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MACROECONOMIC IMPLICATIONS OF DOWNWARD WAGE RIGIDITIES

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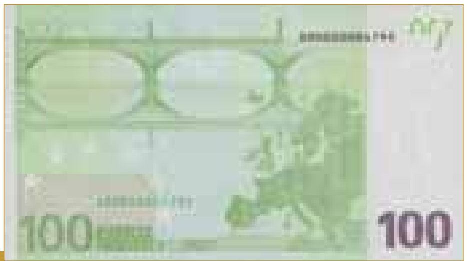

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CONTENTS

Abstract

Growth of wages, unemployment, employment and vacancies exhibit strong asymmetries between expansionary and contractionary phases. In this paper we analyze to what degree downward wage rigidities in the bargaining process affect other variables of the economy. We introduce asymmetric wage adjustment costs in a New-Keynesian DSGE model with search and matching frictions in the labor market. We find that the presence of downward wage rigidities strongly improves the fit of the model to the skewness of variables and the relative length of expansionary and contractionary phases even when detrending the data.

Due to the asymmetry, wages increase more easily in expansions, which limits vacancy posting and employment creation, similar to the flexible wage case. During contractions nominal wages decrease slowly, shifting the main burden of adjustment to employment and hours worked. The asymmetry also explains the differing transmission of positive and negative demand shocks from wages to inflation. Downward wage rigidities help explaining the asymmetric business cycle of many OECD countries where long and smooth expansions with low growth rates are followed by sharp but short recessions with large negative growth rates.

JEL classification: E31; E52; C61.

Key words: labor market, unemployment, downward wage rigidity, asymmetric adjustment costs, non–linear dynamics.

Executive Summary

Wage and employment adjustments exhibit strong asymmetries over the business cycle. Nominal wages tend to grow more sharply in expansionary periods than they fall in contractionary ones, even in detrended data. We introduce asymmetric wage adjustment costs in a New-Keynesian DSGE model with search and matching frictions in the labor market. These costs are modelled by a convex function with lower costs for adjusting wages upwards than for cutting them. This modelling device captures in intuitive and simple terms the downward wage rigidity documented by many empirical papers. The model provides a rigorous framework to study the implications of asymmetric wage adjustment for labor market dynamics, output, inflation and monetary policy. We find that the presence of downward wage rigidities strongly improves the fit of the model to the skewness of variables and the relative length of expansionary and contractionary phases.

The contribution of this paper is on four dimensions. First, we systematically document asymmetries across a number of variables of the business cycle for four countries (France, Germany, United Kingdom, United States) and the euro area by reporting skewness for annual growth rates and by providing statistics on turning points. Unemployment, vacancies and nominal wages are most strongly skewed, whereas the asymmetry of inflation and output appears more muted. Annual growth rates of hours worked show the smallest size of skewness.

Second, we introduce downward nominal wage rigidities (DNWR) in a framework of frictional labor markets in an easily tractable and effective manner. The presence of DNWR introduces an important asymmetry in the business cycle: during expansionary periods real wages and inflation increase considerably, limiting vacancy posting and employment creation; in contractionary periods shocks are mainly absorbed through a strong decline in vacancy posting and employment, while the reaction of inflation is smaller.

Third, we show that models with symmetric wage adjustment costs are unable to generate sizeable asymmetries and even tend towards the opposite direction of what we observe in the data. Downward wage rigidities, instead, correctly explain the directions of the asymmetries over the business cycle and match quantitative results on skewness measures well, especially for labor market variables.

Finally, we find that symmetric monetary shocks have strong asymmetric effects on labor markets, output and also inflation. Expansionary monetary policy shocks lead mainly to growth in nominal wages and prices, but have more limited effects on real variables. Instead, contractionary shocks affect more strongly the real side of the economy. This asymmetry is due to the fact that, following an increase in interest rates, nominal wages are reduced slowly, but inflation decreases faster than wages, raising thereby real wages and having detrimental effects on vacancy posting, employment and output.

Regarding asymmetries in the length of expansionary and contractionary phases, downward wage rigidity affects the length of expansionary phases more than the length of contractionary ones, but at the same time amplifies output collapses during recessions. The sclerotic nature in European labor markets shields employment, but due to the presence of downward wage rigidity hours worked need to adjust by more. Downward wage rigidities are only one source of asymmetries over the cycle, with only limited influence on the length of the cycle when comparing to the data. Other sources of asymmetry appear necessary to explain the short and violent recessions compared to the longer and smoother expansions of real GDP and investment. Ultimately, these alternative sources may complement and amplify the asymmetries stemming from downward rigidities in wages.

