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through the lens of a non-linear Okun's law

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through the lens of a non-linear Okun's law[♦]

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Abstract: This paper aims at investigating the relationship between employment and GDP in the United States. We disentangle trend and cyclical employment components by estimating a non-linear Okun's law based on a smooth transition error-correction model that simultaneously accounts for long-term relationships between growth and employment and short-run instability over the business cycle. Our findings based on out-of-sample conditional forecasts show that, since the exit of the 2008-09 recession, US employment is on average around 1% below the level implied by the long run output-employment relationship, meaning that about 1.2 million of the trend employment loss cannot be attributed to the identified cyclical factors.

Keywords: Okun's law, trend employment, non-linear modeling.

JEL codes: E24, E32, C22.

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1. Introduction

One of the central puzzles following the financial crisis and the ensuing Great Recession has been the sluggish growth in employment during the recovery which began in June 2009, according to the NBER business cycle dating committee. It is somewhat surprising that analysts have worried about how employment growth has recently outpaced GDP, according to Okun's law (Okun, 1962), while others have bemoaned the slow pace of employment growth. Underpinning these discussions is a view that there is instability in this relationship between changes in employment and GDP growth.[1] From 2008Q4 onward, employment growth was below that predicted by a simple regression of employment growth on GDP growth over the 1987Q1-2007Q4 period (Chinn, 2012). This outcome continued on into the recovery period, although the most recent observations have been above the regression line. There does seem to be a consistent pattern wherein contractions are associated with employment growth below that implied by the relationship that obtains over both upswings and downswings.

Our analysis is related to the issue of whether structural unemployment has risen in the wake of the Great Recession. This issue is of major importance for policy-makers, and biased estimation of natural levels of employment and unemployment can lead to inadequate economic policies. For example, in terms of monetary policy-making, over-estimated unemployment gaps can imply an underestimation of optimal monetary policy rates through standard Taylor equations. Within this context, disentangling structural and cyclical employment components is a key question.

In this paper, we estimate a model based on Okun's law, so that we can specify a decomposition of employment between trend and cyclical factors, wherein one could potentially interpret the trend factors as structural in nature. This caveat is necessary because statistically defined trend factors could be structural in origin, but might also conceivably incorporate factors that are not long term in nature, such as enhanced unemployment insurance benefits.[2]

One key problem that arises when dealing with the Okun's law is that several specifications co-exist in the empirical literature[3], rendering comparisons difficult. The relationship between output and employment can be estimated in differences, in gaps or in levels. Here, we implement a non-linear Okun's law for the US that simultaneously accounts for long-term relationships between output and employment as well as instability over the business cycle.

Relying on a non-linear error-correction specification over the 1950-2012 period, our main findings can be summarized as follows. First, if one does not account for the long-term relationship between GDP and employment within the Okun's framework (i.e. if one focuses only on the relationship in differences), then we obtain unrealistic results by overestimating employment by a substantial

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[1] See e.g., Knotek (2007), McCarthy et al. (2012) and Owyang and Sekhposyan (2012).

[2] For instance, CBO (2012) estimates both a long term natural rate of unemployment, and one accounting for short run factors. The former is driven by demographics and skill attributes, while the latter is determined in part by extended unemployment insurance benefits. For the sake of completeness, it should also be noticed that regarding hysteresis effects, part of trend employment will depend on long-lasting cyclical effects.

[3] See Section 3.

amount. Second, a standard error-correction model is able to reproduce the general evolution of employment, but underpredicts the decline in employment during the recession, and therefore overpredicts employment during the recovery. Third, accounting for the US business cycle by using an innovative non-linear smooth transition error-correction model enables a better reproduction of stylized facts, especially by taking the business cycle into account without integrating any exogenous information. Fourth, according to our estimated model, we show however that employment is still on average 1.05% below its potential level after the recession, meaning that the level of employment is 1.17 million lower than would have been predicted on the basis of the historical co-movement of employment and GDP.

The rest of the paper is organized as follows. Section 2 briefly reviews the recent literature. Section 3 describes the econometric framework, and Section 4 presents and discusses the results. The last section concludes the article.

2. A brief review of the recent literature

On the one hand, some papers have concluded that the cyclical component cannot account for the entire change in employment. In this respect, Stock and Watson (2012) argue that the slow recovery is mainly explained by a decline in the trend growth of the labor force.

Several explanations have been proposed regarding the effect of factors affecting structural employment. Estevão and Tsounta (2011) estimate that about 1.75 percentage point of the increase in unemployment between 2006 and 2010 is due to negative interactions of mismatches between demand and supply on the labor market with weak housing conditions. In a multi-country framework, Chen, Kannan, Loungani and Trehan (2011) show that sectoral shocks specific to the Great Recession—namely in the construction sector and to a lesser extent in finance—have contributed to increase the long-duration unemployment rate. Various other explanations include the extension of unemployment benefits and high uncertainty about future economic outlook; however these explanations seem to have less explanatory power (see e.g. Daly et al., 2011).

On the other hand, others argue that there is no evidence of structural impediments on the labor market, given that modest recoveries are commonplace after balance sheets crisis. According to this view, the lack of aggregate demand is the main driver of the current high unemployment rate and consequently the job market will come back to its pre-recession equilibrium when economic conditions will improve. Lazear and Spletzer (2012) conclude that "neither industrial nor demographic shifts nor a mismatch of skills with job vacancies is behind the increased rates of unemployment". They recognize that job market mismatches increased during the recession, but they argue that those mismatches diminished at the same pace just after the recession exit.

In a recent work, Ball, Leigh and Loungani (2013) defend this point of view and argue that there is no jobless recovery in the US, but only a sluggish economic growth that weights on the labor market. To support their analysis, they estimate the Okun's law for a sample of 20 advanced countries and show that there is a strong and stable relationship between output and employment. Based on empirical findings, Rothstein (2012) dismisses any structural factors to explain the low labor market activity.

Also Farber (2012) estimates mobility rates and does not find any evidence that low geographic mobility, due to a deteriorated housing market, explains the weak labor market.

