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**by Stefan Reitz and Ulf D. Slopek**

**No. 1795 | September 2012**

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Keywords: Wage rigidities; inflation dynamics; stochastic frontier model

JEL classification: E24; E32; E52

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# Fixing the Phillips Curve: The Case of Downward Nominal Wage Rigidity in the US

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## Abstract

Whereas microeconomic studies point to pronounced downward rigidity of nominal wages in the US economy, the standard Phillips curve neglects such a feature. Using a stochastic frontier model we find macroeconomic evidence of a strictly nonnegative error in an otherwise standard Phillips curve in post-war data on the US nonfinancial corporate sector. This error depends on growth in the profit ratio, output, and trend productivity, which should all determine the flexibility of wage adjustments. As the error usually surges during an economic downturn, the empirical model suggests that the downward pressure on inflation arising from higher unemployment in a standard Phillips curve framework is significantly cushioned. This might help to understand the robustness of inflation especially in the most recent past. In general, the cyclical dynamics of inflation appear to be more complex than captured by a conventional Phillips curve.

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## 1. Introduction

The Phillips curve and the related concepts of the output gap and the non-accelerating inflation rate of unemployment (NAIRU) provide a convenient and intuitive framework within which macroeconomic developments can be analyzed and forecasted. The Phillips curve continues to shape the thinking of economists and policymakers, even though it is well-known by now that the dynamics of inflation are more complex than described by such a relationship. One of the factors that have largely been neglected by both the traditional Phillips curve framework and the recent policy debate is the downward rigidity of nominal wages. We argue that in the context of relatively low inflation and weakened aggregate demand in the US this downward rigidity could have hindered the clearing of the labor market by preventing nominal wage cuts that would have occurred otherwise. By the same token, this labor market inefficiency might have compensated for deflationary pressures from elevated unemployment thereby stabilizing inflation over the business cycle.

We contribute to the literature on the Phillips curve by providing empirical evidence on the impact of downward wage rigidity on inflation dynamics. As a starting point, we re-estimate the Akerlof et al. (1996) model designed to capture the influence of downward rigidity of nominal wages. Inspired by their approach, we also extend the analysis estimating a stochastic frontier model of the Phillips curve, which seems to be a more natural candidate to empirically identify such a labor market inefficiency. The latter model suggests that a standard Phillips curve underestimates inflation by a markup which depends on variables such as growth in profits, output and productivity. Thus, the cyclical dynamics of inflation might be more complex than suggested by a conventional Phillips curve. We conclude that a standard Phillips curve is in practice no substitute for a thorough and detailed analysis of all forces driving inflation.

The remainder of the paper is organized as follows. In Section 2, we provide a brief overview over the literature. In Section 3 we first review the empirical model put forward by Akerlof et al. (1996). Second, the stochastic frontier model applied to the augmented Phillips curve is introduced. The third subsection contains data description and the estimation results. In the final subsection we report the results of a variety of robustness checks. We have also compiled evidence on other countries in Section 4. Finally, we make some concluding remarks and suggestions for future research.

## **2. The Phillips Curve, Inflation Dynamics, and Downward Rigidity of Nominal Wages**

In the last few decades, the failings of the basic Phillips curve to explain and predict movements in inflation have prompted an extensive literature on the theoretical as well as the empirical relationship between inflation and unemployment.<sup>1</sup> The experience of stagflation in the 1970s led to the appreciation of the role of expectations in driving inflation, while the coincidence of low levels and downward trends in both inflation and unemployment during the 1990s motivated a reassessment of the impact of productivity trends (Ball and Mankiw, 2002). The relationship between inflation and unemployment seemed to weaken over time, leading to a ‘flattening’ of the Phillips curve and impairing the usefulness of inflation forecasts based on it, as spelled out by Atkeson and Ohanian (2001). Nevertheless, inflation continues to be forecasted within a Phillips curve framework at important institutions.<sup>2</sup> It is still shaping the thinking of many policymakers (Kohn, 2008), although its shortcomings and the uncertainties surrounding its estimations are also appreciated (Meade and Thornton, 2010).

Indeed, the more recent policy debate within the Federal Open Market Committee (FOMC) of the Federal Reserve highlights the prominent role played by the employment gap. During several meetings in 2010, FOMC members discussed the extent to which the high level of unemployment in the US was driven by structural factors, with the majority of participants perceiving relatively large resource slack within the economy. The dissent also extended to the risks surrounding the inflation outlook in late 2010, when some saw the balance of risks as tilted to the downside and a couple to the upside. The debate continued within the FOMC in 2011, culminating prior to the controversial decision on the latest round of monetary stimulus.<sup>3</sup>

However, while the labor market in general – and the distinction between the cyclical and the structural impact on unemployment in particular – seemed to have been central to the recent monetary policy debate, the downward rigidity of nominal wages has not yet been discussed. This contrasts with microeconomic studies increasingly finding evidence in favor of its prevalence in the US, thereby overcoming an earlier dispute

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<sup>1</sup> For an overview of the evolution of the Phillips curve and its role in monetary policy see King (2008).

