Downward wage rigidity and business cycle asymmetries
Appendix

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1. Data Appendix

Abbritti and Fahr (2013) explain asymmetries over the business cycle in nominal and real variables through the presence of downward nominal wage rigidities (DNWR). This appendix provides additional information on the empirical findings, a comparison with the results in McKay and Reis (2008), henceforth MR08, and robustness analysis with alternative model specifications, covering in particular asymmetric employment and investment adjustment costs.

1.1. Additional empirical evidence: Skewness

The findings in the main text are based on the skewness of selected macroeconomic variables in annual growth rates after correcting for outliers in the original series. This section documents the evidence on skewness in more detail and provides measures for the statistical significance of the findings.

Table 1 presents in columns 1 and 2 the skewness in the variables' annual growth rates for the original data series and those corrected for outliers. Outliers are defined as growth rates that deviate more than ± 3.5 standard deviations from the median growth rate. The outlier-corrected series (column 2) is presented in the main paper. The table indicates that correcting for outliers may markedly reduce skewness towards zero for the cases where outliers are detected. For example, the skewness of wage inflation in the UK declines from 1.74 to 1.02 when excluding outliers, and the skewness in unemployment growth in France is reduced from 1.24 to 0.68. The skewness based on quarterly growth rates and log differences is presented in Table 2 with broadly similar results.

Column 3 of Table 1 contains the p-values to a one-sided test of symmetry of the distribution of annual growth rates based on Bai and Ng (2005) with a Parzen Kernel and pre-whitening of the residuals, identical to the specification presented in MR08.[1] Using a Bartlett kernel, as in column 4, only marginally affects the p-values. On the contrary, with no pre-whitening of the errors the p-values are generally lower (column 5) and would indicate that the skewness in the data is statistically more significant.

The test statistic by Bai and Ng (2005) relies on asymptotic properties. In order to better exploit the sample information and to avoid relying on asymptotic properties, the p-values in columns 6 and 7 are based on bootstrapped samples. The bootstrap methodology uses stationary block bootstrap with geometric decay in the block length following Politis and Romano (1994), which accounts for serial correlation in the annual growth rates of the samples. The optimal block

[1] The test has been computed using the code by McKay and Reis (2008) which is itself based on the code by Bruce Hansen used in Hansen (1995).

length for the original sample, following the methodology by Patton et al. (2009) and Politis and White (2004), is between 6 and 14 for quantity variables such as employment, unemployment and GDP, whereas it is between 17 and 23 for price and wage inflation and real wage growth (see Table 3). For simplicity and reproducibility we settle on block lengths of 10 for quantity variables and 20 for nominal variables. The block length for the transformed cubic sample is only marginally shorter, we therefore stick to the same block length size.

To compute the distributions under the null hypothesis, the sample used for bootstrapping is obtained by subtracting the original sample's third moment from the cubed sample observations: $z_t = (x_t - \bar{x})^3 - \overline{(x_t - \bar{x})^3}$, where x_t are the sample observations and z_t is the transformed sample which by construction has zero skewness and thereby fulfills the null hypothesis. The p-value to the one-sided test is the percentage of bootstrapped samples with skewness larger (positive skewness) or smaller (negative skewness) than the skewness of the sample. Figures 1 and 2 plot the bootstrapped distributions and plot the sample skewness (vertical line) for comparison.

The percentiles presented in columns 8 and 9 are based on bootstrapped samples from the non-transformed data and represent the percentage of bootstrapped samples that exhibit skewness of opposite direction to the one found in the data for most countries. For nominal and real wages, inflation and unemployment the reference skewness is positive (right skew) whereas for the remaining variables it is negative (left skew). Column 8 uses a block length of 10 whereas column 9 uses a block length 20. One minus the percentiles of columns 8 and 9 represent the one-sided level of confidence for skewness. The right column of Figures 1 and 2 presents the distribution of bootstrapped samples together with the 10th and 90th percentiles and the sample skewness.

The different measures of statistical significance for skewness give varying degrees of statistical power. But overall there is a tendency for the series to exhibit positive skewness for nominal variables and unemployment, whereas real variables are negatively skewed. Results appear particularly clear cut for unemployment (except France), real wages (except UK) and real GDP (except FR and UK).

1.2. Additional empirical evidence: Turning points

Table 4 shows the results of applying the Harding and Pagan (2002) dating algorithm to the GDP per working age population series, and to the employment rate series in levels. The results show that expansions are much longer than recessions (except for the French employment cycle) but that recessions are more violent, as measured by the larger negative growth rate during recessions (in deviation from the mean) compared to the positive growth rates in expansions.

The presence of asymmetries in trending data does not imply by itself a need for an asymmetric model. In fact, as noted by Harding and Pagan (2002), a linear model with trend is able to reproduce the asymmetric length and intensity of expansions and recessions. In order to measure exclusively the asymmetry surrounding the trend we apply the dating algorithm to Hodrick-Prescott (λ =1600)–detrended series in Table 5, and to the Band-Pass (6,32)–detrended series in Table 6.

The results show that removing the trend from the data does not remove the asymmetries between expansions and recessions, although they are considerably reduced for real GDP. The use of the Band-Pass filter instead of the Hodrick-Prescott filter changes marginally the summary statistics, but recessions continue to be shorter and more violent than expansions.

1.3. Comparison with McKay and Reis (2008): Skewness

MR08 present results on skewness of US employment and real GDP growth which differ from those in Abbritti and Fahr (2013) (henceforth AF13). The main difference regards the assessment of the skewness in real GDP growth. There are three main differences in our analysis to the one of MR08. First, we use growth rates instead of log-differences. Second, we correct the original series for outliers, defined as observations deviating more than ±3.5 std. deviations from the median. Third, we use a different sample period; MR08 covers the period 1948q1-2005q1 while we cover the period 1970q1-2011q2 to allow for international comparison. It turns out that the main reason behind the different results on the skewness of GDP is related to the different sample used, as documented in Table 7. This reproduces the results by MR08 using log-differences of employment and real GDP. It further provides results for different samples (shortened, lengthened and shifted) and compares these results to the sample used in AF13. The results are based on log-differences, following MR08, while results in our paper are in annual growth rates. The employment rate is defined in this table as one minus unemployment rate for coherence with MR08, whereas it is employment over working age population in our paper. These two differences do not affect the main results.

As becomes evident from the Table, a lengthened sample up to 2011q2 only marginally increases the significance of the skewness of GDP, but omitting the first four years (1948q1-1951q4) of MR08's sample strongly reduces the p-value of 4-quarter differences from 0.41 in the original sample to 0.03 in the shortened sample, indicating that skewness turns statistically significant. In the shifted sample (from 1952q1-2011q1) the p-value is 0.05.

A closer analysis of the real GDP series reveals that the three quarterly growth rates for 1950q1-q3 have been among the five highest postwar observations in US real GDP and have brought the annual growth rate to a large 11.4% in 1950q3. The period has been strongly influenced by the Korean war and we therefore consider these observations as outliers. Excluding these observations leads to evidence for negative skewness in US real GDP growth. Other reasons for discrepancy in the skewness also play a role, but to less a degree.