Given this lack of consensus regarding the decomposition of employment between structural and cyclical factors in the wake of the Great Recession, we propose an econometric model based on the Okun's law which enables us to decompose movements in employment into trend and cyclical components. Indeed, to evaluate the relationship between output and employment, the empirical Okun's law turns out to be a valuable tool as pointed out by Ball, Leigh and Loungani (2013) among others. Knotek (2007) also suggests evidence that Okun's relationship between changes in the unemployment rate and output growth can be a useful forecasting tool, in spite of considerable instability over time and over the business cycle (see also Owyang and Sekhposyan, 2012, on this point). However, this instability in the relationship is not confirmed by Ball, Leigh and Loungani (2013), who also reject evidence of non-linearity based on sub-samples investigations.

3. An econometric approach to estimating Okun's law

Arthur Okun documented the evidence for his eponymous law, the empirical relationship between the unemployment rate and output growth, in 1962. Since then, several versions of Okun's law have been developed. Some are expressed in levels, some in deviations from natural levels (gaps), and some in growth rates. For example, the original Okun's law was expressed in differences such as:

$$\Delta UNR = \alpha + \beta \times \Delta LGDP, \tag{1}$$

where $\Delta LGDP$ is the change in the logarithm of real GDP and ΔUNR is the change in the unemployment rate. The parameter β is sometimes referred to the Okun's coefficient and is expected to be negative, reflecting thus the negative correlation between changes in unemployment and output growth. The ratio $-\alpha/\beta$ is an estimate of the rate of output growth necessary to stabilize the unemployment rate.

Alternatively, the gap version of the Okun's law linearly relates the unemployment rate with the output gap, as defined by the difference between the observed GDP and its potential value, such as:

$$UNR = \delta + \lambda \times (LGDP - LGDP^*), \tag{2}$$

where *LGDP** is the potential of log-GDP, which has to be estimated by a given econometric method, and *(LGDP - LGDP*)* is the output gap. The parameter δ can be seen as the unemployment rate consistent with full employment. Alternatively, the natural unemployment rate *U** can be estimated exogenously before entering into equation (2). In that case, the left-hand side of equation (2) becomes *(UNR − UNR*)*, referred to as the unemployment gap, and δ is set to zero. This gap specification is generally easier to estimate than the differences specification as variables involved are smoother. But the main drawback is that potential GDP and natural unemployment rate are unobserved values and have to be previously estimated using econometric methods, such as filtering

techniques (Hodrick-Prescott or band-pass filters). As there is no consensus on the way to estimate such quantities,[4] measurement error exacerbates the imprecision in estimating the relationship.

Departures from those original versions of Okun's law given by equations (1) and (2) are motivated by two observations. First, those equations do not include any long-term effect between the two variables as the low-frequency information is eliminated by the differentiation operation or by subtracting potential log-GDP. Yet, it is generally observed in econometrics that accounting for long-term effects can lead to fruitful results. In this respect, we decide to focus on the long-term relationship between employment and output in the framework of error-correction models, as both log-GDP and log-employment series are obviously integrated. We show in the following section how this choice is validated by the results. Using employment data instead of unemployment data also presents the great advantage of neglecting the participation rate that can lead to spurious measurement effect. Indeed, it has been shown (Stock and Watson, 2012) that the participation rate decreased from 66% in 2007 to less than 64% in 2012, implying thus a lower unemployment rate for a given level of unemployment in the years 2011-12.

Second, some authors have detected evidence of instability in Okun's law over time. Using standard rolling regressions, and allowing the estimation of the relationship over many different samples, Knotek (2007) underlines a great variation overtime of the estimated parameters of the Okun's law. In particular, he shows that the Okun's law is sensitive to the state of the business cycle. Other authors have also investigated the non-linear dynamics of the Okun's law, including Lee (2000), Viren (2001) and Harris and Silverstone (2001). According to Harris and Silverstone (2001), four factors may explain the presence of non-linearity in the Okun's relationship: capacity constraints, signal extraction, costly adjustment and downward nominal wage rigidity. In addition, McCarthy, Potter and Ng (2012) underline that the Okun's law has not been a consistently reliable tool to forecast the amplitude of decline in the unemployment rate during the last three recessions.

In this paper, our aim is to account simultaneously for those two stylized facts described above, namely long-term and instability effects. In this respect, we consider a non-linear, smooth transition error correction model (STECM) whose parameters are allowed to evolve through time. More specifically, we retain the following non-linear specification with two regimes:

$$\Delta LEMP_t = \alpha_0 + \alpha_1 \Delta LEMP_{t-1} + \alpha_2 \Delta LGDP_t + \alpha_3 \Delta LGDP_{t-1} + \alpha_4(LEMP_{t-1} - \beta_0 - \beta_1 LGDP_{t-1}) + [\alpha'_0 + \alpha'_1 \Delta LEMP_{t-1} + \alpha'_2 \Delta LGDP_t + \alpha'_3 \Delta LGDP_{t-1} + \alpha'_4(LEMP_{t-1} - \beta_0 - \beta_1 LGDP_{t-1})] \times G(\gamma, c, Z_t) + \varepsilon_t, \qquad (3)$$

where *LEMP* denotes private non-farm payroll employment in logarithm, *LGDP* the logarithm of GDP, ε_t is a Gaussian white noise process, *G* denotes the transition function, γ is the slope parameter that determines the smoothness of the transition from one regime to the other, *c* is the threshold parameter, and *Z* denotes the transition variable.

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[4] In particular, Lee (2000) has shown that the estimated Okun's relationship is sensitive to the method used for extracting the cyclical component.

This non-linear ECM takes the long-term relationship into account, as well as two regimes for the short-term relationship—the long run relationship remaining invariant to the regime. The economy can evolve in two states, but the transition between those two regimes is smooth: the two regimes are associated with large and small values of the transition variable relative to the threshold value, the switches from one regime to the other being governed by the transition variable Z (here, lagged GDP growth). The smooth transition function, bounded between 0 and 1, takes a logistic form given by:[5]

$$G(\gamma, c, Z_t) = \left[1 + exp\left(-\gamma(Z_t - c)\right)\right]^{-1} \qquad (4)$$

It is noteworthy that when the function G(.) is equal to zero, it turns out that the non-linear STECM equation collapses to a standard linear ECM.

