on inflation in order to minimize aggregate inflation's deviations from target. While the correlation is only negative in region 2 and positive in region 1, in a pooled setting the negative correlation dominates due to the wider dispersion of output gap realizations and inflation deviations in region 2.

All results so far come from simulated data for a given parametrisation of the model regarding the heterogeneity of slopes presented in section 2.1. It is easy to show that the bigger the regional deviations from the aggregate slope are, the bigger the biases will be. For small deviations, regional data can still help come reasonably close to identifying the slope, while the bias becomes substantial even in regional data with levels of heterogeneity assumed in the baseline parametrisation of the model. When using aggregate data, already small levels of heterogeneity lead to substantial underestimations of the slope of the aggregate Phillips Curve.[9] As a consequence, growing heterogeneities among members of a currency union could - according to this simple model - offer an explanation for

[9] More detailed results for the analysis of the aggregate and regional bias, including graphical evidence, is available on request from the authors.

an observed flattening of the Phillips Curve when estimating a common coefficient using aggregate or panel data, while in reality the curve has only flattened for some members and steepened for others.[10]

2.3.3 Controlling for Slope Heterogeneity

In this last part of the simulation exercise, we apply two different techniques that deal specifically with slope heterogeneity and contrast these results with those obtained from aggregate or panel OLS regressions. The first is a mean group estimator with common correlated effects (Pesaran et al., 1999). Kapetanios et al. (2020) have applied this approach to estimate Phillips Curve slopes from U.S. state-level data using mean group estimators augmented by common correlated effects, i.e. average values across all panel groups of all variables in the regression for each time period. This approach takes into account slope heterogeneity by averaging over the country-specific slopes. Breitung & Salish (2020) confirm that mean group estimators are unbiased under systematic slope heterogeneity but point out that they are inefficient. They propose a GLS regression that is augmented by the regressor z_{it}:

$$z_{it} = x_{it}\left(\frac{1}{T}\Sigma_{t=1}^{T}x_{it}^2 - \frac{1}{NT}\Sigma_{i=1}^{N}\Sigma_{t=1}^{T}x_{it}^2\right) \tag{13}$$

This approach specifically tackles the systematic nature of slope heterogeneity that is likely to be present when estimating Phillips Curves. A key pattern in the above simulation exercise is that output gaps in regions with flat Phillips Curves are much more volatile than those with steep curves. The augmenting regressor z_{it} captures this pattern to control for slope heterogeneity. The significance of the coefficient for the augmenting regressor therefore also serves as a test for the existence of slope heterogeneity. If there is no systematic slope heterogeneity, the difference between second moments of the main regressor and their average across all panel groups shouldn't differ across panel groups and the coefficient on z should not be significantly different from zero.

In columns 3, 7 and 8 of Table 1, the two methods are applied to the simulated data under slope homogeneity and heterogeneity. Column 3 shows that the mean group estimator performs equally well under slope homogeneity as OLS estimators. It also recovers the area-wide slope under slope heterogeneity (column 8). The augmented GLS regression results in the same point estimate but is estimated much more precisely, which

[10] Note that the pattern of growing biases to coefficients coming from reduced form regressions as a consequence of slope heterogeneity does not depend on the symmetric nature of heterogeneity assumed in the simulations. Any differences in regional slopes lead to differential implicit weights of member regions in the central bank's optimal monetary policy, and thus a bias to the coefficient in reduced form estimations.

is in line with the result on the relative efficiency of the two estimators provided by Breitung & Salish (2020).

3 Slope Heterogeneity and the Euro Area Phillips Curve

In the previous section we illustrated a potential endogeneity problem that arises when measuring the slope of a monetary union's Phillips Curve through a reduced form specification in the presence of slope heterogeneity among the union's members. Now, we focus on the Euro Area to analyze to what degree such slope heterogeneity matters in practice. To that end, we first provide evidence on the existing degree of heterogeneity in country-specific inflation-unemployment trade-offs, for which we use the methodology from (Barnichon & Mesters, 2021). In a second step, we apply the estimator proposed by Breitung & Salish (2020) to understand whether *reduced-form* panel regressions of inflation on unemployment (and other controls) at the sub-union level suffer from biases due to Phillips Curve slope heterogeneity. We also investigate whether the effects of slope heterogeneity on these reduced form approaches are time-varying.

As output gap estimates are only available at annual frequency in the Euro Area, we use the unemployment rate as a proxy of the existing slack in the economy in all analyses of this section, relying on the relatively stable relationship between the two variables first documented by Okun (1962). This implies that the theoretical sign of the Phillips Curve relationship reverses as unemployment and inflation should be negatively correlated.