<sup>2</sup> See for example Arnold (2008) for the re-estimation of the Phillips curve at the Congressional Budget Office (CBO).

<sup>3</sup> See the Minutes of the Federal Open Market Committee, November 2-3, 2010, and September 20-21, 2011, <http://www.federalreserve.gov/monetarypolicy/files/fomcminutes20101103.pdf>, <http://www.federalreserve.gov/monetarypolicy/files/fomcminutes20110921.pdf>.

within the literature. Particularly, the International Wage Flexibility Project concludes that the degree of downward rigidity of nominal wages in the US is high compared to other advanced economies (Dickens et al., 2007), which might be explained by behavioral factors.<sup>4</sup> But such a feature of the economy has important implications for monetary policy as it opens up the possibility of a long-run trade-off between inflation and unemployment, as has already been suggested by Tobin (1972) and elaborated in detail by Akerlof et al. (1996). If an inflation target is set too low in the presence of downward rigidity, nominal wage growth might not be able to fully accommodate a sudden, large fall in aggregate demand, so that the adjustment in the labor markets falls on employment rather than (real) wages. Depending on the microeconomic evidence on the degree of downward rigidity, Fagan and Messina (2009) infer an optimal steady-state US inflation rate of 2%-5% from a DSGE model, markedly higher than for some European countries (0%-2%).

Stylized facts on the US labor market in recent years seem to fit a scenario of an economy facing a lower limit of nominal wage growth (Deutsche Bundesbank, 2011). While nominal wage growth, as shown by several relevant indicators such as compensation data or the Employment Cost Index (ECI), declined during the recession, it remained stubbornly positive, thereby bolstering real wages and probably exacerbating the drop in employment. Surprisingly, although the recent performance of the US labor market has been subject to close scrutiny,<sup>5</sup> the behavior of wages has only been stressed by Shimer (2010). Given the potential role which the downward rigidity of nominal wages might have played in recent years, and its far-reaching implications, we investigate its empirical evidence at the macroeconomic level.

### **3. Empirical Evidence**

Not only have Akerlof et al. (1996) refined the basic argument proposed by Tobin (1972) into an explicit macroeconomic model yielding a nonlinear Phillips curve in simulations, which is vertical at low rates of unemployment and flat at high rates. They have also tried to bring forward empirical evidence by identifying wage inflexibility as a nonnegative inefficiency term in an otherwise standard price Phillips curve. A

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4 Bewley (1999) collected survey evidence pointing to the impact on morale and productivity of their employees as the main reason why firms refrain from cutting nominal wages.

5 See for example Elsby et al. (2010).

significant impact of firms' profits on the wage setting process is revealed by a quite specific recursive nonlinear model. However, with respect to postwar data (1954-95) their modification provides little additional information so that their approach seems to be of minor practical relevance. Gordon (1996) and Mankiw (1996) argue that any evidence on downward nominal wage rigidity from a period of marked inflation may have no implication for an economy subject to price stability as, along the lines of the Lucas critique, the rigidity could simply vanish. Moreover, Gordon (1996), advocating a strictly linear Phillips curve, notes that Akerlof et al. (1996) did not provide direct evidence on the nonlinear shape of the Phillips curve, because their additional term enters the equation linearly and might capture the impact of variables otherwise omitted.

In order to address this criticism and to provide evidence on the role of downward wage rigidity in determining inflation dynamics we follow two different empirical approaches. First, we briefly recap the model of Akerlof et al. (1996) and update their regression results using a different dataset. By encompassing the more recent past, this dataset also reflects the working of the US economy under price stability. Given that the empirical model aims at identifying a strictly nonnegative bias in the Phillips curve, a much simpler and more straightforward alternative covering the aforementioned critique is to estimate a stochastic frontier model. Thus, we also provide regression results from this empirical framework.