Further, inspection of equation (3) highlights the fact that we impose the strong assumption that the *long-run* relationship between employment and GDP is constant over the 1950-2012 period (the employment predicted by this long run relationship is the *trend* employment which we refer to). We attempt to relax this assumption in robustness tests.

4. Results for the US economy

In this section we implement the previous non-linear ECM given by equations (3) and (4) until the beginning of the Great Recession, then we use the estimated model in an out-of-sample conditional forecasting approach in order to assess losses in US trend employment.

4.1 In-sample analysis

We estimate the model given by equations (3) and (4) over the period 1950Q1 – 2007Q4 for US data of log-GDP and log-employment as presented in Figure 1.[6] This graph clearly highlights a long-term co-movement between both variables as well as evidence of non-stationarity, suggesting thus a cointegrated system. Formally, the implementation of Johansen's cointegration test leads to conclude to the existence of a cointegrating relationship between *LEMP* and *LGDP*.[7]

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[5] See Teräsvirta and Anderson (1992).

[6] As previously mentioned, we do not estimate the equations over our entire sample, as we reserve the 2008Q1-2012Q3 period for out-of-sample forecasts.

[7] We adopt a specification with one lag of first differences for the Johansen's test. The non-stationarity of employment and GDP series is also confirmed by the usual unit root tests (results are available upon request to the authors).

Figure 1: Log-GDP (top) and log-employment (bottom) over the period 1950Q1 – 2012Q3
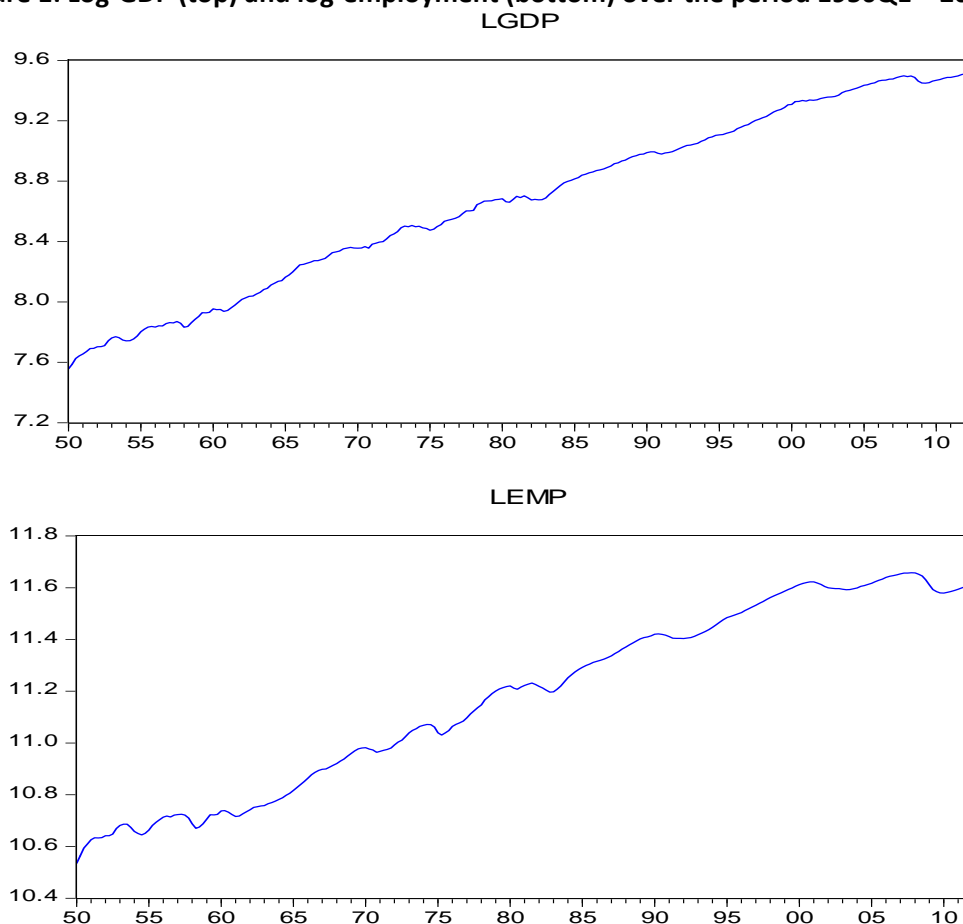
Source: Data are from the Bureau of Economic Analysis (GDP) and Bureau of Labor Statistics (employment). Quarterly GDP data used to estimate the models are seasonally adjusted, expressed in billions of chained 2005 dollars. Employment series corresponds to private non-farm employment, seasonally adjusted. Quarterly employment figures are average of monthly figures.

First, we estimate the long-term linear relationship through ordinary least-squares over the period 1950Q1 – 2007Q4.[8] The residuals from the long-term equation are obtained from the following estimated relationship:

$$u_t = LEMP_t - 5.8501 - 0.6155 \times LGDP_t,$$

and are presented in Figure 2.

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[8] As a robustness check, we have also estimated the cointegrating relationship using the Dynamic OLS (DOLS) procedure, leading to very similar results. In addition, to address the issue of stability of our long-run relationship—a question that may be important as regards to the IT productivity shock initiated in the mid-1990s—we have applied various usual break tests. Our results were not convincing, a finding that is not surprising given that such tests are not suitable when dealing with productivity shocks. Indeed, as pointed out by Benati (2007) and Turner and Boulhol (2008) among others, those shocks are generally gradual. We have thus followed an alternative way by introducing the total factor productivity in the long-run relationship. Our results (available upon request to the authors) are very similar to those presented here.