3.1 Evidence on Cross-Country Heterogeneity in the Inflation-Unemployment Trade-off

To assess whether country-specific heterogeneity in Phillips Curve slopes exists in the Euro Area, reduced form evidence will not help us: country-specific regressions of inflation on unemployment may be misspecified as we cannot control for period fixed effects and panel regressions only recover a (potentially biased) union-wide estimate of the slope. Instead, we estimate the country-specific size of the inflation-unemployment trade-off using a methodology proposed by Barnichon & Mesters (2021). To avoid biases due to the endogenous reaction of monetary policy to demand shocks and due to the effects of cost-push shocks, Barnichon & Mesters (2021) exploit monetary policy surprises as exogenous changes in slack that move the economy along the Phillips Curve - and therefore allow the researcher to observe its slope. The key difference to reduced-form approaches at the country-level is that we identify co-movement in inflation and unemployment due to exogenous variations in unemployment. Applying this methodology at the country-level in the Euro Area can therefore expose the existing heterogeneity in country-level estimates of the inflation-unemployment trade-off. It should be noted that these so-called Phillips Multiplier estimates are not necessarily identical to estimates of the slope of the Phillips Curve. Due to the lack of country-level data on quantitative inflation expectations in the Euro Area, we can only quantify the total change in inflation due to a given monetary policy-induced change in unemployment. This total trade-off can include second-round effects that run through inflation expectations. There are two cases in which the Phillips Multiplier would be equal to the slope: i.) expectations are fully anchored at the target or ii.) expectations are entirely backward-looking.[11] This section therefore serves as a gauge of the dispersion of country-specific inflation-unemployment trade-offs around the Euro Area aggregate according to a common methodology that allows identification.

Specifically, we estimate a sequence ($h = 12, 13, .., 36$) of the following regression:

$$\Sigma_{j=0}^{h}\pi_{t+j} = \psi_h \Sigma_{j=0}^{h} u_{t+j} + X_t'\gamma_h + \epsilon_{t+h} \tag{14}$$

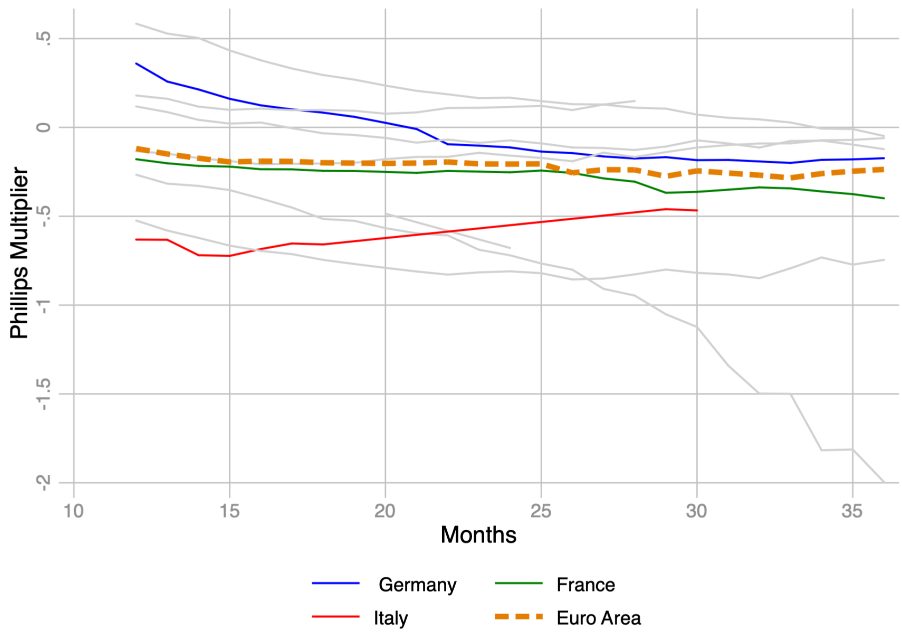
where $\Sigma_{j=0}^{h}\pi_{t+j}$ is the cumulative inflation rate from date t to date $t+h$, ψ_h is the Phillips Multiplier at horizon h, $\Sigma_{j=0}^{h}u_{t+j}$ is the cumulative unemployment rate and X_t is a vector of control variables, namely lagged unemployment and inflation. The cumulative unemployment rate $\Sigma_{j=0}^{h}u_{t+j}$ is instrumented by high frequency identified monetary policy surprises θ_t following the methodology of Jarociński & Karadi (2020). Specifically, we use the change in the 3-month ahead overnight indexed swaps (OIS) in a thirty minute window around the publication of the press release and the press conference after a monetary policy decision of the ECB Governing Council on days in which the OIS and the Euro Area stock market index EURO STOXX 50 moved in opposite directions. Jarociński & Karadi (2020) show that under these circumstances the actual monetary policy shock outweighs the effect of the publication of the central bank's outlook on future economic conditions.