Employment growth and real GDP growth in the sample from 1970q1 to 2011q2 used in AF13 have similar skewness for US employment growth and real GDP growth to the samples starting in 1952q1, though exhibit lower statistical significance. In AF13, the sample starts in 1970q1 to compare the evidence across five countries in a coherent manner and provides evidence that asymmetries are present across a large number of variables, in particular for unemployment, real wages and real GDP, and are common across countries with very different labor market institutions.

1.4. Comparison with McKay and Reis (2008): Turning Points

In addition to the skewness, MR08 provide in the technical appendix a battery of robustness tests based on turning points to show that contractions in US employment rate are shorter than expansions, whereas this asymmetry is not present for output. The analysis is based on US data from 1948q1-2005q1 and uses mainly industrial production as series for output and one minus the unemployment rate as measure for employment. In AF13, we extend the analysis to other four European countries and to a different sample period. We find that expansions of GDP and the employment rate are longer, but smoother, than contractions for nearly all countries and the applied detrending methods.

Table 8 shows the results of the Turning Point analysis for the US, following MR08's methodology and applying it to different sample periods.[2] The t-statistics are for a test of equal average duration of expansions and contractions. The W- statistics are for a Wilcoxon test of the null hypothesis that the distributions from which durations are drawn are the same for expansions and recessions. The employment rate is defined as one minus unemployment rate for coherence with

[2] For the analysis we employ the code by MR08 made available by Alisdair McKay (http://people.bu.edu/amckay/).

MR08, whereas it is employment over working age population in AF13. Following MR08, the raw data is detrended using the Rotemberg modified Hodrick-Prescott filter, while in AF13 we use the standard Hodrick-Prescott filter. These two differences do not affect the main results.

We find that the US employment and real GDP cycle exhibit longer expansions than contractions, independently from the sample considered. In the case of the employment cycle, the difference between expansions and recessions is always statistically significant, while for the GDP series the difference is significant only for the sample starting in 1970q1. Using statistics based on turning points we thus find evidence that, consistent with MR08, the employment cycle tends to be more asymmetric than the GDP cycle, at least for the US.

2. Model robustness

We present two robustness exercises to the baseline model, with baseline calibration values reported in Table 9. The first exercise focuses on the relevance of the structure of the labor market and the monetary policy rule, the second exercise studies the relevance of asymmetric adjustment costs on employment or investment for business cycle asymmetries.

2.1. The role of monetary policy and labor market institutions

To better understand the relevance of labor market institutions and the role of monetary policy for the behavior of the model, we compare the results of the baseline model to two alternative calibrations. The first calibration reflects a more flexible US-style labor market where the quarterly job finding rate is set to 0.7 (instead of 0.35 in the baseline calibration) and the unemployment rate is set to 5% (instead of 10%) in steady state.[3] The second calibration captures a less aggressive monetary policy rule, where the weight on output stabilization is raised to $\omega_{\Delta y} = 0.25$ (instead of $\omega_{\Delta y} = 0$), but the labor market calibration follows the one used in the baseline. Tables 10, 11 and 12 summarize the results with the alternative calibrations.

A more flexible labor market, as captured by higher job-finding and separations rates, strongly increases the volatility of real variables in the model economy (Table 10), whereas the volatility of inflation and real wages - especially relative to that of output - are reduced. The effects on skewness of a more flexible labor market are limited. In the US-style calibration the skewness of employment and vacancies is reduced, while the skewness of inflation and real wages is slightly increased. The skewness of the unemployment rate is also strongly increased, but this may be due to the low steady state level of unemployment in the US calibration ($ur = 0.05$) as further unemployment reductions imply a stronger and possibly non-linear tightening of the labor market compared to a situation with higher steady state unemployment, implying therefore stronger skewness.

As regards turning points (Table 12), a more flexible labor market with higher turnover slightly reduces the average length of business cycles, but the asymmetry between expansionary and recessionary phases remains largely unaffected. Instead, business cycles become more violent due to the stronger quantitative response of employment and output to positive and negative shocks.

A less aggressive monetary policy which gives some weight to output growth stabilization lowers the skewness of all macroeconomic variables (Table 11). It also lowers the asymmetry between expansionary and contractionary phases, but the length and violence of business cycles are only weakly affected (Table 12). The monetary rule smooths the asymmetries of the business cycle by better balancing the effects on output to those on inflation. Different monetary policies may thus partially explain why different countries present different degrees of asymmetries across variables.

[3] To be internally consistent, this calibration also implies a higher separation rate.

Even with the more balanced monetary policy, the model with DNWR falls short of matching the output asymmetry observed in the data, which may indicate the importance of alternative sources of asymmetry in the economy.

2.2. Alternative sources of asymmetries

Downward wage rigidities is only one of the possible explanations for the asymmetries in the data. Would alternative sources of asymmetries better explain the asymmetries of business cycles? To address this question, we sketch two extensions to the model. The first extension incorporates asymmetric adjustment costs in employment into the model, the second extension allows for asymmetric adjustment costs in investment.

2.2.1. Asymmetric employment adjustment costs

Adjusting the number of workers in a firm may imply very asymmetric costs. While in some countries firing costs continue to be a major impediment for layoffs, a more substantial cost may be training costs after hiring (on-the-job). We capture asymmetric employment adjustment costs in an admittedly simple, but effective way, similar to the way we captured wage adjustment costs in the baseline model. Specifically, we assume:

$$\begin{aligned} AC_t\left(\frac{n_t}{n_{t-1}}\right) &= \frac{\phi_N - 1}{2}\left(\frac{n_t}{n_{t-1}} - 1\right)^2 + \\ &\quad \frac{1}{\psi_N^2}\left\{\exp\left[-\psi_N\left(\frac{n_t}{n_{t-1}} - 1\right)\right] + \psi_N\left(\frac{n_t}{n_{t-1}} - 1\right) - 1\right\} \end{aligned}$$

with $\phi_N > 0$ and $\psi_N < 0$ to capture the fact that increasing employment is more costly than decreasing it.[4]

The representative firm maximizes the expected sum of discounted profits with the additional adjustment costs

$$\mathbb{E}_t\left\{\sum_{j=0}^{\infty}\beta_{t,t+j}\left[\varphi_{t+j}Y_{t+j} - w_{t+j}n_{t+j}\left(1 + c^w_{t+j}\right) - \gamma^{t+j}AC_{t+j} - \frac{\kappa}{\lambda_{t+j}}v_{t+j} - \left(1 + T_{t+j}\right)I_{t+j}\right]\right\}$$

subject to the aggregate production function Y_t and to the sequence of laws of motion of labor and capital. The wage is set in a bilateral bargaining between the worker and the firm, abstracting from terms due to intra-firm bargaining.

The representative firm pays two distinct hiring costs: the vacancy posting costs $\frac{\kappa}{\lambda_t}v_t$, and the employment adjustment cost $\gamma^t AC_t$ (which grow with trend productivity to ensure balance growth).[5] Other equations affected by the employment adjustment costs are the value to the firm of an employment relationship and the bargained wage:

$$J_t = \alpha\varphi_t\frac{Y_t}{n_t} - w_t\left(1 + c^w_t\right) - \gamma^t\frac{\partial AC_t}{\partial n_t} + \mathbb{E}_t\left[\beta_{t,t+1}\left(\left(1 - s\right)J_{t+1} - \gamma^{t+1}\frac{\partial AC_{t+1}}{\partial n_t}\right)\right]$$

[4] The asymmetry is parametrized in this way to explain the observed skewness of the data. Models with firing costs due to severence payments would imply the opposite asymmetry in employment adjustment costs.