Once the estimation of this long-term relationship is realized, we integrate the lagged residuals into our main non-linear equation (3). To account for the business cycle in the short-term relationship, we select as transition variable the average GDP growth over 2 quarters, lagged by 2 quarters, i.e.:[9]

$$Z_t = 0.5 \times (\Delta LGDP_{t-2} + \Delta LGDP_{t-3})$$

Figure 2: Deviations to the estimated long-term relationship between log-employment and log-GDP
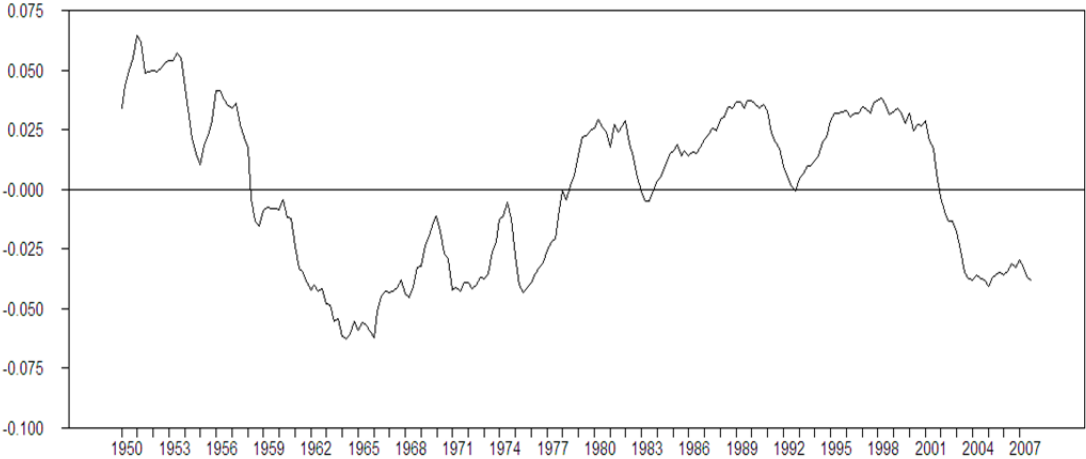
Source: authors' calculations.

The estimation of the non-linear specification follows the methodology proposed by Teräsvirta (1994). We start by testing for the null hypothesis of linearity using the test introduced by Luukkonen et al. (1988). Once the null of linearity has been rejected, we select the specification of the transition function using the test sequence presented in Teräsvirta (1994).[10] We then estimate the non-linear ECM, leading to the results presented in Table 1.[11]

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[9] Note that we have also tried other transition variables, such as changes in the employment rate and other lags for GDP growth rate. Using the average GDP growth over 2 quarters leads to the strongest rejection of the null of linearity, justifying our choice from an econometric viewpoint.

[10] We refer for example to van Dijk, Teräsvirta and Franses (2002) for details on smooth transition models.

[11] Note that the estimated model has successfully passed the usual misspecification tests: test of no residual autocorrelation (Teräsvirta, 1998), LM-test for no-remaining non-linearity (Eitrheim and Teräsvirta, 1996) and ARCH-LM test.

Table 1: Estimation results of the non-linear error-correction model

	Regime 1	Regime 2
Constant	-0.0071***	0.0067***
$\Delta LEMP_{t-1}$	0.2149	0.3741***
$\Delta LGDP_t$	0.6439***	-0.3361***
$\Delta LGDP_{t-1}$	0.1932*	-0.1976
$Resids_{t-1}$	-0.0193**	0.0070
$\hat{\gamma}$	5.1624	
$\hat{c}$	0.0001	

Note: *** (resp. **): significant at the 1% (resp. 5%) level.
In order to obtain the relevant coefficients in Regime 2, add the
Regime 2 coefficient to the corresponding Regime 1 coefficient.

The estimated value $\hat{c}$ of the threshold c is close to zero, delimiting thus periods of expansion and periods of recession, as shown by the transition function displayed in Figure 3. The transition function clearly highlights the existence of two regimes in the short-term relationship between employment and output, which are strongly related to the business cycle phases, though slightly lagged. There is one regular regime that occurs most of the time, with an unconditional probability of 89%, while the second regime is more exceptional and appears only 11% of the time (i.e. when the transition function exceeds the natural threshold of 0.50).

Figure 3: Estimated transition function and US recessions until 2007Q4
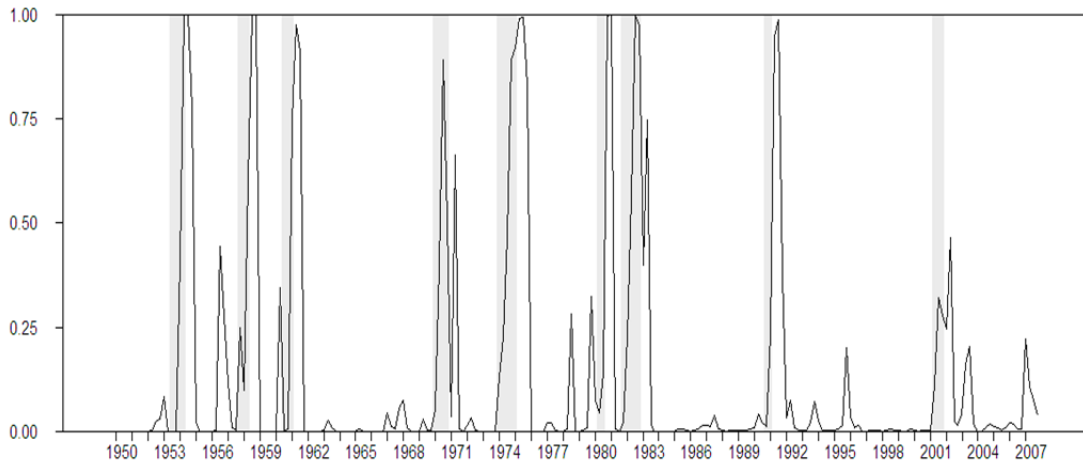
Sources: authors' calculations, and NBER for the dating of recessions. The gray bands represent US recessions.