1 Introduction

Wage and employment adjustments exhibit strong asymmetries over the business cycle. Nominal wages tend to grow more sharply in expansionary periods than they fall in contractionary ones, even in detrended data. The current crisis is no different in this respect: while nominal wages have grown at a similar pace than inflation before the crisis, they failed to adjust downwards since its incept, causing implicitly a sharp increase in real labor costs due to a decline in inflation. This has affected the adjustment of both hours worked and employment. In all industrialized countries the decline of labor input during the financial crisis has been sizeable and fast. This paper picks up on this stylized fact and raises the question: what are the implications of downward nominal wage rigidities (DNWR) for the asymmetry of business cycle dynamics and for the length and violence of recessions? Specifically, we want to understand to what degree the observed asymmetries in different variables may be explained by downward wage asymmetries. For this, we assume that the main asymmetry in the economy is linked to the wage setting process of the labor market. It turns out that wage setting is not only at the core of labor market adjustments, but, in addition, it shapes the dynamics and asymmetries of other variables over the business cycles.[1]

The contribution of this paper is on four dimensions. First, we systematically document asymmetries across a number of variables of the business cycle for four countries and the euro area by reporting skewness for annual growth rates and by providing statistics on turning points. Unemployment, vacancies and nominal wages are most strongly skewed, whereas the asymmetry of inflation and output appears more muted. Annual growth rates of hours worked show the smallest size of skewness.

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Finally, we find that symmetric monetary shocks have asymmetric effects on labor markets, output and also inflation. Expansionary shocks with reductions in interest rates lead mainly to growth in nominal wages and prices, but have more limited effects on real variables. Instead, contractionary shocks affect more strongly the real side of the economy. This asymmetry is due to the fact that, following an increase in interest rates, nominal wages are reduced slowly, but inflation reacts faster downward compared to wages, raising thereby real wages and having detrimental effects on vacancy posting, employment and output.

Ample empirical work indicates that nominal and/or real wages in many European and non–European countries are downwardly rigid. In the context of the International Wage Flexibility Project, Dickens et al. (2007) use micro data on wage changes to show that asymmetries in wage setting are widespread in industrialized countries. Within the Eurosystem Wage Dynamics Network, Messina et al. (2010) confirm and update some of these findings, quantifying the extent of downward wage rigidity across a number of European countries. By using more aggregate wage

[1] Barnichon (2010) draws the attention instead on the asymmetries in job flows, i.e. job-destruction and job creation, and finds a strong importance for job destruction at business cycle turning points, beyond those documented in Shimer (2007) and Elsby et al. (2009).

data Holden and Wulfsberg (2009) confirm the existence of both nominal and real downward wage rigidities at the industry level for many OECD countries over the period 1973–1999.[2]

To study the implications of downward wage rigidities we start by analyzing the business cycle of four industrialized countries (France, Germany, the United Kingdom, the US) and the euro area as a whole to systematically document asymmetries across a number of variables over the business cycle. This is done by computing the skewness of annual growth rates across variables and by determining turning points in economic activity and the employment cycle, which reveals the length of expansionary and contractionary phases as well as their growth rates. These methodologies deliver a robust set of findings on asymmetric adjustments, in particular of wages, unemployment and vacancies. Nominal and real wages and unemployment increase more sharply than they fall, while vacancies ad employment tend to fall more rapidly than to increase. This labor market asymmetry is transmitted to other variables and leads at the level of aggregate output to shorter and deeper recessions followed by longer and smoother expansions. We show that these asymmetries are large and the findings are robust across countries.[3]

Following the empirical analysis we introduce downward wage rigidities into a New Keynesian framework with frictional labor markets. In the matching literature pioneered by Diamond (1982), Mortensen (1982) and Pissarides (1985) the adjustment of wages for new and existing employment relationships has been at the center of analysis for understanding labor market dynamics. Shimer (2005) and Hall (2005) call for wage rigidity as an important factor in explaining vacancy and unemployment volatility. Blanchard and Galí (2010) and Christoffel et al. (2009) identify wage rigidity as an important transmission mechanism from labor markets to inflation. Our model is developed to understand the effects of different shocks on their transmission to the economy at large via the asymmetric response of wages. It will be relevant to understand which variables counteract the wage asymmetry and what degree of asymmetry is ultimately visible at the level of aggregate GDP and inflation.