[5] Notice that the baseline model is obtained by setting ϕ_N and ψ_N to 0.

$$
\begin{aligned}
w_t &= \omega_t \left(\alpha \varphi_t \frac{Y_t}{n_t} - c_t^w w_t - \gamma^t \frac{\partial AC_t}{\partial n_t} + \mathbb{E}_t \left[\beta_{t,t+1} \left((1-s) J_{t+1} - \gamma^{t+1} \frac{\partial AC_{t+1}}{\partial n_t} \right) \right] \right) \\
&\quad + (1-\omega_t) \left\{ b_t - (1-s) \mathbb{E}_t \left[\beta_{t,t+1} (1 - f_{t+1}) \left(\tilde{N}_{t+1} \right) \right] \right\}
\end{aligned}
$$

Employment adjustment costs reduce the firm's value of an employment relationship and consequently reduce the bargained wage. Since the costs of increasing workers are higher than the costs of firing them, J_t and w_t increase by less with the expansion of labor while they decrease more strongly in a contraction.

2.2.2. *Asymmetric investment adjustment costs*

To allow for asymmetric investment adjustment costs, the investment adjustment cost function is slightly modified to

$$
\begin{aligned}
T\left(\frac{I_t}{I_{t-1}}\right) &= \frac{\Theta_I - 1}{2} \left(\frac{I_t}{\gamma I_{t-1}} - 1 \right)^2 \\
&\quad + \frac{1}{\psi_I^2} \left\{ \exp\left[-\psi_I \left(\frac{I_t}{\gamma I_{t-1}} - 1 \right) \right] + \psi_I \left(\frac{I_t}{\gamma I_{t-1}} - 1 \right) - 1 \right\},
\end{aligned}
\tag{1}
$$

with $\Theta_I > 0$ and $\psi_I < 0$ to capture the fact that increasing investment is more costly than decreasing it. The first order conditions with respect to investment and capital are as before

$$
\begin{aligned}
Q_t &= 1 + T_t + \frac{\partial T_t}{\partial I_t} I_t + \mathbb{E}_t \beta_{t,t+1} \frac{\partial T_{t+1}}{\partial I_t} I_{t+1} \\
Q_t &= (1-\alpha) \varphi_t \frac{Y_t}{K_t} + \mathbb{E}_t \beta_{t,t+1} \left\{ Q_{t+1} (1-\delta) \right\}.
\end{aligned}
$$

The main difference with the baseline case is in the terms T_t, $\partial T_t / \partial I_t$ and $\partial T_{t+1} / \partial I_t$ which are now asymmetric functions of the rate of growth of investment. The asymmetric investment adjustment costs tend to increase more strongly in periods of capital expansions, limiting profits, investment, hirings and wage increases, whereas they are much lower in recessions, amplifying the response of investment and, due to the complementarity in production between capital and labor, the one of employment and wages.

2.2.3. *Calibration strategy*

To ease the comparison between the baseline model and the two extensions, most parameters are kept at their values of the baseline calibration.

Wage adjustment costs have been asymmetric in the baseline calibration, but are imposed to be symmetric in the two extensions in order to better capture the asymmetry stemming from investment and employment adjustment costs. We thus set the convexity parameter of wage adjustment costs to $\phi^w = 10.9$, and the degree of asymmetry ψ to zero. The parameters of the employment adjustment costs are calibrated to match the relative volatility of employment to output, and the skewness of annual employment growth rates. We get $\phi_N = 1.25$ and $\psi_N = -1700$. The parameters of the investment adjustment cost function are instead calibrated to match the relative volatility of investment to output, and the skewness of annual investment growth rates, which yields $\Theta_I = 1.5$ and $\psi_I = -240$.

2.2.4. Results

Table 14 shows the second moments of the three models with asymmetric adjustment costs. The absolute volatilities of the models with asymmetric employment (EAC) and investment (IAC) adjustment costs are slightly reduced by the additional frictions on the real side of the economy. The relative volatilities and covariances with output, however, remain remarkably close to the ones of the model with downward nominal wage rigidities (DNWR). The main difference between the DNWR model and the IAC and EAC models is the cyclicality of real wages, which remains extremely - and counterfactually - high in the models with IAC or EAC, while it is lowered to values closer to the data in the model with DNWR. This confirms our hypothesis that the presence of downward wage rigidities may be important to explain the low cyclicality of real wages.

The turning point analysis on the output and employment cycles appears less useful in discriminating between the empirical relevance of the three sources of asymmetry. All three models deliver qualitatively similar results with shorter and more violent contractions than expansions (Table 15).

The assessment alters strongly when considering skewness (Table 16). The EAC and IAC models capture the negative skewness of employment and output, but fail to capture the skewness in inflation and in nominal and real wages. In particular, the skewness of real wages is positive in the data but negative in the IAC and EAC models.

To understand the reason behind this discrepancy, consider for instance a technology shock. A positive technology shock leads to an increase in employment, investment and wages. The presence of asymmetric EAC and IAC, however, not only limits increases in employment and investment, but also reduces the surplus generated by the firm. This, in turn, limits the wage increase. On the contrary, following a negative technology shock, employment, investment and wages are less limited by the adjustment costs and thus fall by more. Hence, in the presence of asymmetric EAC or IAC, wage growth is more muted in an upswing than in a downswing, contrary to the empirical evidence.

Asymmetric adjustment costs on investment or employment are able to reproduce the asymmetries of the quantity variables in the economy, but do not provide asymmetries of real wages, prices and wage inflation that are consistent with the data.