We run these local projections for the ten founding members of the Euro Area and Greece as well as the Euro Area (changing composition) on aggregate. Inflation is measured with the core inflation rate (HCPI excluding energy and food). The sample runs from January 1999 to March 2019.[12] We estimate the Phillips Multiplier for horizons between 1 and 3 years to capture the full effects of a monetary policy shock after the transmission lag has passed. The results from this exercise will show to what degree the reaction of inflation to demand shocks induced by monetary policy surprises differs i) across individual Euro Area economies and ii) from the union wide multiplier.

[11] In the latter case, we would be controlling for inflation expectations through the inclusion of lagged inflation in equation 14.

[12] For Italy and Greece, the sample starts in January 2001

Figure 3: Phillips Multipliers: percent change in core inflation in response to monetary policy change that increases unemployment by 1pp



Note: The series of equations mentioned in equation 14 is run for each country individually. Control variables are 36 lags of core inflation and unemployment. Point estimates at individual horizons are excluded from the graph if 68% Anderson-Rubin confidence intervals are infinite or include gaps (Anderson & Rubin, 1949).

Figure 3 shows the Phillips Multiplier estimates between 12 and 36 months after the monetary policy shock.[13] The estimate of the multiplier for the Euro Area aggregate is just below -0.1 at 12 months after the impact of the shock, and drops to about -0.2 after 15 months and further to -0.25 after around 25 months. These estimates are roughly in line with the results in Eser et al. (2020).

For most countries, the estimated Phillips Multiplier is quite stable between 12 and 36 months after the monetary policy shock. Only Austria's estimate drops throughout the estimation horizon. Table 2 shows the mean and median multiplier estimate between 12 and 36 months after the shock for each country as well as 68% confidence intervals corresponding to the median point estimate. The vast majority of point estimates is below zero with the exception of Belgium and Spain. It should be pointed out that the

[13] Due to the lag in the transmission of monetary policy, the Phillips Multiplier is initially indeterminate, we therefore only report results at horizons between 12 and 36 months.

estimate for Belgium is falling steadily over the 3 year horizon and turns negative in the last months. For Spain, we cannot estimate the multiplier beyond a horizon of 28 months. Germany, France, the Netherlands and Portugal are closely clustered around the Euro Area wide multiplier. Austria is the only clear outlier below the union wide estimate. Overall, these estimates do not suggest that the reaction of inflation to exogenous, monetary policy induced shocks to unemployment differs widely across the early members of the Euro Area. The only clear outlier, Austria, accounts for little more than 3% of the Euro Area's GDP. Individual graphs of the estimated Phillips Multipliers by country including confidence intervals can be found in appendix B.

Table 2: Mean and Median Phillips Multiplier between 12 and 36 months after monetary policy shock and 68% Anderson-Rubin confidence intervals corresponding to the median Phillips Multiplier estimate

	Point Estimates		68% CI	
	Mean	Median	Upper	Lower
Austria	-0.876	-0.720	-0.248	-1.321
Belgium	0.202	0.165	0.248	0.087
Germany	-0.041	-0.113	0.021	-0.238
Spain	0.114	0.109	0.731	-0.062
France	-0.281	-0.253	-0.136	-0.365
Ireland	-0.762	-0.793	-0.545	-2.482
Italy	-0.626	-0.653	-0.138	-10.472
Netherlands	-0.054	-0.074	0.134	-0.371
Portugal	-0.147	-0.159	0.013	-0.347
Euro Area	-0.218	-0.205	-0.091	-0.323

Note: We do not report any results for Greece as Anderson-Rubin confidence intervals are either infinite or with gaps at all horizons. Finland is excluded from the table as multipliers and confidence intervals can only be estimated for two periods. The point estimate closest to zero is -0.485 and the corresponding confidence interval ranges from 0.265 to -32.638.

One prediction from the previous simulation exercise is that countries with steeper slopes should experience less volatility in their output gaps as the central bank will tolerate changes in these countries' output gap less due to their disproportionate effect on union-wide inflation. Our data do not offer support for this hypothesis. The correlation between the country-specific Phillips Multipliers estimates and the corresponding standard deviation of the country's unemployment rate over the same time frame is insignificant.

3.2 Reduced Form Evidence

Country-specific Phillips Multiplier estimates are unbiased estimates of the inflation-unemployment trade-off. The previous section found some heterogeneity in the Euro Area founding member states. Now, we want to obtain estimates of the *union-wide* slope of the Phillips Curve using reduced form panel regressions of inflation on a measure of economic slack (and other controls) and analyse the potential bias arising from the slope heterogeneity.[14] [15] We contrast results of regressions that omit slope heterogeneity controls with regressions that include those controls using the approach introduced by Breitung & Salish (2020). This methodology can detect and control for slope heterogeneity and is more efficient than a mean group estimator. In the analysis, we control for (qualitative) household inflation expectations using the European Commission's business and consumer survey.[16] Previous research shows the informational value of household inflation expectations (Coibion & Gorodnichenko, 2015) and their usefulness in Phillips Curve estimations (McLeay & Tenreyro, 2019). We also control for six lags of core inflation as well as seasonality. The sample runs from 1999 to the end of 2019.