### 3.1 The Augmented Phillips Curve of Akerlof et al. (1996)

As a starting point of the analysis on the effects of downward wage rigidity a Phillips curve derived from a wage setting equation is considered:

$$w_t = p_t^e \omega_t^n, \quad (1)$$

Due to equation (1) the actual nominal wage  $w_t$  is the product of the expected price level  $p_t^e$  and the real notional wage  $\omega_t^n$ . The latter is determined by the wage bargaining process and will therefore depend on the level of unemployment. The current price level is assumed to be the product of a markup factor  $m$  and aggregate expected unit labor costs

$$p_t = m p_t^e \frac{\omega_t^n}{G_t}, \quad (2)$$

where  $G_t$  denotes aggregate labor productivity. Subtracting the natural log of the lagged price level from the natural log of eq. (2) and assuming the notional wage per unit of output to be a log linear function of unemployment  $u_t$ ,

$$\pi_t = \pi_t^e + c - \alpha u_t, \quad (3)$$

we arrive at the well-known Phillips curve, where  $\pi_t$  is the actual rate of inflation and  $\pi_t^e$  is the expected rate of inflation. The expected rate of inflation is formulated as a linear function of lagged actual inflation, in which the sum of coefficients is restricted to unity. On the basis of the Akaike Information Criterion (AIC) we allow the expected rate of inflation to be determined by lagged actual inflation back to time  $t - 4$ :<sup>6</sup>

$$\pi_t^e = \gamma_0 \pi_{t-1} + \gamma_1 \pi_{t-2} + \gamma_2 \pi_{t-3} + \gamma_3 \pi_{t-4}. \quad (4)$$

From a theoretical perspective it might be argued that given the structure of the model, inflation expectations should rationally include additional forward looking arguments. Although theoretically more convincing, the appropriate empirical specification remains an issue of open debate. For example, in a time-varying coefficients framework for a number of European countries Hondroyannis et al. (2009) provide some support for the view that the inertia components in hybrid Phillips curves models that use GMM estimation might reflect specification biases. Since the aim of the paper is to provide empirical evidence on the influence of downward wage rigidity we consider the results of Canova (2007) and Stock and Watson (2007, 2008) and stick to the more parsimonious autoregressive specification. To augment this standard Phillips curve with an additive term reflecting the effects of downward wage rigidities, Akerlof et al. (1996) define a shift term  $s_t$  as the gap between the real actual wage and the real notional wage deflated by labor productivity

$$s_t = \frac{w_t - w_t^n}{p_t^e G_t}, \quad (5)$$

or, using eq. (1) and rearranging,

$$w_t = p_t^e \omega_t^n \left( 1 + \frac{G_t}{\omega_t^n} s_t \right). \quad (6)$$

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<sup>6</sup> Auxiliary regressions of the AR( $k$ ) process of inflation reveal similar AIC results for  $k = 3$  and  $k = 4$ , so we opt for the more general framework.

The shift in unit labor costs due to downward wage rigidity has the same effect on the Phillips curve as any other change in unit labor costs. Due to the assumed pricing behavior, the price level (2) is also determined by the shift term:

$$p_t = mp_t^e \frac{\omega_t^n}{G_t} \left( 1 + \frac{G_t}{\omega_t^n} s_t \right). \quad (7)$$

Akerlof et al. (1996) suggest that  $G_t/\omega_t^n$  can be approximated by  $\beta/(\beta-1)$ , whereby  $\beta$  denotes consumers' elasticity of demand. Taking logs leads to the augmented price Phillips curve

$$\pi_t = \pi_t^e + c - \alpha u_t + \frac{\beta}{\beta-1} s_t. \quad (8)$$

Because of downward wage inflexibility, the actual nominal wage will be the maximum of the notional wage and the lagged nominal wage. Assuming that the notional and the lagged wage are jointly normally distributed  $s_t$  may be derived recursively using

$$s_t = \sigma \phi(v_t/\sigma) + v_t \Phi(v_t/\sigma) \quad (9)$$

and

$$v_t = \frac{s_{t-1} - [\beta/(\beta-1)][\Delta p_t^e + g_t - \alpha(u_t - u_{t-1})]}{1 + \Delta p_t^e + g_t} + \delta(r_t - r_{t-1}). \quad (10)$$

where  $\Delta p_t^e = \pi_t^e + \pi_{t-1} - \pi_{t-1}^e$  is the rate of change of price expectations,  $\phi$  and  $\Phi$  are, respectively, the standard normal density function and the cumulative normal distribution function,  $\sigma$  is the standard deviation of  $v_t$ , and  $r_t$  are firms profits at time  $t$ .