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Variables in annual growth rates		Skew orig. series	Skew outlier corr.	Parzen prewh. MR08	Bartlett with pre-white	Bartlett no pre-white	Bootst. 10 block p-value	Bootst. 20 block p-value	Bootst. 10 block perctle	Bootst. 20 block perctle
Nominal wages	DE	0.89	0.89	0.00	0.00	0.04	0.08	**0.08**	0.01	**0.01**
	FR	0.83	0.83	0.30	0.30	0.15	0.11	**0.13**	0.01	**0.01**
	UK	1.74	1.02	0.08	0.08	0.04	0.12	**0.14**	0.00	**0.00**
	US	0.29	0.29	0.24	0.24	0.21	0.30	**0.31**	0.00	**0.00**
	EA	0.78	0.78	0.17	0.17	0.15	0.12	**0.15**	0.01	**0.01**
Prices	DE	0.69	0.69	0.12	0.12	0.09	0.14	**0.16**	0.18	**0.21**
	FR	0.84	0.84	0.37	0.36	0.15	0.10	**0.12**	0.03	**0.02**
	UK	1.76	1.41	0.08	0.07	0.04	0.09	**0.11**	0.07	**0.05**
	US	1.16	1.16	0.06	0.07	0.09	0.08	**0.10**	0.05	**0.08**
	EA	0.67	0.67	0.40	0.40	0.18	0.13	**0.17**	0.05	**0.08**
Real wages	DE	0.86	0.86	0.00	0.00	0.01	0.07	**0.06**	0.03	**0.05**
	FR	0.92	0.92	0.01	0.01	0.03	0.16	**0.18**	0.03	**0.03**
	UK	0.23	0.23	0.15	0.15	0.08	0.28	**0.24**	0.56	**0.62**
	US	0.56	0.56	0.06	0.06	0.08	0.22	**0.23**	0.43	**0.44**
	EA	0.95	0.95	0.00	0.00	0.02	0.12	**0.16**	0.06	**0.07**
Unemploy.	DE	1.55	1.48	0.04	0.04	0.02	**0.03**	0.03	**0.17**	0.15
	FR	1.24	0.68	0.13	0.14	0.08	**0.17**	0.18	**0.01**	0.02
	UK	1.16	0.99	0.01	0.02	0.02	**0.05**	0.05	**0.00**	0.00
	US	1.62	1.38	0.01	0.01	0.02	**0.03**	0.03	**0.10**	0.08
	EA	1.14	0.74	0.03	0.03	0.02	**0.08**	0.09	**0.00**	0.00
Employment	DE	-0.47	-0.47	0.24	0.24	0.06	**0.15**	0.16	**0.09**	0.07
	FR	0.01	0.01	0.51	0.51	0.52	**0.51**	0.51	**0.75**	0.76
	UK	-0.38	-0.38	0.24	0.25	0.09	**0.28**	0.24	**0.29**	0.29
	US	-0.77	-0.77	0.12	0.14	0.06	**0.16**	0.17	**0.05**	0.03
	EA	-0.28	-0.28	0.34	0.34	0.19	**0.28**	0.29	**0.19**	0.23
Vacancies	DE	-0.24	-0.24	0.30	0.31	0.19	**0.29**	0.29	**0.01**	0.01
	FR	0.41	-0.10	0.41	0.41	0.34	**0.41**	0.39	**0.10**	0.12
	UK	0.82	0.31	0.71	0.71	0.73	**0.70**	0.71	**0.00**	0.00
	US	0.15	0.15	0.65	0.64	0.73	**0.62**	0.61	**0.02**	0.01
	EA	-	-	-	-	-	**-**	-	**-**	-
Investment	DE	-0.39	-0.39	0.05	0.05	0.07	**0.14**	0.11	**0.06**	0.06
	FR	-0.41	-0.41	0.17	0.17	0.10	**0.18**	0.16	**0.01**	0.00
	UK	-0.23	-0.23	0.34	0.34	0.28	**0.37**	0.37	**0.06**	0.10
	US	-0.58	-0.58	0.14	0.15	0.08	**0.18**	0.18	**0.08**	0.12
	EA	-1.02	-0.76	0.05	0.05	0.05	**0.08**	0.07	**0.02**	0.04
Output	DE	-0.75	-0.36	0.07	0.06	0.11	**0.16**	0.12	**0.00**	0.00
	FR	-0.31	-0.31	0.24	0.25	0.17	**0.28**	0.25	**0.10**	0.09
	UK	-0.98	-0.82	0.12	0.12	0.06	**0.14**	0.11	**0.13**	0.12
	US	-0.77	-0.77	0.08	0.08	0.03	**0.11**	0.10	**0.00**	0.00
	EA	-1.09	-0.66	0.06	0.06	0.06	**0.10**	0.06	**0.01**	0.01

Table 1: Column 1 and 2 present skewness of the original data series and the outlier corrected series. Outliers are defined as observations deviating more than +/- 3.5 std. deviations from the median. Column 3-5 reports significance tests based on Bai and Ng (2005) with Parzen or Bartlett kernel and with or without pre-whitening. Columns 6-7 present significance tests based on bootstrapped samples under the null hypothesis of zero skewness with a block length of 10 or 20 quarters (in bold those closer to the optimal block length). Columns 8 and 9 present the percentile of bootstrapped samples based on the outlier-corrected sample with opposite skewness.

Skewness		Annual growth		4-quarter log diff		Quarterly growth		1-quarter log diff	
		Skew	p-val	Skew	p-val	Skew	p-val	Skew	p-val
Nominal wages	DE	0.89	0.00	0.84	0.01	0.99	0.00	0.96	0.00
	FR	0.83	0.30	0.78	0.30	0.71	0.03	0.70	0.03
	UK	1.02	0.08	0.88	0.07	0.66	0.04	0.61	0.04
	US	0.29	0.24	0.25	0.27	0.09	0.40	0.06	0.44
	EA	0.78	0.17	0.74	0.18	0.47	0.09	0.43	0.12
Prices	DE	0.69	0.12	0.65	0.14	0.93	0.00	0.91	0.00
	FR	0.84	0.37	0.81	0.38	0.94	0.00	0.93	0.00
	UK	1.41	0.08	1.31	0.07	1.11	0.01	1.07	0.01
	US	1.16	0.06	1.12	0.06	1.08	0.00	1.07	0.00
	EA	0.67	0.40	0.64	0.41	0.77	0.01	0.76	0.01
Real wages	DE	0.86	0.00	0.82	0.00	1.04	0.01	1.00	0.01
	FR	0.92	0.01	0.87	0.01	0.13	0.26	0.11	0.29
	UK	0.23	0.15	0.16	0.23	0.30	0.08	0.26	0.11
	US	0.56	0.06	0.50	0.07	0.56	0.14	0.51	0.15
	EA	0.95	0.00	0.92	0.00	0.68	0.00	0.67	0.00
Unemploy.	DE	1.48	0.04	1.15	0.02	1.20	0.00	1.06	0.00
	FR	0.68	0.13	0.35	0.20	0.87	0.01	0.74	0.01
	UK	0.99	0.01	0.79	0.04	0.91	0.03	0.80	0.03
	US	1.38	0.01	1.13	0.02	1.24	0.00	1.17	0.00
	EA	0.74	0.03	0.65	0.06	0.71	0.05	0.58	0.08
Employment	DE	-0.47	0.24	-0.49	0.22	-0.46	0.02	-0.47	0.02
	FR	0.01	0.51	-0.02	0.46	0.03	0.54	0.21	0.73
	UK	-0.38	0.24	-0.42	0.21	-0.33	0.07	-0.34	0.06
	US	-0.77	0.12	-0.82	0.12	-0.36	0.06	-0.37	0.05
	EA	-0.28	0.34	-0.30	0.33	-0.50	0.01	-0.51	0.01
Vacancies	DE	-0.24	0.30	-0.83	0.08	-0.58	0.04	-0.71	0.02
	FR	-0.10	0.41	-0.52	0.23	0.23	0.82	-0.16	0.25
	UK	0.31	0.71	-0.56	0.19	-0.48	0.16	-0.83	0.02
	US	0.15	0.65	-0.38	0.15	-0.52	0.00	-0.70	0.00
	EA	-	-	-	-	-	-	-	-
Investment	DE	-0.39	0.05	-0.52	0.03	-0.15	0.30	-0.10	0.37
	FR	-0.41	0.17	-0.50	0.12	-0.46	0.05	-0.49	0.04
	UK	-0.23	0.34	-0.51	0.23	-0.02	0.46	-0.14	0.26
	US	-0.58	0.14	-0.69	0.07	-0.06	0.43	-0.16	0.33
	EA	-0.76	0.05	-0.70	0.01	-0.08	0.36	-0.15	0.26
Output	DE	-0.36	0.07	-0.41	0.05	-0.11	0.32	-0.15	0.27
	FR	-0.31	0.24	-0.38	0.21	-0.28	0.17	-0.31	0.16
	UK	-0.82	0.12	-0.81	0.08	-0.99	0.00	-1.03	0.00
	US	-0.77	0.08	-0.85	0.07	-0.63	0.01	-0.35	0.14
	EA	-0.66	0.06	-0.72	0.06	-0.34	0.13	-0.36	0.12