Table 3 shows the results of these reduced form regressions. The dependent variable in all regressions is core inflation. Columns 1 to 3 are OLS regressions pooling all available data from the Euro Area founding members excluding Ireland and including Greece without controlling for slope heterogeneity. As others have shown before, the inclusion of period and region fixed effects steepens the estimated slope substantially McLeay & Tenreyro (2019). In column 3 we estimate a union-wide slope of -0.016 that is significantly negative.

Next, we move on to columns 4 to 6 in which we apply a FGLS estimator with panel group specific AR(1) autocorrelation structure and for panels in which $N < T$ (Parks, 1967). This estimator eventually allows the estimation of the model controlling for slope heterogeneity proposed by Breitung & Salish (2020) and introduced in section 2.3.3. The evolution of the slope estimate before and after the inclusion of country fixed effects (columns 4 and 5) shows a very similar pattern as in columns 2 and 3. Column 6 additionally controls for slope heterogeneity by including the augmenting regressor for

[14] See Eser et al. (2020), Hazell et al. (2020) or McLeay & Tenreyro (2019) for recent examples of this reduced form approach

[15] Of course, the methodology applied in the previous section is also a reduced form analysis. The key difference is that it allows identification of the multiplier at the country-level and therefore a measure of the heterogeneity.

[16] The business and consumer survey reports country specific balance statistics on expected inflation constructed from the household survey answers on price expectations. It subtracts the share of respondents that expect falling prices from those expecting rising prices. It can therefore not be interpreted as a point estimate of the future inflation rate. Due to incomplete expectations data for Ireland, we exclude the country from the panel analysis.

unemployment defined in equation 13.[17] The augmenting regressor scales each country's unemployment rate by the difference between the second moments of that country's unemployment rate and the aggregate unemployment rate over the whole sample period. As explained before, it is a direct measure of the mechanism by which countries with flat Phillips Curves will experience larger volatility of unemployment than those with steep slopes.

While the coefficient of the augmenting regressor in column 6 is not significantly different from zero, the point estimate of the unemployment coefficient steepens from -0.015 (without slope heterogeneity control) to -0.019 (with slope heterogeneity control) giving the steepest slope estimate of all regressions presented in the table. Both point estimates are significantly different from zero. The insignificant coefficient on the augmenting regressor can be a reflection of the relatively homogeneous country-specific multipliers found in section 3.1.

Of course, any heterogeneity in size, in the elasticity of intertemporal substitution or in other structural parameters can trigger a similar mechanism as heterogeneity in the Phillips Curve slope: heterogeneity in these variables will alter the implicit weight of a region in the central bank's interest rate rule. Without slope heterogeneity however, they would not lead to biased estimates of the union-wide Phillips Curve. Despite varying degrees of dispersion of output gap and inflation, the regional slopes would be the same. Nonetheless, to clearly illustrate the mechanism of slope heterogeneity, these other structural parameters were set to equal values for all regions. In reality this may not be the case.[18] Regarding the elasticity of intertemporal substitution, the determination is harder to make, mainly due to a lack of comparable cross-country estimates.[19]

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17 When constructing the augmenting regressor, we replace the term $\frac{1}{NT}\Sigma_{i=1}^{N}\Sigma_{t=1}^{T}x_{it}^{2}$ with the average squared Euro Area unemployment rate instead of the average of all country specific rates to take into account the different weights with which countries enter the Euro Area's aggregate. However, the results remain qualitatively unchanged when exchanging the two variables. The variable is also scaled by a factor of 0.001 for better readability of the results. Additionally, we do not present regression results when allowing for heterogeneity in the coefficient of expected inflation across regions as we do not detect any heterogeneity when allowing for it.

18 Unreported evidence shows that it is not necessarily large member states that have lower unemployment volatility. Controlling for the relative size of member states also does not change any of the results presented in this section.

19 In a meta study of estimates on elasticity of intertemporal substitution across countries Havranek et al. (2015) report very heterogeneous results for Euro Area countries, but point out that for a number of countries few estimates are available making the average for those countries highly dependent on individual modeling choices.