Downward wage rigidities are introduced by assuming that firms face asymmetric wage adjustment costs as in Fahr and Smets (2010). The costs are modelled by a convex function with lower costs for adjusting wages upwards than for cutting them.[4] This modelling device captures in intuitive and simple terms the downward wage rigidity documented by many empirical papers. The model provides a rigorous framework to study the implications of asymmetric wage adjustment for labor market dynamics, output, inflation and monetary policy.

A similar framework has also been proposed by Kim and Ruge-Murcia (2009) in a model with monopolistic labor supply and wage setters as in Erceg et al. (2000). Their paper focuses on the greasing effects of DNWR and indicates strong asymmetries in the adjustment following positive and negative shocks. Fahr and Smets (2010) extend this to downward rigidity of real wages in a setup of a monetary union, and show that downward real wage rigidity has strong detrimental effects for the competitiveness of the country in a currency union. More recently, Benigno and Ricci (2010) model the greasing effects in an extreme manner whereby wages can never be cut and highlight the implications for the slope of the long–run Philips curve. Our paper complements this literature by introducing DNWR into frictional labor markets to better capture

[2]Real wage rigidity can be understood as the combination of indexation, either formalized or informal, and nominal downward wage rigidity around the level of inflation assumed for indexation. In some countries within the EMU, such as Belgium and Spain, indexation of wages to a specific price index is institutionalized. And even though indexation in itself generates symmetric wage rigidity, its application is often different during times of rising and declining price inflation, especially if inflation is low or negative.

[3]The analysis of business cycle patterns, particularly of output, initiated by Burns and Mitchell (1946), has focused mainly on the asymmetry of GDP with inconclusive results as summarized by Harding and Pagan (2002). Compared to GDP other variables exhibit much stronger asymmetries in their cyclical adjustment. See also McKay and Reis (2008) and their appendix for a discussion of alternative methods for the measurement of asymmetries

[4]Specifically, the asymmetry is inserted through a combination of a symmetric and a linex adjustment cost function dependent on either nominal or real wage increases.

and document differing effects on hours and employment, and to study the interaction of labor market institutions with downward wage rigidities. Differently to the models of monopolistic labor supply the need to bargain wages leads to a situation where the adjustment cost is partly transferred to the employee through wage negotiations. The transfer varies over the business cycle, generating an additional channel of endogenous response.[5]

McKay and Reis (2008) document a similar type of asymmetry for labour markets in the US business cycle, but explain the fact that recessions are briefer and more violent with asymmetric labor adjustment costs and the timing of technology adoption. Their setup is embedded in a real business cycle model and may have difficulties in generating real wage increases during recessions, which we, instead, attribute to the interaction of demand shocks with downward nominal wage rigidities.

In the last part of the paper we confront the model to the data and answer two questions. First, are asymmetric features, beyond the non-linearities already incorporated in standard New-Keynesian models, necessary to generate the asymmetries observed in the data? Second, do downward wage rigidities improve the match between the moments of the data and those of the model? To this aim we simulate the model with and without asymmetries in wage adjustment costs to obtain the simulated statistics comparable to those in the empirical part. We show that symmetric adjustment costs do not generate the type of asymmetries observed in the data, for some variables the asymmetries even point in the opposite direction. The presence of downward wage rigidities improves the fit considerably. Not only do all variables in the simulation present skewness in the same direction as in the data, but the magnitudes are surprisingly well matched, especially for labor market variables. The model is also able to reproduce the fact of shorter and more violent recessions than expansions. Nevertheless, the relative length and the relative growth rates between recessions and expansions of the model cannot be fully reconciled with the data. This suggests that asymmetries in other sectors of the economy may be relevant in shaping the adjustment over the business cycle.

The remainder of the paper is structured as follows. Section 2 presents the evidence of asymmetries of a variety of variables, Section 3 outlines the monetary model with frictional labor markets and downward wage rigidity. Section 4 discusses the baseline calibration, and the main results are described in Section 5. We conclude in Section 6.

2 The extent of labor market asymmetries

This section documents stylized business cycle facts on asymmetries for four industrialized countries and the euro area as a whole. The asymmetries are measured on the one hand by skewness in annual growth rates of macroeconomic series and on the other hand by a turning point analysis following Bry and Boschan (1971) and Harding and Pagan (2002). The latter methodology delivers statistics on the length and violence of expansions and recessions.