Table 2: Skewness of the different variables in annual growth rates, 4-quarter log differences, quarterly growth and 1-quarter log differences. Corresponding p-values are based on the test for skewness by Bai and Ng (2005) using Parzen kernel and pre-whitening of errors.

Optimal Block length	FR samp	FR 3rd	DE samp	DE 3rd	UK samp	UK 3rd	US samp	US 3rd	EA samp	EA 3rd	Simul
Nominal Wages	22.4	19.4	21.4	13.4	21.5	7.7	21.0	18.3	22.9	23.0	20
Prices	22.2	19.3	21.2	12.6	21.1	8.6	21.5	13.9	22.4	21.6	20
Real Wages	21.7	21.0	13.6	9.7	4.6	5.0	9.1	7.1	23.3	24.3	20
Unemployment	9.3	6.7	11.3	7.9	10.0	7.1	7.1	5.9	11.6	5.8	10
Employment	8.4	5.9	11.4	9.5	10.4	10.4	9.7	7.2	14.4	12.0	10
Investment	10.1	8.2	8.4	39.0	9.5	7.4	9.1	7.2	8.9	7.1	10
Output	9.5	6.8	32.8	5.6	9.8	6.5	7.8	6.5	8.5	6.4	10

Table 3: Optimal block lengths for the original sample (samp) and the 3rd power of the sample (3rd) used for bootstrapping under the null hypothesis. The values have been computed using the code by Patton and Politis and White (2009) and Politis and White (2004). The last column (Simul) indicates the mean block length used for each variable in the bootstrapping exercise.

Turning Point Analysis (Variables in levels)	Duration (quarters) Cycle	Duration (quarters) Exp.	Duration (quarters) Rec.	Growth rates (annualized) Exp.	Growth rates (annualized) Rec.	Growth rates (dev. from mean) Exp.	Growth rates (dev. from mean) Rec.	Cumulative growth rates Exp.	Cumulative growth rates Rec.
Output per capita									
DE	24.5	19.8	4.4	2.95	-1.89	1.24	-3.60	14.6	-2.1
FR	22.3	18.7	3.7	2.26	-1.68	0.64	-3.30	10.6	-1.6
UK	34.9	29.8	5.0	3.59	-3.87	1.79	-5.67	26.7	-4.8
US	19.5	14.6	4.6	3.16	-2.79	1.74	-4.21	11.5	-3.2
EA	27.0	22.0	4.8	2.37	-1.68	0.70	-3.35	13.0	-2.0
Employment rate									
DE	19.1	11.9	6.8	1.12	-1.26	0.92	-1.26	3.3	-2.1
FR	15.1	7.3	7.8	1.19	-1.54	1.38	-1.35	2.2	-3.0
UK	27.5	15.5	10.4	0.89	-1.50	0.89	-1.50	3.4	-3.9
US	26.0	17.0	8.0	1.17	-2.13	1.13	-2.17	5.0	-4.3
EA	24.4	15.0	9.8	0.78	-0.95	0.73	-1.00	2.9	-2.3

Table 4: Turning point analysis for four selected countries and the euro area for the output per capita and the employment rate series (in levels). Expansions are measured from trough to peak and contractions from peak to trough. Growth rates during expansions and contractions are annualized growth rates, cumulative growth rates are the quarterly sums during expansions and contractions. Analysis obtained with Harding-Pagan methodology using the code by James Engel.

Turning Point Analysis HP(1600)–detr.	Duration (quarters) Cycle	Exp.	Rec.	Exp./ Rec. ratio	Growth rates (annualized) Exp.	Rec.	Cumulative growth rates Exp.	Rec.
Output per capita								
DE	13.7	7.5	6.0	1.3	2.05	-2.61	3.84	-3.92
FR	13.3	8.2	5.0	1.6	1.06	-1.63	2.17	-2.04
UK	10.0	5.3	4.7	1.1	2.48	-2.31	3.29	-2.91
US	12.7	6.8	6.0	1.1	2.22	-2.37	3.77	-3.55
EA	13.8	8.3	5.3	1.6	1.03	-1.89	2.14	-2.50
Employment rate								
DE	15.1	7.4	7.5	1.0	0.90	-0.92	1.67	-1.73
FR	11.4	6.0	5.5	1.1	1.17	-1.07	1.76	-1.47
UK	14.0	7.3	6.6	1.1	0.78	-0.86	1.42	-1.42
US	13.3	8.1	5.8	1.4	0.99	-1.41	2.00	-2.04
EA	18.4	10.7	7.9	1.4	0.53	-0.74	1.42	-1.46

Table 5: Turning point analysis for HP(1600)-detrended output and employment per capita. Expansions are measured from trough to peak and contractions from peak to trough. Growth rates during expansions and contractions are annualized growth rates, cumulative growth rates are the quarterly sums during expansions and contractions. Analysis obtained with Harding-Pagan methodology using the code by James Engel.

Turning Point Analysis BP(6,32)–detrended	Duration (quarters) Cycle	Exp.	Rec.	Exp./ Rec. ratio	Growth rates (annualized) Exp.	Rec.	Cumulative growth rates Exp.	Rec.
Output per capita								
DE	14.7	7.2	7.5	1.0	1.44	-1.62	2.60	-3.04
FR	11.3	6.2	5.1	1.2	1.02	-1.41	1.58	-1.80
UK	12.4	6.7	5.7	1.2	1.62	-1.85	2.71	-2.64
US	15.4	8.6	6.8	1.3	1.67	-2.24	3.59	-3.81
EA	13.6	7.4	6.2	1.2	1.04	-1.34	1.92	-2.08
Employment rate								
DE	16.8	8.6	8.2	1.0	0.78	-0.76	1.68	-1.56
FR	11.6	6.2	5.4	1.2	0.65	-0.76	1.01	-1.03
UK	15.1	7.8	7.3	1.1	0.69	-0.60	1.35	-1.10
US	15.5	8.7	6.8	1.3	0.98	-1.31	2.13	-2.23
EA	16.7	8.7	8.0	1.1	0.55	-0.57	1.20	-1.14

Table 6: Turning point analysis for BP(6,32)-detrended real GDP and employment per capita. Expansions are measured from trough to peak and contractions from peak to trough. Growth rates during expansions and contractions are annualized growth rates, cumulative growth rates are the quarterly sums during expansions and contractions. Analysis obtained with Harding-Pagan methodology using the code by James Engel.