Table 3: Reduced form Phillips Curve estimations with core inflation as dependent variable

	OLS			FGLS		
	(1)	(2)	(3)	(4)	(5)	(6)
Unemployment	-0.004*	-0.003	-0.016***	-0.004**	-0.015***	-0.019***
	(0.002)	(0.002)	(0.004)	(0.002)	(0.003)	(0.004)
Expected Inflation	0.213***	0.145**	0.218***	0.112**	0.209***	0.228***
	(0.039)	(0.048)	(0.030)	(0.047)	(0.058)	(0.060)
Augmenting Regressor Unemployment						0.003
						(0.002)
Constant	0.016	0.122	0.250**	0.132	0.195**	0.209**
	(0.032)	(0.096)	(0.097)	(0.082)	(0.085)	(0.085)
# Lags Inflation	6	6	6	6	6	6
Period Fixed Effects	No	Yes	Yes	Yes	Yes	Yes
Country Fixed Effects	No	No	Yes	No	Yes	Yes
Observations	2436	2436	2436	2436	2436	2436
R^2	0.895	0.913	0.910			
RMSE	0.317	0.304	0.302	0.292	0.290	0.290

Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
Note: (1) is a pooled OLS regression of country-level core inflation on unemployment and expected inflation. (2) additionally controls for period fixed effects and (3) for country fixed effects. (4) is a FGLS regression with panel group specific AR1 autocorrelation structure and period-fixed effects. (5) additionally controls for country fixed effects. (6) augments (5) with the augmenting regressor defined in equation 13 following Breitung & Salish (2020). All regressions include seasonal dummies.

3.3 Slope Dynamics and Heterogeneity

The simulation results presented in section 2 clearly suggest that when slope heterogeneity is not controlled for, a change in the Phillips Curve slope in a monetary union observed in reduced form regressions could be entirely due to an increase in heterogeneity among members. This would mean that instead of a union-wide flattening, the curve has steepened for some members and flattened for others. The results from section 3.2 suggest that in the reduced form estimation on Euro Area data, unemployment coefficients steepen mildly when controlling for heterogeneity. However, the augmenting regressor meant to control for slope heterogeneity is insignificant, pointing to relatively homogeneous slopes across member economies. The aim of this section is to analyze to what degree slope heterogeneity has contributed to a potentially changing slope over time.

To detect potential changes in slope heterogeneity, unemployment and the augmenting regressor are both interacted with a dummy variable that takes the value 1 for the sub-period from 2009-2019.[20] The interaction terms indicate whether the coefficients on unemployment and the augmenting regressor differ between the two sub-periods. Table 4 presents the results. They suggest that the slope of the Euro Area Phillips Curve has steepened since 2009 - and that slope heterogeneity has masked the steepening to some

[20] As in the previous section, we do not allow for heterogeneity in the coefficient of expected inflation as all results are invariant to the inclusion of interaction terms.

degree if uncontrolled for.

Before 2009, we observe a coefficient on unemployment of about -0.01 in both specifications. Therefore, during the period 1999 to 2008, controlling for slope heterogeneity does not change the coefficient on unemployment. The augmenting regressor is insignificant. The results are different in the period between 2009 and 2019. Column 1 shows that without control for slope heterogeneity, the slope estimate steepens by a factor of roughly 1.6 compared to the period between 1999 and 2008.[21] In this sub-period however, introducing the augmenting regressor to control for slope heterogeneity leads to significant changes in the Phillips Curve slope estimates. First, the augmenting regressor is significant between 2009 and 2019. Secondly and consequently, the coefficient on unemployment changes when controlling for slope heterogeneity. It steepens to -0.022 compared to -0.016 without control. As the coefficient on unemployment during the first period is essentially unchanged between columns 1 and 2, we can conclude that slope heterogeneity was more pronounced in the second sub-period and a failure to control for it leads to an underestimation of the observed but insignificant steepening in column 1. When controlling for slope heterogeneity, we estimate a steepening by a factor of roughly 2 between the two sub-periods, compared to 1.6 in column 1.[22]

The results suggest that if slope heterogeneity is unaccounted for, the observed steepening of the slope is underestimated due to increasing slope heterogeneity within the Euro Area. The coefficient estimated with slope heterogeneity control in column 2 is more than 30% steeper than the one in column 1. To further illustrate this result, Figure 4 shows yearly estimates of the unemployment coefficient without (top row) and with (middle row) control for slope heterogeneity. The bottom row shows the coefficient of the augmenting control variable by year. When controls for heterogeneity are omitted, the estimated coefficient on unemployment is at zero for most of the early 2000s before falling slightly below around 2008. The middle row shows that once heterogeneity is controlled for, the fall in the slope after 2008 is somewhat more pronounced. However, it should also be noted that confidence intervals around the point estimate under heterogeneity control widen.

[21] A t-test of equality of coefficients on unemployment in column 1 can only be rejected with a p-value of 0.2.