It is striking to observe that the second regime always begin at the end of recessions, generally one quarter before the end. The average duration of this recession regime is slightly greater than 3 quarters. In fact during this specific period of time, the persistence of the growth rate of employment tends to increase, as the first-order autoregressive estimate jumps to 0.589 from 0.215 in the regular regime. In addition, the contemporaneous elasticity dips from 0.644 to 0.308 and the lagged

elasticity dies out. Thus, in this second regime, the dependence of employment growth on output growth is reduced. One explanation may be due to the fact that GDP growth tends to strongly bounce-back after recessions before returning to a "normal" expansion regime. Evidence of such behavior is documented in the papers of Bec, Bouabdallah and Ferrara (2011) and Morley and Piger (2012). Yet, during this bounce-back period, employment growth does not follow at the same pace, leading to a reduction in the dependence on output growth and an increase in its persistence.

It is notable that the point estimate for the coefficient on the lagged error term is equal to - 0.0123 (= 0.0070 - 0.0193) in the second regime. In other words, the extent of disequilibria has minor impact on the pace of net job growth when GDP growth is negative.

In order to compare those latter results stemming from our model, we need to consider benchmark models. To this end, we also estimate over the same period (i) a standard ECM given by equation (3) with function G(.) being equal to zero and (ii) an Okun's law expressed in differences as given by equation (1). Series in log-differences over one quarter are presented in Figure 4.

Figure 4: Log-GDP in differences over 1 quarter (top) and log-employment in differences over 1 quarter (bottom)
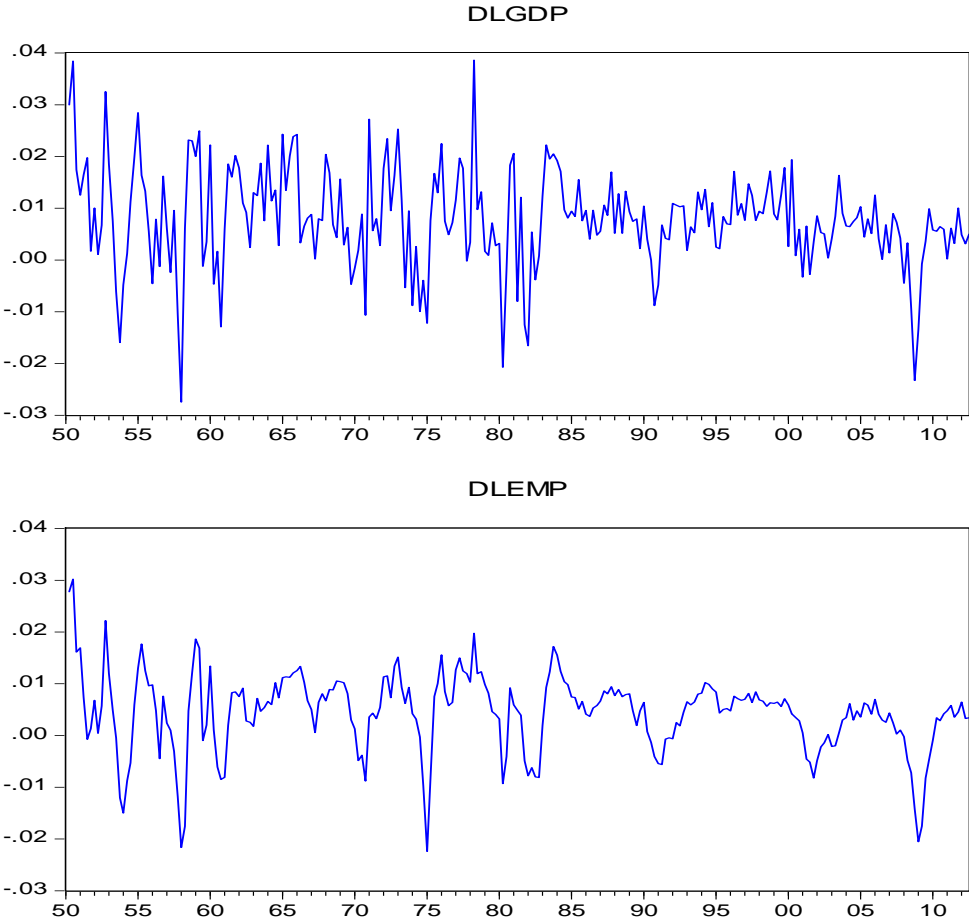
Source: authors' calculations based on data extracted from BEA and BLS.

As regards the specification of the linear ECM, we impose for short-term dynamics a similar structure to the one given in equation (3). Results of parameter estimation are given in Table 2.

Table 2: Estimation results of the linear error-correction model

	Estimates
Constant	-0.0013***
ΔLEMP_{t-1}	0.5402***
ΔLGDP_t	0.3733***
ΔLGDP_{t-1}	0.0358
Resids_{t-1}	-0.0133**

Note: *** (resp. **): significant at the 1% (resp. 5%) level.

It is noteworthy that those estimates are rather close to the sum of the corresponding parameters in Regime 1 and Regime 2 (Table 1). The lagged log-difference GDP is not significant at usual levels.

The estimated equation in differences is given by:

$$\Delta\widehat{LEMP}_t = 0.0003 + 0.5400 \times \Delta LGDP_t.$$

The estimated parameter associated with GDP is significant at the 5% level, but residuals appear to be serially correlated according to usual whitening tests. In order to improve the goodness-of-fit, we include short-term dynamics into the regression model. The estimated model is the following:

$$\Delta\widehat{LEMP}_t = -0.0012 + 0.3846 \times \Delta LGDP_t + 0.5729 \times \Delta LEMP_{t-1}.$$

All estimated parameters are significant at the 5% level, and we do not reject the null of no-autocorrelation within residuals.

4.2 Conditional forecasts

We now compare the previous models on the basis of conditional dynamic forecasts of the variable *LEMP* over the period 2008Q1 – 2012Q3. This means that we forecast employment based on the knowledge of the *ex post* path for *LGDP*. Those conditional forecasts are dynamic in the sense that, for each step, we use the previously forecasted employment value instead of the observed value.