Skewness in log differences (United States)		Employment rate	Real GDP	Real GDP per capita
MR08 sample	qoq	-1.08	-0.10	
1948Q1-2005Q1	(t-stat, p-val)	(-2.04, 0.02)	(-0.39, 0.35)	
	yoy	-0.70	-0.06	
	(t-stat, p-val)	(-2.02, 0.02)	(-0.23,0.41)	
Lengthened sample	qoq	-1.12	-0.12	
1948q1 – 2011q2	(t-stat, p-val)	(-2.30, 0.01)	(-0.45,0.33)	
	yoy	-0.84	-0.15	
	(t-stat, p-val)	(-2.21, 0.01)	(-0.48,0.31)	
Shortened sample	qoq	-1.28	-0.32	-0.38
1952Q1-2005Q1	(t-stat, p-val)	(-1.92, 0.03)	(-1.15,0.12)	(-1.30, 0.10)
	yoy	-0.89	-0.38	-0.45
	(t-stat, p-val)	(-2.04, 0.02)	(-1.90, 0.03)	(-2.06,0.02)
Shifted sample	qoq	-1.31	-0.34	-0.41
1952q1 – 2011q2	(t-stat, p-val)	(-2.19,0.01)	(-1.27, 0.10)	(-1.45, 0.07)
	yoy	-1.03	-0.46	-0.52
	(t-stat, p-val)	(-2.19,0.01)	(-1.61, 0.05)	(-2.01,0.02)
AF13 sample	qoq	-1.39	-0.34	-0.33
1970q1 – 2011q2	(t-stat, p-val)	(-0.89,0.19)	(-1.15,0.12)	(-1.90,0.03)
	yoy	-1.08	-0.72	-0.67
	(t-stat, p-val)	(-1.24,0.11)	(-0.86,0.20)	(-1.27,0.10)

Table 7: Measures of skewness across different samples for employment rate, real GDP and real GDP per capita (available from 1952q1) in quarter-on-quarter (qoq) or year-on-year (yoy) log-differences. The t-statistics and the p-values are based on hypothesis tests by Bai and Ng (2005), identical to MR08. The results are based on log-differences. Employment rate is defined as one minus unemployment rate.

Turning Point Analysis (United States)		Employment rate	Real GDP	Real GDP per capita
MR08 sample	Expansion	18.0	11.5	
1948Q1-2005Q1	Contraction	8.0	9.5	
	t-stat (p-val.)	-2.63 (0.00)	-0.76 (0.22)	
	W-stat (p-val.)	-3.45 (0.00)	-0.41 (0.35)	
Lengthened sample	Expansion	15.7	10.3	
1948q1 – 2011q2	Contraction	8.1	9.0	
	t-stat (p-val.)	-2.65 (0.01)	-0.61 (0.27)	
	W-stat (p-val.)	-2.50 (0.00)	-0.74 (0.24)	
Shortened sample	Expansion	18.0	12.3	12.0
1952Q1-2005Q1	Contraction	9.75	9.2	9.4
	t-stat (p-val.)	-1.97 (0.02)	-1.12 (0.13)	-0.90 (0.19)
	W-stat (p-val.)	-1.58 (0.08)	-0.89 (0.20)	-0.16 (0.45)
Shifted sample	Expansion	17.8	10.6	12.0
1952q1 – 2011q2	Contraction	9.7	8.8	9.4
	t-stat (p-val.)	-2.13 (0.02)	-0.93 (0.18)	-0.95 (0.17)
	W-stat (p-val.)	-1.86 (0.05)	-1.16 (0.16)	-0.37 (0.36)
AF13 sample	Expansion	19.4	15.0	14.5
1970q1 – 2011q2	Contraction	10.0	9.6	11.0
	t-stat (p-val.)	-2.19 (0.01)	-1.56 (0.06)	-0.90 (0.18)
	W-stat (p-val.)	-2.47 (0.03)	-1.82 (0.06)	-0.90 (0.21)

Table 8: Turning point analysis across different samples for US employment rate, real GDP and real GDP per capita (available from 1952q1). The t-statistics are for a test of equal average duration of expansions and contractions. The W- statistics are for a Wilcoxon test of the null hypothesis that the distributions from which durations are drawn are the same for expansions and recessions. Employment rate is defined as one minus unemployment rate.

Parameter	Value	
Real business cycle		
Discount rate β	0.992	Annual real interest rate of 3.3%
Elasticity of product substitution ϵ	11	Mark–up on differentiated goods 1.10
Production function α	0.3	Capital ratio of 30%
Capital depreciation rate δ	0.03	Conventional value
Labour market		
Job finding rate f	0.35	Elsby et al. (2009)
Job separation rate s	0.06	Implied by $ur = 10\%$ and $f = 35\%$
Aggregate hiring costs	$0.01Y$	1% of ss. output (see, e.g., Walsh 2005)
Elasticity of matches ζ	0.5	Petrongolo and Pissarides (2001)
Bargaining power η	0.5	Conventional value, Blanchard and Galí (2010)
Price rigidity ϕ^p	60.5	Conversion of Calvo estimate of 0.67
Wage rigidity ϕ^w	37.6	Targets $std(\pi_t^W) = 0.60$
Wage asymmetry ψ	24100	Targets nominal wage skewness of 0.78
Monetary policy		
Response to inflation	1.5	Conventional value, e.g. Christoffel et al. (2009)
Interest rate smoothing coefficient	0.85	Conventional value, e.g. Christoffel et al. (2009)
Shocks		
Std. deviation interest rate shock σ_z	0.1%	Thomas and Zanetti (2009)
Autocorr. of productivity shocks ρ_z	0.95	Sahuc and Smets (2008)
Std. deviation productivity shock σ_z	0.64%	Smets and Wouters (2003)
Autocorr. of risk premium shocks ρ_R	0.85	Christoffel et al. (2009)
Std. dev. of risk premium shocks σ_R	0.1%	Targets GDP std. deviation of 1.19

Table 9: The table reports the parameter values used in the baseline calibration.

	$\sigma(x)$			$\sigma(x)/\sigma(y)$			$\rho(x,y)$		
	EA cal.	US cal.	Mon.pol.	EA cal.	US cal.	Mon.pol.	EA cal.	US cal.	Mon.pol.
Nominal wages	0.60	0.56	0.53	0.51	0.42	0.48	0.36	0.42	0.36
Prices	0.39	0.28	0.41	0.33	0.21	0.37	0.25	0.37	0.21
Real wages	0.68	0.66	0.64	0.58	0.49	0.57	0.60	0.66	0.68
Employment	0.77	1.05	0.72	0.65	0.78	0.65	0.78	0.83	0.72
Unemployment	6.63	21.15	6.23	5.61	15.82	5.61	-0.77	-0.77	-0.71
Vacancies	19.46	13.55	18.13	16.50	10.14	16.38	0.51	0.68	0.48
Investment	3.06	3.43	2.88	2.57	2.55	2.57	0.95	0.95	0.95
Output	1.19	1.34	1.12	1.00	1.00	1.00	1.00	1.00	1.00

Table 10: The table reports second moments of three different calibrations of the model (see text).