The functional form of eq. (9) ensures that  $s_t \in [0, v_t]$  is strictly nonnegative and has the following intuitive interpretation. In a constrained situation where firms face low inflation rates and little growth in labor productivity, the shift term  $s_t$  gets larger and finally approaches  $v_t$ . This implies that actual wages do not follow decreasing notional wages, but remain at the level of last period's actual wage. On the other hand, in a situation characterized by high inflation rates and/or strong growth in labor productivity actual wages will be set at their notional level. In fact,  $v_t$  will then be very negative resulting in a zero shift term. Since the change of the notional wage is driven by expected inflation, growth in productivity, and unemployment, the shift term has the same set of arguments. By the logic of eq. (10), productivity and inflation will narrow the gap between actual and notional wages, while unemployment reduces the notional

wage leading to an increase of the shift term. Besides the standard variables determining the wage setting, Akerlof et al. (1996) consider firms' profits as an important argument of the downward wage inflexibility. They reason that the downward rigidity of nominal wages is not perfect and that the constraint should be relaxed for firms under severe stress, since workers may accept necessary pay cuts in the face of firm losses or because firms go out of business and the employees are rehired by new firms at lower wages. As a result, a decline in the profit share  $r_t$  should reduce the inefficiency term  $s_t$ .

### 3.2 A Stochastic Frontier Model

The Akerlof et al. (1996) theoretical model of wage inflexibility fits naturally into a specification that can be estimated using Stochastic Frontier Analysis.<sup>7</sup> The classic applications of Stochastic Frontier Analysis, such as Aigner, Lovell and Schmidt (1977), estimate production or cost functions that are viewed as the most efficient outcomes possible. Individual observations deviate from this ideal by a symmetric error that has zero mean, and by a one-sided error that is interpreted as inefficiency specific to that firm. Stochastic Frontier Analysis has been applied in financial economics by Green, Hollifield and Schurhoff (2006) to study financial intermediation in the municipal bond market, by Berger and Mester (1997) and Altunbas, Gardener, Molyneux and Moore (2001) to study efficiency in the banking industry. In our application, the time varying shift component arising from downward wage rigidity can be viewed as an inefficiency term in the price Phillips curve, which raises actual inflation above 'efficient' inflation. Such an inflation markup is based on the assumption that firms are able to shift excess labor costs to output prices. Whether or not this assumption holds during the entire business cycle is also an empirical question.

To arrive at an econometric specification, we augment the price Phillips curve in equation (3) with two error terms. First, a symmetric error  $\varepsilon_t \sim N(0, \sigma^2)$  that accounts for additional temporary cost push factors unrelated to the variables specified in the above model. Second, a strictly nonnegative inefficiency term

$$\xi_t = s_t, \tag{11}$$

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<sup>7</sup> Greene (2002) provides a discussion of Stochastic Frontier Analysis at a textbook level.

where  $s_t$  is assumed to be double exponential. The density on each side of the mean is 0.5 times the exponential density with parameter  $\lambda_t$ . The distribution conditional on  $s_t \geq 0$  is exponential with parameter  $\lambda_t$ . The one-sided error  $\xi_t$ , conditional on  $\xi_t \geq 0$ , therefore is exponentially distributed with parameter  $\lambda_t$ . The first two moments of  $\xi_t$  are

$$E[\xi_t | \xi_t \geq 0] = 1/\lambda_t, \quad (12)$$

$$V[\xi_t | \xi_t \geq 0] = 1/\lambda_t^2. \quad (13)$$

Given the suggested influence of various variables on wage rigidity as outlined in the Akerlof et al. (1996) model we estimate specifications where the exponential error term has parameter  $1/\lambda_t$  that is a log-linear function of the change of firms' profit ratio  $\Delta r_t$ , the growth in output  $y_t$ , and the trend growth of labor productivity  $g_t^{trend}$ . With stronger growth in output or trend productivity downward pressures on nominal wages should recede and, thus, the inefficiency should become smaller. In contrast to developments in trend productivity, output growth is supposed to capture the impact of the business cycle. Thus,

$$E[\xi_t | \xi_t \geq 0] = b_0 \exp(b_1 \Delta r_t + b_2 y_t + b_3 g_t^{trend}). \quad (14)$$

Since increased labor productivity tends to reduce unit labor costs we may also expect a dampening effect on inflation.<sup>8</sup> Thus, for the sake of generality, we introduce the growth of labor productivity as a separate variable in the Phillips curve. The coefficients of the resulting augmented Phillips curve

$$\pi_t = \pi_t^e + c + \alpha u_t + \theta g_t + \varepsilon_t + \xi_t, \quad (15)$$

where again

$$\pi_t^e = \gamma_0 \pi_{t-1} + \gamma_1 \pi_{t-2} + \gamma_2 \pi_{t-3} + \gamma_3 \pi_{t-4} \quad (4)$$

are estimated by maximum likelihood. In the stochastic frontier model, we do not impose any restrictions on the sum of coefficients of lagged inflation. This is a deviation from standard procedure in estimating Phillips curves which assumes that the coefficients add up to unity. However, as stressed already by Sargent (1971), rational

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<sup>8</sup>In the long run, there is also some room for a reversed causal relationship. In an endogenous growth model of learning by doing merged with a New Keynesian model with sticky wages Vaona (2012) derives a positive intertemporal elasticity of substitution of working time. Adopting various semiparametric and instrumental-variable estimation approaches on a cross-country/time-series data set, it is shown that increasing inflation may reduce real economic growth.

expectations imply that such a restriction would only be reasonable in case the inflation generating process was governed by strong autocorrelation.