First we compare the three linear models, namely the model in differences, the model in differences with dynamics and the ECM. Conditional forecasts are presented in Figure 5.

Both models in differences largely miss the drop in employment during the Great Recession. In particular, conditional forecasts stemming from the Okun's law in differences exceed the pre-recession values of employment by end of 2010. Those results are clearly at variance with reality and point to a failure in the employment version of Okun's law. If we integrate dynamics in the equation in differences, conditional forecasts are shifted downwards due to the presence of lagged differences of employment. We observe that at the end of 2012, conditional forecasts are close to observed values of employment, meaning that, at this date, the level of employment would be consistent with

its historical equilibrium. Yet, this hardly makes this model convincing as an explanation for employment dynamics during the Great Recession.

When taking the long-term relationship into account, conditional forecasts partly reproduce the dip in employment due to the large decrease in GDP level during this specific period of time. However, there is still a wide gap between observed values of employment and conditional forecasts stemming from the ECM. In addition, this gap tends to persist after the end of recession.

**Figure 5: Conditional forecasts of log-employment stemming from linear models**
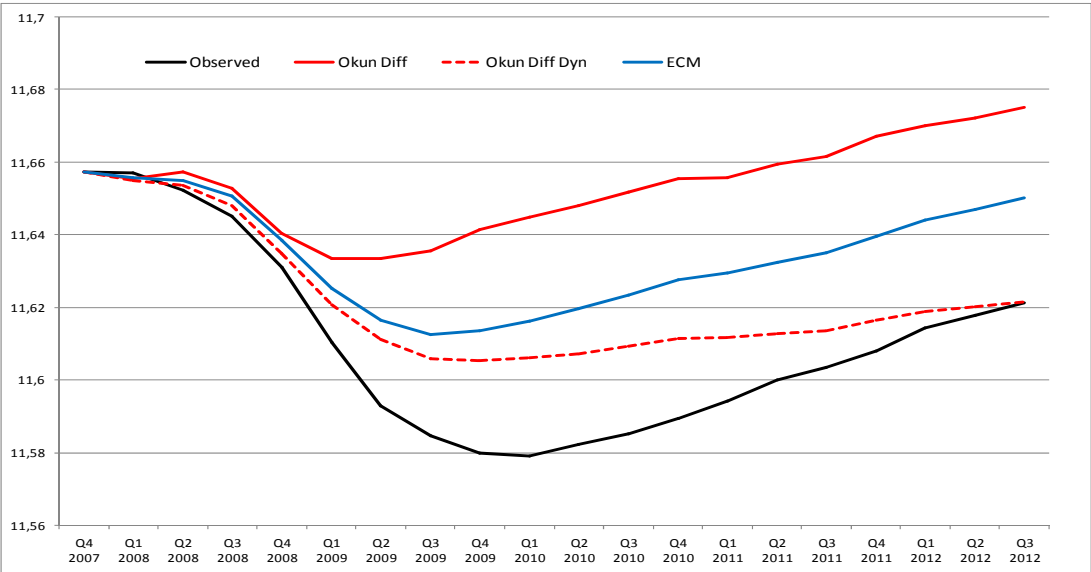
Note: Conditional forecasts stemming from the model in differences (red), the model in differences with dynamics (dotted red) and the ECM (blue). Observed values are presented in the dark line.

Let us now turn to the comparison of the ECM and the non-linear ECM based on those conditional forecasts. Figure 6 presents the observed employment (dark line), as well conditional forecasts from a standard (linear) ECM (blue line) and from the non-linear ECM (green line).

Both ECMs are able to reproduce the main movements in employment during and after the recession. However, there is a persistent gap between the observed employment (dark line) and the conditional forecasts from both models (blue and green lines), meaning that the employment is currently well below what it should be according to the models. When comparing both ECMs, taking the non-linear business cycle into account through the non-linear ECM (green line) leads to an important reduction in the gap. The contribution of the non-linear cycle to the employment is quite high (the average difference between the blue and the green lines is around 2.6 % in 2010) but tends to diminish (the green line slightly tends to the blue line), the average difference being only of 1.6% during the first three quarters of 2012.

Figure 6: Conditional forecasts of log-employment stemming from linear and non-linear error-correction models
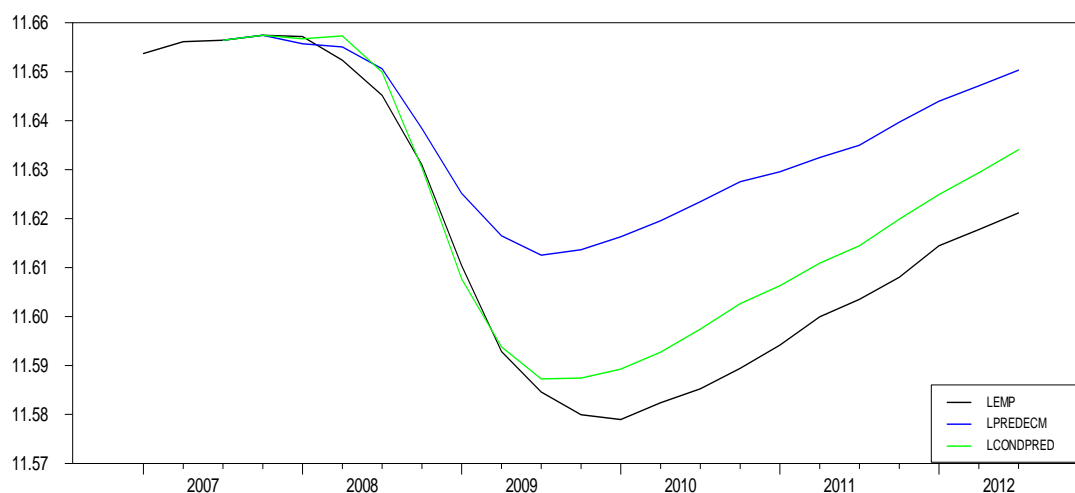
Note: Conditional forecasts stemming from the linear ECM (blue) and the non-linear ECM (green). Observed values are presented in the dark line.