Skewness of variables in ann. growth rates	EA cal. $f = 0.35$ $ur = 0.10$	US cal. $f = 0.70$ $ur = 0.05$	Mon. policy $\omega_\pi = 1.5$ $\omega_{\Delta y} = 0.25$
Nominal wages	0.82	0.83	0.81
Prices	0.27	0.35	0.25
Real wages	0.33	0.47	0.22
Employment	-0.42	-0.34	-0.31
Unemployment	0.77	2.08	0.64
Vacancies	-0.17	-0.04	-0.12
Investment	-0.20	-0.19	-0.09
Output	-0.21	-0.23	-0.12

Table 11: Interaction of downward wage rigidities with different labour market institutions and different monetary policy regimes. The table reports the skewness of annual growth rates of different variables under different calibrations (see text).

Turning Point Analysis (Detrended series)	Duration (quarters)			Growth rate (annualized)		Cumulative growth rate	
	Cycle	Exp.	Rec.	Exp.	Rec.	Exp.	Rec.
Output per capita							
EA Calibration f=0.35, ur=0.10	13.3	6.9	6.4	1.69	-1.87	2.84	-2.88
US calibration f=0.70, ur=0.05	13.0	6.8	6.1	1.96	-2.23	3.27	-3.34
Mon. policy ω_π=1.5, $\omega_{\Delta y}$=0.25	13.3	6.8	6.5	1.60	-1.69	2.66	-2.66
Employment rate							
EA Calibration f=0.35, ur=0.10	12.9	7.0	5.9	1.12	-1.36	1.91	-1.94
US calibration f=0.70, ur=0.05	12.7	6.9	5.8	1.61	-2.01	2.69	-2.82
Mon. policy ω_π=1.5, $\omega_{\Delta y}$=0.25	12.8	6.8	6.0	1.10	-1.26	1.82	-1.83

Table 12: Turning point analysis on the detrended GDP per capita series and on the employment rate series. Sensitivity to different calibrations (see text).

Calibrations across model variants		Wage rigidity	Empl. adj. costs $\phi_N = 1.25$	Inv. adj. costs $\phi_I = 1.5$	Shocks
DNWR	Symmetric	Symm.	No	Baseline	Baseline
	Asymmetric	Asymmetric	No	Baseline	Baseline
EAC	Asymmetric	Symm.	$\psi_N = -1700$	Baseline	Baseline
IAC	Asymmetric	Symm.	No	$\psi_I = -240$	Baseline

Table 13: The table reports the calibration of the key parameters of three models: the model with downward wage rigidities (DNWR in the Table), the model with employment adjustment costs (EAC) and the model with investment adjustment costs (IAC). See the text for additional details.

Second Moments	σ(x)			σ(x)/σ(y)			ρ(x, y)		
	DNWR	EAC	IAC	DNWR	EAC	IAC	DNWR	EAC	IAC
Nominal wages	0.60	0.59	0.56	0.51	0.55	0.54	0.36	0.38	0.37
Prices	0.39	0.44	0.39	0.33	0.41	0.38	0.25	0.20	0.19
Real wages	0.68	0.63	0.58	0.58	0.57	0.56	0.60	0.94	0.97
Employment	0.77	0.59	0.57	0.65	0.54	0.54	0.78	0.74	0.70
Unemployment	6.63	5.17	5.03	5.61	4.75	4.81	-0.77	-0.73	-0.69
Vacancies	19.46	16.28	14.69	16.50	14.99	14.04	0.51	0.47	0.48
Investment	3.06	2.76	2.59	2.57	2.52	2.44	0.95	0.94	0.85
Output	1.19	1.09	1.05	1.00	1.00	1.00	1.00	1.00	1.00

Table 14: The table reports second moments of HP-detrended series in the DNWR, the IAC and the EAC model.

Turning Point analysis		Duration (quarters)			Growth rate (annualized)		Cumulative growth rate	
		Cycle	Exp.	Rec.	Exp.	Rec.	Exp.	Rec.
Output per capita								
EA Data		**13.8**	**8.3**	**5.3**	**1.03**	**-1.89**	**2.14**	**-2.50**
Symmetric model		13.1	6.5	6.6	1.68	-1.63	2.67	-2.63
DNWR model		**13.3**	**6.9**	**6.4**	**1.69**	**-1.87**	**2.84**	**-2.88**
Robustness	EAC	13.2	6.8	6.4	1.58	-1.67	2.62	-2.63
	IAC	13.3	7.0	6.3	1.47	-1.69	2.52	-2.58
Employment rate								
EA Data		**18.4**	**10.7**	**7.9**	**0.53**	**-0.74**	**1.42**	**-1.46**
Symmetric model		12.8	6.3	6.5	1.06	-0.97	1.61	-1.54
DNWR model		**12.9**	**7.0**	**5.9**	**1.12**	**-1.36**	**1.91**	**-1.94**
Robustness	EAC	13.1	7.4	5.7	0.84	-1.08	1.52	-1.50
	IAC	13.0	6.8	6.2	0.93	-0.98	1.53	-1.45

Table 15: Turning point analysis on the detrended GDP per capita series and on the detrended employment rate series. Sensitivity to different calibrations (see text).

Skewness annual growth rate	**Data EA**	Symmetric Model	**DNWR Model**	Robustness EAC	IAC
Nominal wages	**0.78**	0.03	**0.82**	-0.02	-0.36
Prices	**0.67**	0.10	**0.27**	0.10	0.06
Real wages	**0.95**	0.01	**0.33**	-0.22	-0.31
Employment	**-0.28**	0.09	**-0.42**	-0.28	-0.31
Unemployment	**0.74**	0.17	**0.77**	0.55	0.56
Vacancies	**n.a.**	0.03	**-0.17**	-0.08	-0.04
Investment	**-0.76**	0.10	**-0.20**	0.01	-0.76
Output	**-0.66**	0.06	**-0.21**	-0.04	-0.27

Table 16: Comparison between different models of business cycle asymmetries. The table reports the skewness of annual growth rates of different variables under different calibrations (see text).