### 3.3 Estimation Results

The estimation results are based on data provided by the Bureau of Labor Statistics (BLS) and the Bureau of Economic Analysis (BEA) on the nonfinancial corporate sector. Even though this sector only accounted for roughly half of GDP in 2010, it represents the (nonfinancial) part of the economy that is profit-oriented and does not depend on self-employment.<sup>9</sup> The main advantage of this sectoral limitation is that BLS and BEA provide consistent measures for output, productivity, costs, prices and profits. Firms' profits refer to profits per unit of output as published by the BEA and the profit share is the ratio of unit profits and unit price. The respective figures are constructed as the first difference of the log of seasonally adjusted indices. The unemployment rate is defined as the ratio of total civilian unemployment (sixteen years and above) and the civilian labor force, both seasonally adjusted and provided by the BLS. The variable  $g_t^{trend}$  entering the inefficiency term is the Hodrick-Prescott trend of labor productivity growth. This data transformation circumvents problems of slow convergence and excessive sensitivity to the choice of starting values of the likelihood maximization routine. The quarterly data ranges from 1Q1958 to 1Q2011. Table 1 contains the final estimation results.

[Insert Table 1 about here]

The estimation results of the Akerlof et al. (1996) model contained in the first column of Table 1 reveal statistically significant coefficients of appropriate sign. As a preliminary impression, the analysis of the extended data range suggests that the presence of downward wage rigidity is a robust empirical phenomenon. When looking at the details the following issues are worth mentioning. Since we are dealing with quarterly data we allowed for four lags determining the inflation expectations. As in the

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<sup>9</sup> The sector excludes: general government, nonprofit institutions, private households, unincorporated business and financial corporations. We discard financial corporations because of their possibly specific developments in profits, in particular in recent years.

original paper, the coefficients of lagged inflation are constraint to add up to unity, although the third lag is not statistically significant. The estimated parameter  $\alpha$  in eq. (8) points to a decrease of inflation in the presence of unemployment thereby confirming standard mechanics of the Phillips curve. The central contribution of Akerlof et al. (1996), however, is the identification of a labor market inefficiency, which is driven by the dynamics of the shift term  $S_t$ . The empirical results indicate that in a recession, when firms are constrained by relatively low productivity growth and inflation wages are set in the neighborhood of wages last period, which imply a comparatively high value of the inefficiency term. In case of high productivity growth and/or inflation, in contrast, wages are set at the notional level driving the inefficiency term to zero. The estimated coefficient  $\delta$  reveals that within this setting, declining firms' profit shares reduce the reluctance of workers to accept notional wages in times of recession. Indeed, the empirical results from this model show that during recessions inflation rates have been higher than the standard Phillips curve would have suggested.

Given the quite specific recursive structure of the Akerlof et al. (1996) model and the criticism by Gordon (1996) it seems straightforward to ask whether the influence of downward wage rigidity can also be identified in a simpler nonlinear empirical framework. A natural candidate is the stochastic frontier model outlined in sub-section 3.2. The linear component of the empirical Phillips curve departs from the Akerlof et al. (1996) model in two different respects. First, we introduce productivity growth to possibly exert a dampening effect on current inflation (Ball and Mankiw, 2002). Second, we refrain from restricting the coefficients of lagged inflation determining the inflation expectations to sum up to unity. This allows for a stationary process of inflation implying that shocks to inflation from productivity growth, unemployment or the inefficiency term may remain temporary.<sup>10</sup>

The estimation results in the second column of Table 1 confirm the usefulness of the modeling strategy. While the statistically significant parameter of labor productivity growth reveals the expected dampening influence on inflation, the sum of lagged inflation rates is well below unity suggesting stationary inflation dynamics. Moreover, the coefficient of unemployment is estimated considerably lower than in the Akerlof et al. (1996) model, though still statistically significant.

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<sup>10</sup> Implicitly, this also leaves room for the central bank to stabilize inflation by anchoring inflation expectations.