2.1 Asymmetries over the business cycle

The shape of the adjustment of wages, unemployment and vacancies is very different during expansionary and contractionary phases of the labor market. Figures 1–3 show visually the distribution of the annual log changes in real wages, vacancies and unemployment for four countries: France, Germany, the UK and the US.[6] For all four countries considered, real wage

[5] In an attempt to solve the "unemployment volatility puzzle" with the presence of downward wage rigidities, Costain and Jansen (2009) model downward wage rigidity in the context of efficiency wages through a non-shirking condition. They also find that the worker's bargaining power is countercyclical.

[6] A similar picture is obtained using euro area data (see also Table 1). We did not include the euro area in the graphs because the series of vacancies is not available at the euro area level.

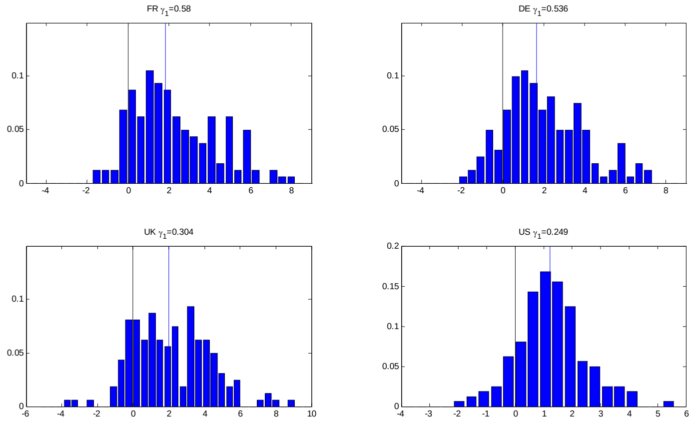

Figure 1: Distributions of annual growth rates in real hourly wages for France, Germany, UK and USA. γ_1 represents the value of skewness. The vertical lines represent zero and the median of the distribution. Source: OECD Economic Outlook.

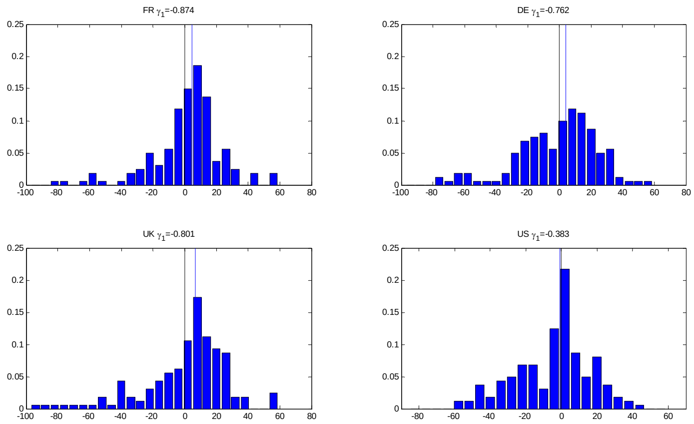

Figure 2: Distributions of annual growth rates in vacancies for France, Germany, UK and USA. See also caption of figure 1.

changes are positively skewed, which is also the case for the underlying nominal wage growth and the inflation rate of the GDP deflator (not depicted, see Table 1). The positive skewness of real wages implies sharp rises in rare occasions and reductions only by small steps.

Vacancy and unemployment growth rates are skewed in opposite directions. Vacancy growth is strongly negatively skewed, hence falling occasionally sharply; unemployment changes are positively skewed, with rare strong increases. The opposite skewness of the two distributions highlights the strong link between unemployment and vacancies through the Beveridge curve.[7]

Table 1 collects statistics on skewness for more variables in the four countries and the euro area. All data is quarterly and covers the period from 1970:Q1 to 2010:Q1[8]. Other moments

[7] The mean of the distributions captures implicitly trend components, such as productivity for real wages or trends in unemployment rates over the sample period.

[8] The skewness is computed on the annual log changes of selected macroeconomic variables, i.e $\Delta x_t = \log(x_t/x_{t-4})$. The original data is quarterly and stems from the OECD Economic Outlook and Main Economic Indicators. Computing the skewness on the quarterly log changes gives similar results. Excluding the recent period of the great recession does not alter the skewness of most variables.