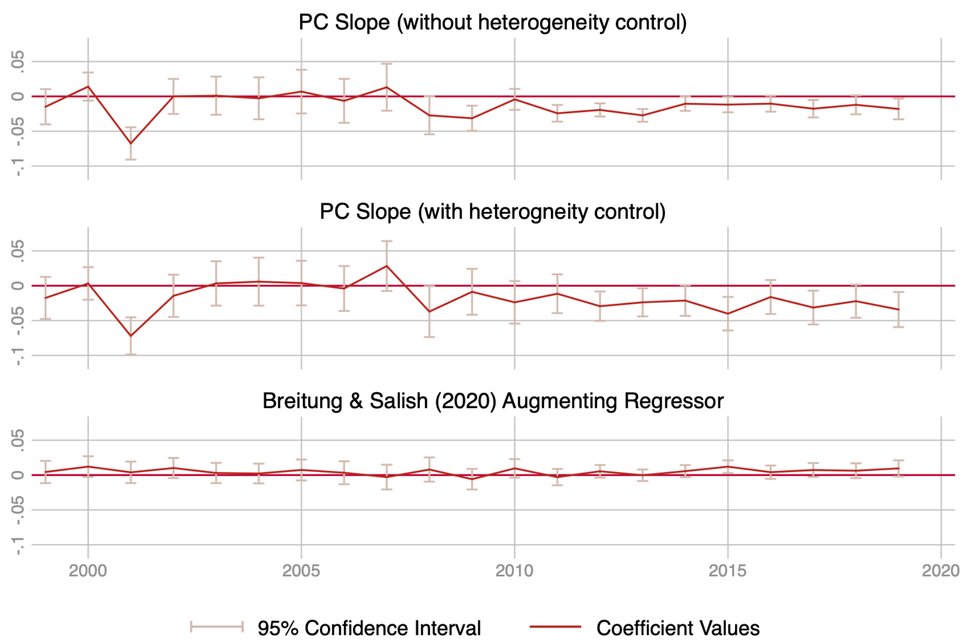
[22] A t-test of equality of coefficients on unemployment in column 2 between the two sub-periods is rejected with a p-value of 0.1.

Table 4: Reduced form Phillips Curve estimates by sub-period

	(1) FGLS	(2) Augmented FGLS
D1999-2008 × Unemployment	-0.010*	-0.011*
	(0.006)	(0.006)
D2009-2019 × Unemployment	-0.016***	-0.022***
	(0.003)	(0.005)
D1999-2008 × Augmenting Regressor Unemployment		0.006
		(0.004)
D2009-2019 × Augmenting Regressor Unemployment		0.005**
		(0.003)
Expected Inflation	0.194***	0.216***
	(0.060)	(0.060)
Constant	0.217**	0.255***
	(0.086)	(0.089)
# Lags Inflation	6	6
Period Fixed Effects	Yes	Yes
Country Fixed Effects	Yes	Yes
Observations	2436	2436
RMSE	0.290	0.290

Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Figure 4: Phillips Curve slope with and without heterogeneity control



Note: The top panel shows marginal effect of unemployment on the core inflation rate by year in a FGLS regression with panel group specific AR1 autocorrelation structure without controlling for slope heterogeneity. The middle panel shows the marginal effect of unemployment when including the slope heterogeneity regressor proposed by Breitung & Salish (2020). The bottom row shows the marginal effect of the augmenting regressor by year. All regressions control for expected inflation and include seasonal dummies and period fixed effects.

4 Conclusion

In this paper we illustrate the impact of slope heterogeneity among members of a currency union on estimations of the union-wide slope in reduced form regressions. If regional slopes differ, any attempt to estimate a union wide slope either on aggregate or pooled regional data will suffer from substantial omitted variable bias. The reason is that the slope of the Phillips Curve changes the implicit weight a union member gets in the central bank's monetary policy rule. In regions with steep Phillips Curves, demand shocks will be stabilized to a larger degree than the mere size of the economy would justify as these demand shocks would impact aggregate union inflation to a larger degree than demand shocks in regions with flat Phillips Curves. The more pronounced the heterogeneity, the larger the bias to coefficients from aggregated or pooled estimations.

In the second part of the paper we test whether the patterns in simulated data hold in Euro Area country-level data. First, we provide evidence on causally identified estimates of the inflation-unemployment trade-off for a group of 10 Euro Area member states. We go on to show that applying controls for slope heterogeneity proposed by Breitung & Salish (2020) lead to an insignificant steepening of the estimated Phillips Curve slopes when analyzing the Euro period as a whole. A sub-period analysis reveals that the slope of the Euro Area Phillips Curve has steepened by more than what reduced form estimates omitting heterogeneity controls suggest in the period since 2009 and the augmenting regressor controlling for slope heterogeneity turns significant.