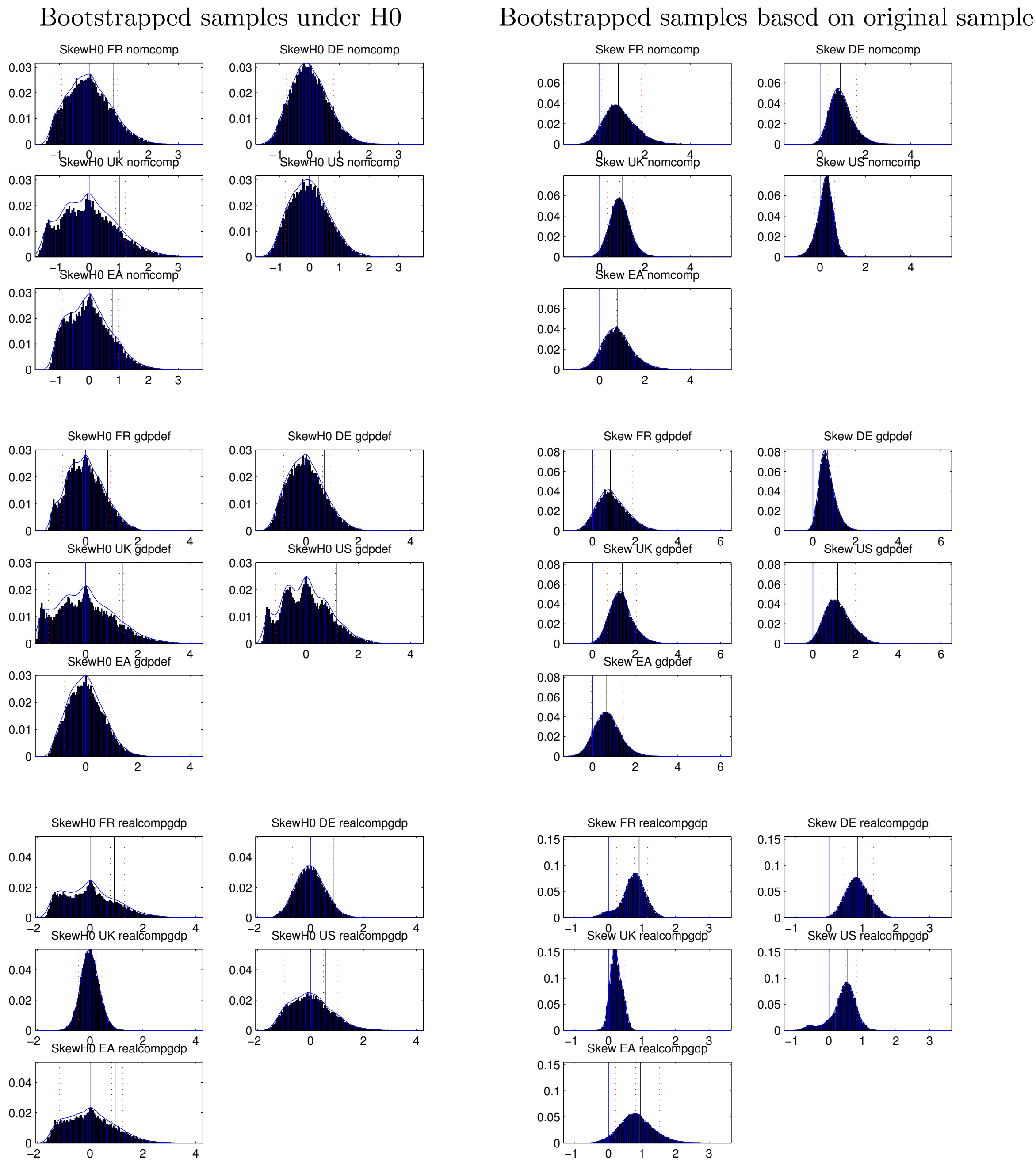

Figure 1: The left column presents the distribution of bootstrapped samples under the null hypothesis of zero skewness for nominal wage inflation, price inflation and real wage growth obtained by transforming the original sample. The right hand column presents the distribution of bootstrapped samples using the original series. The dotted red lines represent the 10th and 90th percentiles, the dotted black line is the median of the bootstrapped distribution and the vertical black line is the sample skewness of the data sample.

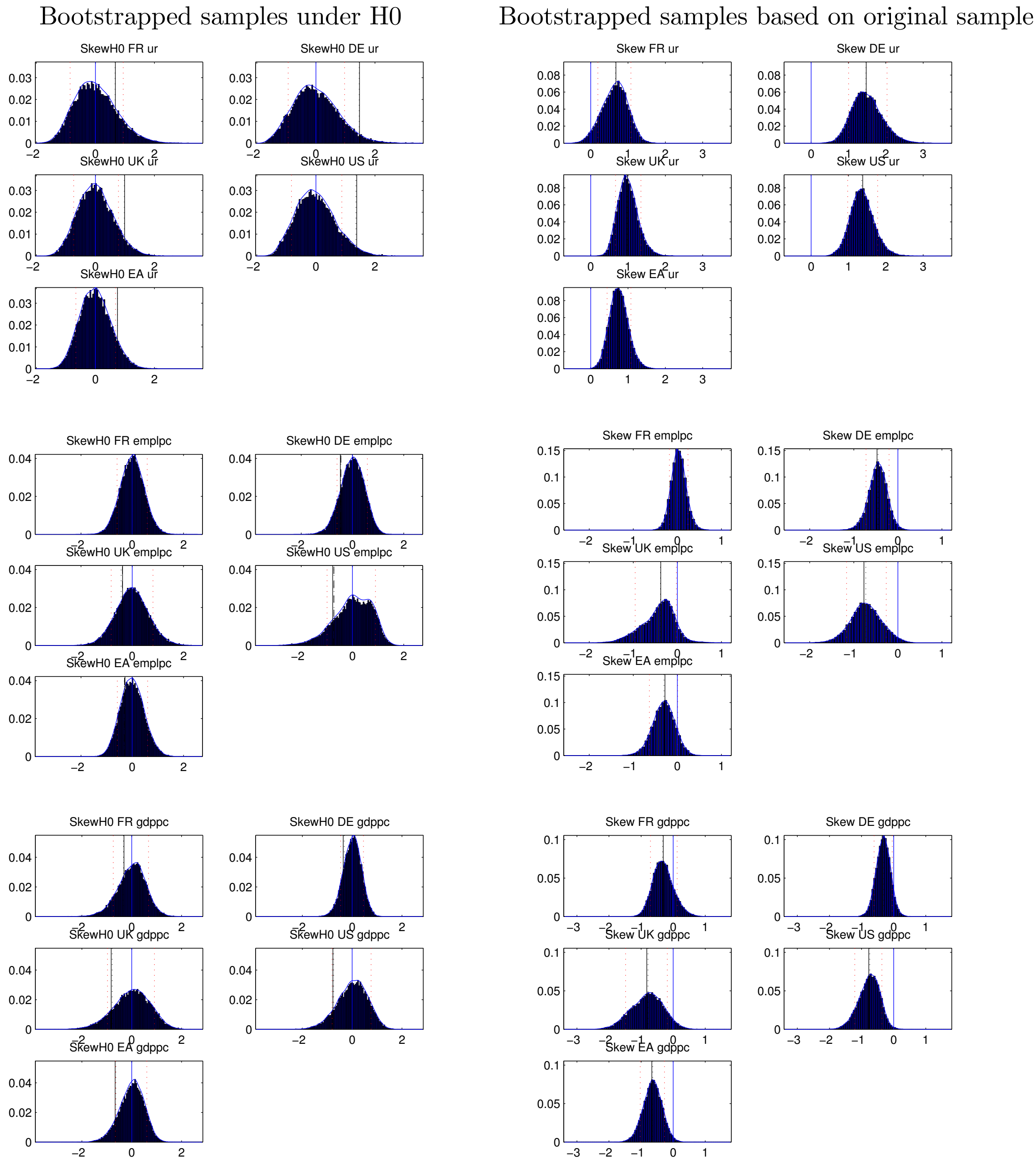

Figure 2: See caption of Figure 1. The variables considered here are growth of unemployment rate, employment rate and real GDP per capita.