Our findings lead us to conclude that there has been indeed an effect of the Great Recession on the long-term private employment. Specifically, on average, since the exit of the recession (2009Q2), we find that employment is 1.05 % below predicted levels (according to the non-linear ECM), meaning that about 1.17 million of jobs have been lost due to non-cyclical reasons. This interpretation is in line with the recent literature on this topic, as pointed out for example by Chen, Kannan, Loungani and Trehan (2011) or Stock and Watson (2012).

4.3 Robustness checks

As robustness checks, we compute confidence intervals for conditional forecasts and evaluate the sensitivity of our results to alternative measures of employment.
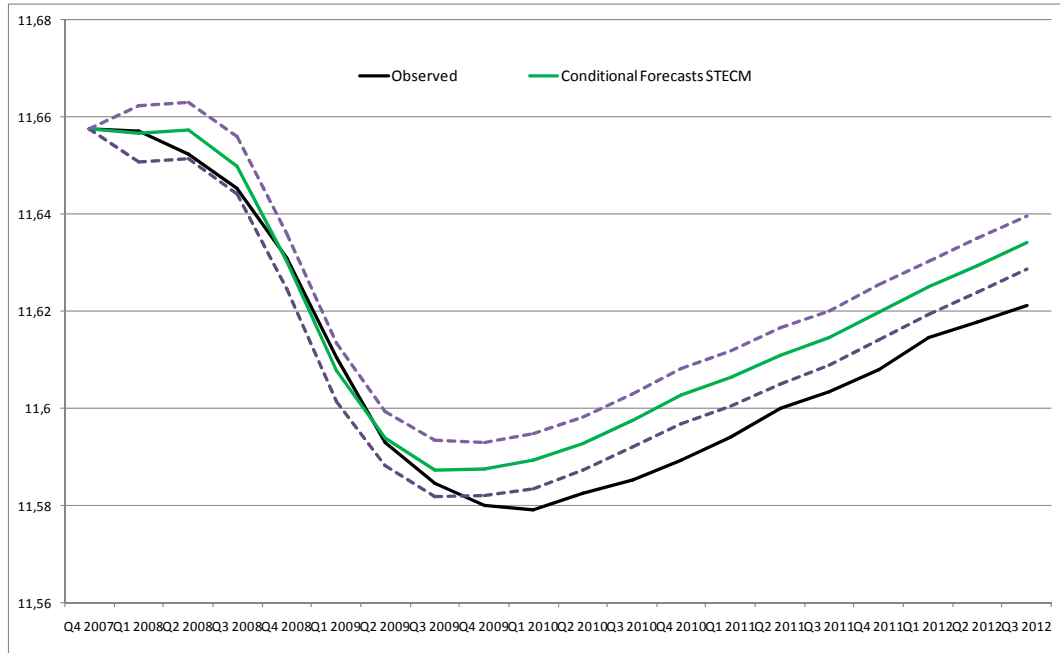
- <u>Confidence intervals</u>

  To assess the quality of conditional forecasts, we compute confidence intervals based on a re-sampling bootstrap approach. As previously mentioned, residuals $(\hat{\varepsilon}_t)$ stemming from equation (3) over the sample 1950-2007 are proved to be non-correlated for low lags. In addition, they are not far from being normally distributed, according to the Jarque-Bera test of Normality at the 1% level[12]. Thus, we choose to implement a bootstrap resampling approach based on those residuals in order to estimate confidence bounds around conditional forecasts $\Delta \widehat{LEMP}_t$ over the period from 2008Q1 to 2012Q3. As new residuals based on the difference between observed and conditional forecasts become available, we

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[12] The null of Normality is accepted at the 1% level but rejected at the 5% level (p-value of 0.013).

integrate them in the re-sampling approach. The number of bootstrap replications is fixed at B=1000. Figure 7 displays the 95% confidence interval.

Figure 7: Confidence interval at 95% for conditional forecasts based on the STECM

Note: Conditional forecasts stemming from the non-linear ECM (green) with corresponding bootstrapped 95% confidence interval. Observed values are presented in the dark line.

This confidence interval is quite narrow, due to the low standard deviation of residuals (equal to 0.0029), and illustrates the reliability of our forecasts.[13] Starting from the exit of recession, the realized employment stays clearly below the lower bound of the confidence interval until the end of the sample.

- Robustness to the employment series

We now assess the sensitivity of our findings to the choice of the employment series. To this end, we focus on total non-farm payroll employment (LEMPTOT) instead of only private non-farm payroll employment. First, we estimate the long-term linear relationship over the period 1950Q1 – 2007Q4, leading to the following residual series:

$$u_t = \text{LEMPTOT}_t - 5.9296 - 0.6273 \times \text{LGDP}_t.$$

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[13] Note that we have assumed that parameters in equation (3) are known. Obviously, as in any other empirical applications, parameters need to be estimated, which leads to an additional uncertainty in predicted values. To our knowledge, there is no available clear procedure when dealing with a STECM, in spite of papers dealing with other types of non-linear models (see for example Li, 2011, or Bec, Bouabdallah and Ferrara, 2013, in the case of univariate threshold models).

As shown, the long-run elasticity is very close to the one estimated with private employment (0.6155). We then estimate a linear ECM over the same period, as well as the STECM given by equation (3).[14] Parameter estimates of both models are given in Table 3; they are consistent with those obtained when dealing with private employment. The speed of adjustment to the long-term target is lower here and even non-significant, reflecting a less cyclical pattern. The transition function also describes very precisely the business cycles, though the probabilities do not reach one in this framework. This likely reflects the fact that the public employment is counter-cyclical during these specific periods (see Figure 8).