Our results have implications for reduced form analyses of the Phillips Curve relationship. We show both theoretically and empirically that accounting for slope heterogeneity in a monetary union can steepen the estimated coefficient on unemployment. There are many recent examples of analyses that omit such controls and may therefore conflate trends of changing heterogeneity among sub-union entities with changes in the slope of the Phillips Curve, see for example Eser et al. (2020) for the Euro Area, Hazell et al. (2020) for an analysis of US state-level data and McLeay & Tenreyro (2019) for an analysis of US city-level data. Due to their relevance for reduced form analyses our results also have implications for monetary policy making. Some of the above mentioned papers originate from central bank research departments. When basing monetary policy on reduced form analyses lacking control for slope heterogeneity could lead to an underestimation of monetary policy effectiveness.

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Appendices

A Omitted Variable Bias

We start from equation 6. Since expectations are zero in every period, the model can be easily simplified to the following two expressions for the output gap in both regions in terms of the demand shocks:

$$x_1 = \frac{1}{s}\left(r_1(\sigma^{-1} + s_1) - r_2 s_1\right) \tag{15}$$

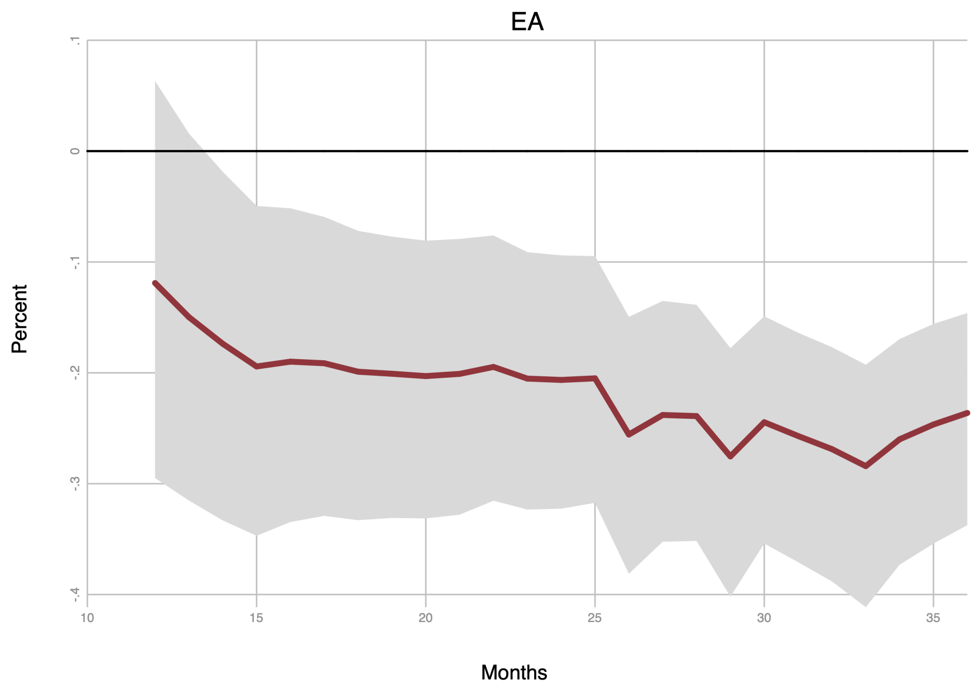
$$x_2 = \frac{1}{s}\left(r_2(\sigma^{-1} + s_2) - r_1 s_2\right) \tag{16}$$

where $s = \lambda_x + \lambda_\pi \kappa + \sigma^{-1}$, $s_1 = \lambda_x w_2 + \lambda_\pi \kappa_2 w_2$ and $s_2 = \lambda_x w_1 + \lambda_\pi \kappa_1 w_1$. The coefficient δ_{agg} in a regression of $\Sigma_{i=1}^{N} w_i \eta_i x_{it}$ on $\bar{x}$ is therefore:

$$\begin{aligned} \delta_{agg} = &\Big\{\sigma_{r_1}^2\Big[\left(w_1\eta_1\left(s_1 + \sigma^{-1}\right) - w_2\eta_2 s_2\right)\left(w_1\left(s_1 + \sigma^{-1}\right) - w_2 s_2\right)\Big] \\ &+\sigma_{r_2}^2\Big[\left(w_2\eta_2\left(s_2 + \sigma^{-1}\right) - w_1\eta_1 s_1\right)\left(w_2\left(s_2 + \sigma^{-1}\right) - w_1 s_1\right)\Big]\Big\} \\ &\Big\{\sigma_{r_1}^2\Big[w_1\left(s_1 + \sigma^{-1}\right) - w_2 s_2\Big]^2 \\ &+\sigma_{r_2}^2\Big[w_2\left(s_2 + \sigma^{-1}\right) - w_1 s_1\Big]^2\Big\}^{-1} \end{aligned} \tag{17}$$