Concerning the inefficiency term we find that firms' profit share, output growth and the trend in productivity growth significantly constitute a nonlinear influence on current inflation.<sup>11</sup> Consistent with the rationale in Akerlof et al. (1996) strong growth in output and trend productivity imply less constrained firms in the sense that wages are set close to efficient levels. As a result, the strictly nonnegative inefficiency term diminishes substantially. When looking at the influence of the third variable we find that a decline of firms' profit share tends to dampen inflation. As Akerlof et al. (1996) have reasoned, in such a situation workers are more willing to accept wage rates set at their efficient level, which implies less upward pressure on output prices according to eq. (2).

Regarding the overall significance of the inefficiency term, it has to be borne in mind that the stochastic frontier model does not provide a simple test statistic. Most applications of the stochastic frontier model test the null hypothesis that  $V[\xi_t|\xi_t \geq 0] = 0$  versus alternate hypothesis that  $V[\xi_t|\xi_t \geq 0] > 0$  using a number of different statistics. However, Coelli (1995) shows that a likelihood ratio test, where the restricted model simply refers to the linear Phillips curve, performs best in terms of power and size. Calculating the test statistic  $LR = -2 \cdot [\log(L_0) - \log(L_1)]$ , where  $\log(L_0)$  is the log likelihood value under the null hypothesis (OLS model) and  $\log(L_1)$  is the log likelihood value assuming the null is false (SF model) reveals an increase of the log likelihood value at the one percent significance level.<sup>12</sup>

To additionally give an idea of whether or not the statistically significant coefficients also constitute an economically relevant component of the Phillips curve we plotted the estimated time series of  $E[\xi_t|\xi_t \geq 0]$  as defined by eq. (14).

[Insert Figure 1 about here]

Remembering that the empirical results are based on quarter-to-quarter percentage changes, Figure 1 suggests strong fluctuations of the inefficiency component peaking up to three percentage points in annualized terms. The peaks generally coincide with US

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<sup>11</sup> We also tested for the influence of unemployment in the shift component, but the estimated coefficient was statistically insignificant.

<sup>12</sup> The  $\chi^2$  distributed test statistic  $LR = 23.34$  exceeds its one percent critical value (11.67). Note that due to the one-sided nature of the inefficiency term  $H_0$  is rejected if  $LR > \chi^2(4, 2\alpha)$  for a test of size  $\alpha$ .

recessions revealing the importance of labor market inefficiencies especially during times of economic downturn.

### **3.4 Robustness Checks**

Although we already perform a robustness test in the sense that the inefficiency term is identified within two different types of models, we further checked whether the results are driven by specific choices of the sample or data. First, we performed sub-sample estimates of the model including simple sample splits, but also rolling regression using a sixty-quarter window. The latter reveals, for instance, that the coefficient of firms' profit share shows some swings generally within the range between 0.1 and 0.15 indicating that the full sample estimate represents a lower threshold of its influence on the inefficiency term. The parameter stability of empirical Phillips curves is confirmed by Milani (2012). The author estimates a structural New Keynesian model to test whether globalization has changed the behavior of U.S. macroeconomic variables. Several key coefficients in the model are allowed to be time-varying, but the empirical results indicate that globalization can explain only a small part of the reduction in the slope of the Phillips curve.

Moreover, we applied various definitions of model variables. For example, we alternatively applied the index of unit profits of nonfinancial corporations as supplied by the Bureau of Labor Statistics instead of the profit measure defined above. Considering possible demographic shifts in the US labor force we also estimated the stochastic frontier model using corrected unemployment rates (Perry, 1980). In general, we are able to conclude that the represented results are robust to a broad variety of tests.<sup>13</sup>

## **4. Estimation Results from European Data**

We also applied our empirical model to data from the UK and Germany. However, two major caveats regarding this attempt should be stressed. First, beyond the US there is no dataset available that is comparable to the BEA/BLS data on the nonfinancial corporate sector in terms of length and consistency. In case of the UK, we use national accounts

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<sup>13</sup> Detailed results of the robustness tests are available from the authors on request.

data on output and output prices for the entire economy stretching back to 1971. Data on profits are also provided by the ONS, but refer to private nonfinancial corporations. As for Germany, we resort to national accounts data on the business sector (excluding domestic services) for output, prices and productivity, whereas aggregate non-labor income is used as profits. Owing to the statistical break introduced by the German reunification, the dataset starts as recently as 1991.

Second, the countries chosen have undergone profound economic changes over the decades so that structural relationships between economic variables may have broken down or shifted. In the UK, major reforms were undertaken during the 1980s aimed at improving the performance of the labor market. Blanchflower and Freeman (1993) concluded that Thatcherite policies had succeeded in weakening union power and might have marginally increased employment and wage responsiveness to market conditions. We try to account for these changes by adding a dummy variable to the impact of trend productivity growth within the inefficiency term. This dummy is set to unity until 1984q4 and 0 afterwards. This dating has been motivated by the end of the miners' strike in early 1985, which is said to have weakened the trade union movement decisively. With respect to Germany, the introduction of a common currency and monetary policy at the European level may have altered the previous tradeoff between inflation and unemployment. Therefore, we add a dummy to the unemployment term which is 1 until 1998q4 and 0 thereafter. The estimation results are reported in Table 2.