Figure 8: Estimated transition function for the total employment and US recessions until 2007Q4
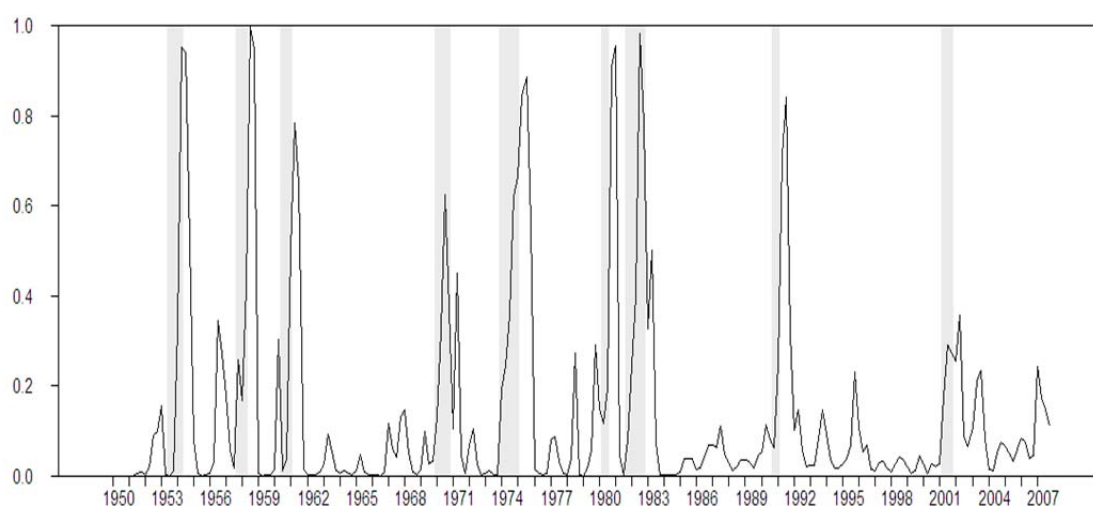
Sources: authors' calculations, and NBER for the dating of recessions. The gray bands represent US recessions.

**Table 3: Estimation results of linear and non-linear ECMs for total payroll employment**

	Linear ECM	Non-linear STECM	
		Regime 1	*Regime 2*
Constant	0.0006**	-0.0055***	0.0055**
$\Delta LEMP_{t-1}$	0.5763***	0.2640	0.3763***
$\Delta LGDP_t$	0.3206***	0.6502***	-0.4094***
$Resids_{t-1}$	-0.0104	-0.0131	0.0057
$\hat{\gamma}$		2.5041	
$\hat{c}$		-0.0015	

Note: *** (resp. **): significant at the 1% (resp. 5%) level.
In order to obtain the relevant coefficients in Regime 2, add the
Regime 2 coefficient to the corresponding Regime 1 coefficient.

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[14] Note that the STECM is estimated without any lagged GDP given that the null of linearity was more strongly rejected when not including lagged GDP. As for the estimation with private employment, the lagged GDP is also non-significant in the linear specification.

Based on those estimates, we compute dynamic conditional forecasts for both linear and non-linear ECMs. Results are presented in Figure 9. Confirming our intuition, it is interesting to note that total employment is much less sensitive to the business cycle. This result is expected because total employment also includes government employment which tends to be less pro-cyclical. Average losses of employment since the exit of the recession amount to 3.9% with the ECM and 1.8% with the STECM. Based on this latter model, this corresponds respectively to an average loss of 2.4 millions of jobs. If we assume that our estimation of the private employment loss at around 1 million is correct, thus it means that the long-run loss of government jobs is likely to be close to 1.4 million on average since the exit of the recession.

Figure 9: Conditional forecasts from linear and non-linear ECMs for total payroll employment
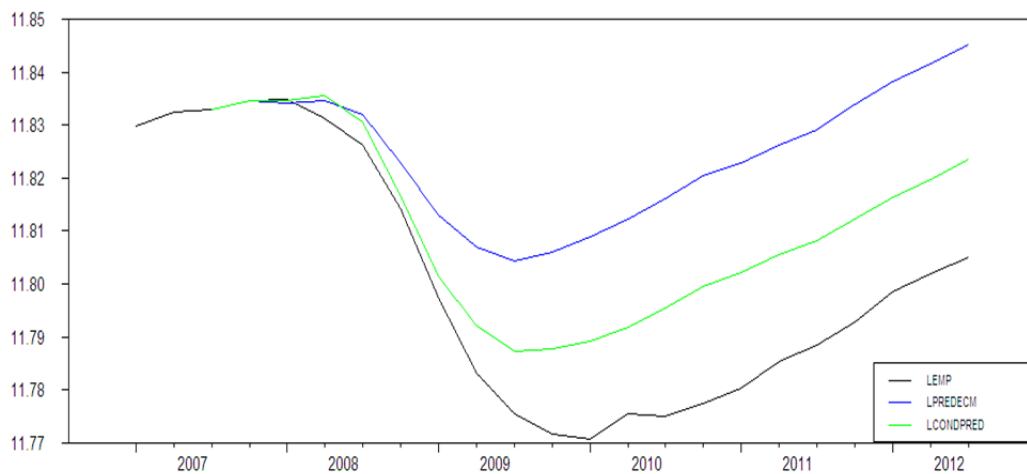
Note: Conditional forecasts stemming from the linear ECM (green) and the non-linear ECM (red). Observed values are presented in the dark line.

5. Conclusion

Addressing the issue of whether structural unemployment has risen in the wake of the Great Recession is of crucial importance for policy makers. Within this context, this paper aims at investigating the links between employment and GDP in the United States. From a statistical perspective, we disentangle trend and cyclical components in US employment based on an innovative non-linear error correction model that accounts for both a (constant) long-term relationships between output and employment and short-run non-linearities in dynamics over the business cycle. Based on this estimated non-linear Okun's law, a conditional forecasting approach shows that the level of US private sector employment is on average around 1% below the level implied by the long run output-employment relationship, meaning that around 1.2 million of the trend employment loss cannot be attributed to the identified cyclical factors.[15] To the extent that trend employment depends on structural factors, eliminating this shortfall will depend upon the

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[15] The misprediction incorporates both estimated trend factors and prediction error due to model uncertainty.

implementation of measures that improve the workings of the labor market, as well as other government policies that raise the natural rate of unemployment.

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