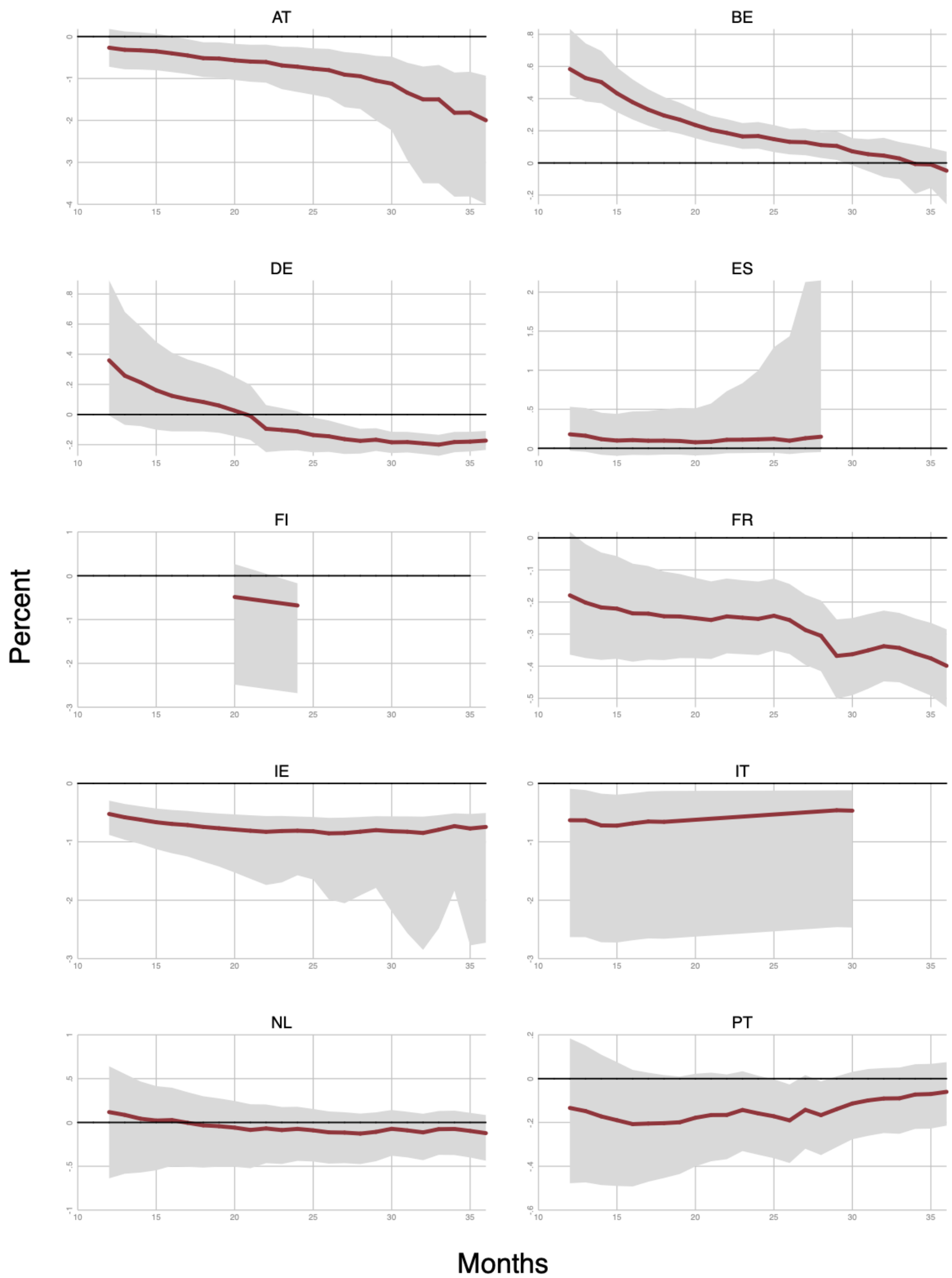
B Phillips Multipliers

Figure 5: Phillips Multiplier for the Euro Area



Note: The graphs shows Phillips Multiplier over horizons between 12 and 36 months after the monetary policy shock for the Euro Area following Barnichon & Mesters (2021). Shaded area indicates 68% confidence intervals. Regressions of cumulative core inflation on cumulative unemployment include 36 lags of core inflation and unemployment. As the multiplier is indeterminate at short horizons due to the transmission lag of monetary policy, we only report horizons between 12 and 36 months.

Figure 6: Phillips Multipliers by Country



Note: The graphs show Phillips Multipliers over horizons between 12 and 36 months after the monetary policy shock by country following Barnichon & Mesters (2021). Shaded areas indicate 68% Anderson-Rubin confidence intervals. Regressions of cumulative core inflation on cumulative unemployment include 36 lags of core inflation and unemployment. As the multiplier is indeterminate at short horizons due to the transmission lag of monetary policy, we only report horizons between 12 and 36 months.