[Insert Table 2 about here]

Overall the model fit appears to be looser for both the UK and Germany. In the former case, the impact of output growth on the inefficiency term is statistically significant with the expected sign merely at the 10% level, whereas the change in profit share is not attributed significant influence. Since the coefficient of the dummy variable is positive, trend productivity growth lowers the inefficiency only after 1984. This heightened efficiency might be consistent with weaker trade unions and improved working of the labor market. Regarding German data, the impact of both the change in profit share and output growth is found to be significant with the expected signs, while trend growth in productivity is apparently irrelevant. Again the coefficient of the dummy variable turns

out significantly positive thereby contradicting other studies pointing to a flattening of the Phillips curve based on linear models. Apart from possible structural breaks affecting the data, the overall looser fit for both the UK and Germany could be due to the varying degree of downward rigidity of nominal wages itself, as highlighted by Dickens et al. (2007).

## 5. Conclusion

Whereas microeconomic studies point to pronounced downward rigidity of nominal wages in the US economy, the Phillips curve generally neglects such a feature. Using a stochastic frontier model we find macroeconomic evidence of a strictly nonnegative error in an otherwise standard Phillips curve in postwar data on the US nonfinancial corporate sector. This error depends on growth in the profit ratio, output, and trend productivity which should all be related to the wage adjustment process. As the error usually surges during an economic downturn, the empirical model suggests that the downward pressure on inflation arising from higher unemployment in a standard Phillips curve framework is significantly cushioned. Put differently, the time varying shift component arising from downward wage rigidity can be viewed as an inefficiency term in the price Phillips curve, which raises actual inflation above ‘efficient’ inflation. This ‘inflation markup’ can be viewed as evidence on firms’ ability to shift excess labor costs to output prices, even in times of economic downturn. This might help to understand the robustness of inflation especially in the most recent past. In general, the cyclical dynamics of inflation appear to be more complex than captured by a conventional Phillips curve.

While we have demonstrated the practical importance of a nonlinear inefficiency in US inflation, we have neglected its impact on employment, which might be the subject of further research. Akerlof et al. (1996) have already argued that the real wage has two components. The first component results from wage bargaining and depends on the unemployment rate, whereas the second component is determined by downward rigidity. An increase in the latter would raise unemployment sufficiently to shrink the first component and leave the real wage unchanged. Thus, the economic significance of the inflation inefficiency which we have identified could imply that the downward

rigidity of nominal wages might have played an important role in the performance of the US labor market in recent years.

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Table 1: Estimation Results from US Data

	<i>Akerlof et al. (1996) Model</i>	<i>Stochastic Frontier Model</i>
Phillips curve		
constant	0.38 <sup>***</sup> (3.10)	0.37 <sup>***</sup> (3.47)
unemployment	-0.10 <sup>***</sup> (4.32)	-0.05 <sup>***</sup> (2.70)
productivity		-0.14 <sup>***</sup> (3.74)
Shift term		
constant		1.40 <sup>**</sup> (2.25)
profits	0.03 <sup>***</sup> (5.98)	0.07 <sup>***</sup> (3.72)
productivity trend		-4.61 <sup>***</sup> (4.16)
output		-0.28 <sup>***</sup> (3.31)
Inflation expectation		
inflation <sub>t-1</sub>	0.60 <sup>***</sup> (10.93)	0.47 <sup>***</sup> (7.01)
inflation <sub>t-2</sub>	-0.02 (0.53)	0.06 (0.93)
inflation <sub>t-3</sub>	0.19 <sup>**</sup> (2.22)	0.10 (1.51)
inflation <sub>t-4</sub>	0.24 <sup>***</sup> (8.31)	0.11 <sup>*</sup> (1.69)
Standard deviation		
	0.43 <sup>***</sup> (11.69)	0.29 <sup>***</sup> (10.30)

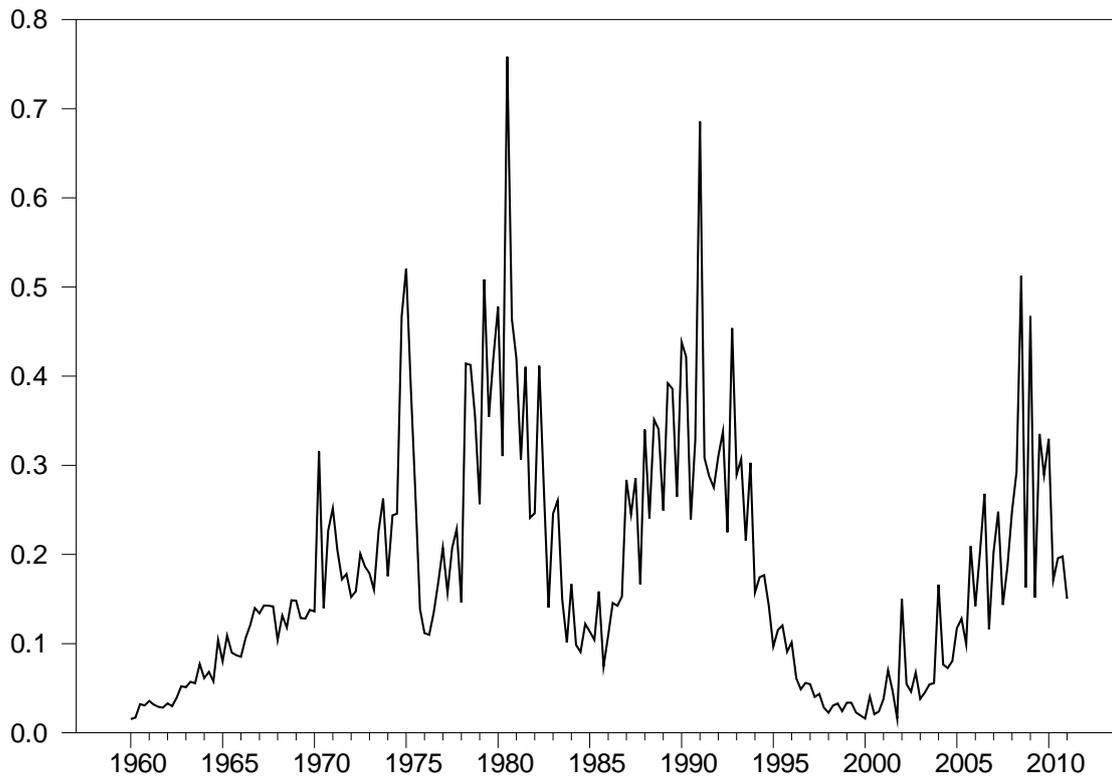
**Notes:** The sample contains quarterly observations from 1958 to 2011. *t*-statistics in parentheses are based on robust estimates of the covariance matrices of the parameter estimates. \* (\*\*, \*\*\*) denotes significance at the 10% (5%, 1%) level.

Table 2: Estimation Results from European Data

	<i>United Kingdom</i> <i>Data from 1971 to 2011</i>	<i>Germany</i> <i>Data from 1991 to 2011</i>
Phillips curve		
constant	0.34 <sup>***</sup> (4.59)	0.49 (1.09)
unemployment	-0.03 <sup>*</sup> (1.75)	-0.08 <sup>**</sup> (2.12)
Unemployment dummy	—	0.02 <sup>**</sup> (2.26)
productivity	-0.22 <sup>***</sup> (3.80)	0.03 (0.61)
Shift term		
constant	0.37 <sup>***</sup> (5.14)	0.31 <sup>*</sup> (1.93)
profits	0.04 (1.62)	0.13 <sup>***</sup> (2.67)
productivity trend	-0.49 <sup>***</sup> (3.37)	-0.05 (0.07)
productivity dummy	2.30 <sup>***</sup> (6.60)	—
output	-0.22 <sup>*</sup> (1.77)	-0.24 <sup>**</sup> (2.08)
Inflation expectation		
inflation <sub>t-1</sub>	0.18 <sup>***</sup> (2.66)	0.23 <sup>**</sup> (2.14)
inflation <sub>t-2</sub>	0.19 <sup>**</sup> (1.99)	0.09 (1.03)
inflation <sub>t-3</sub>	0.24 <sup>***</sup> (4.26)	0.05 (0.30)
Standard deviation		
	0.75 <sup>***</sup> (10.36)	0.26 <sup>**</sup> (2.49)

**Notes:** The sample contains quarterly observations from 1971 to 2011 for the UK and from 1991 to 2011 for Germany, respectively. *t*-statistics in parentheses are based on robust estimates of the covariance matrices of the parameter estimates. \* (\*\*, \*\*\*) denotes significance at the 10% (5%, 1%) level.

Figure 1: Time-Varying Inefficiency in the Price Phillips Curve



Notes: Time-varying inefficiency (in percentage points) from equation (14) of the stochastic frontier model.