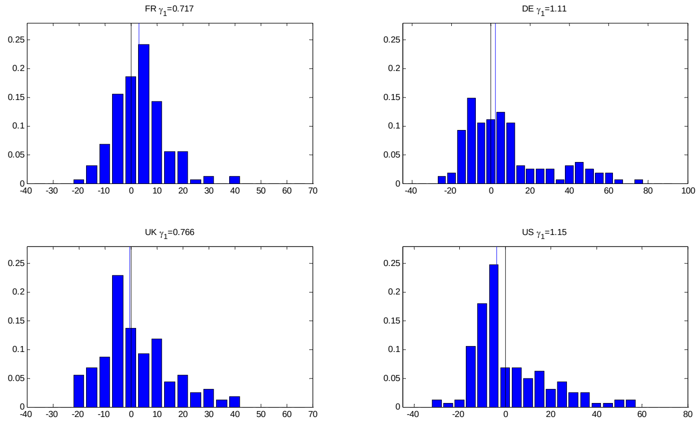

Figure 3: Distributions of annual growth rates in the unemployment rate for France, Germany, UK and USA. See also caption of figure 1.

are reported in the appendix.

Skewness of annual growth rates	**FR**	**DE**	**UK**	**US**	**EA**
Wage rate	0.83	0.91	1.19	0.31	2.64
Nominal compensation rate	0.72	0.84	1.38	0.45	1.45
GDP deflator	0.77	0.64	1.62	1.09	0.58
Wage rate (GDP defl.)	0.95	0.80	0.03	0.21	0.48
Compensation rate (GDP defl.)	0.58	0.54	0.30	0.25	0.41
Unemployment rate	0.72	1.11	0.77	1.15	0.67
Employment	0.15	-0.23	-0.65	-0.78	-0.59
Employment rate	-0.03	-0.40	-0.39	-0.86	-0.56
Weekly hours	0.37	0.63	0.04	-0.06	-0.35
Vacancy rate	-0.87	-0.76	-0.80	-0.38	n.a.
Real GDP per capita	-0.43	-0.67	-0.97	-0.69	-1.15
Labour productivity per employee	0.00	-0.24	-0.81	-0.47	-0.26
Private investment	-0.60	-1.06	-0.73	-0.86	-1.23

Table 1: Skewness of selected macroeconomic variables in annual log changes. The wage rate is the basic hourly wage, while the compensation rate includes also bonuses and social contributions. Source: OECD Economic Outlook and Main Economic Indicators.

A few observations are worth highlighting. First, the wage and compensation rate[9] in nominal and real terms are positively skewed for all countries considered, reflecting the fact that wages increase more strongly than they decrease. Given that GDP price inflation is positively skewed, the positive skewness of real wages seems to suggest that nominal wage asymmetries dominate over price asymmetries. Concerning labor market quantities, unemployment is strongly positively skewed, whereas the employment rate presents a negative skewness. Weekly hours worked exhibit a less clear–cut asymmetry across countries, whereby it is prone to the largest measurement errors. On the side of labor demand, vacancy series are negatively skewed for all countries considered.

[9]The wage rate is the basic hourly wage, while the compensation rate includes also bonuses and social contributions.

Finally, output growth is clearly negatively skewed. If one considers that production composes itself by the inputs hours worked per employee, employment and capital, it appears that the factors with negative skewness prevail in shaping the adjustment of output. Indeed, beyond the variables already discussed, also investment exhibits a strong negative skewness.

Overall, these statistics point to the presence of important asymmetries over the business cycle, which appear to be key structural features of industrialized economies. Many possible features may lead to asymmetries, differing speed of hiring or firing of workers, lumpiness in investment, or endogenous borrowing constraints that require the built–up of wealth. In this paper we focus only on one of these factors and analyze to what degree downward rigid wages can generate asymmetries similar to the ones in the presented stylized facts.

2.2 Turning Point Analysis

An alternative possibility for analyzing business cycle asymmetries is to identify turning points in univariate time series. Harding and Pagan (2002) propose an adaptation of the automatic algorithm designed by Bry and Boschan (1971) to characterize expansionary and recessionary episodes. Their algorithm earns dates of turning points similar to the NBER reference cycle for US GDP. The procedure focuses on duration, amplitude and cumulative changes during expansions and contractions.[10] We compute the following statistics:

- **Average cycle duration:** average between peak–to–peak and trough–to–trough of a variable's time series.
- **Average duration of expansions and recessions:** average duration from troughs to peaks (expansions) and average duration from peaks to troughs (recessions). The ratio indicates the asymmetry in the length of expansionary and recessionary phases.
- **Average growth rate during expansions and recessions**: the ratio indicates the asymmetry in the violence of recessions and expansions.

Output per capita	Duration (quarters)			Growth rates (annualized)		Growth rates (dev.from mean)		Cumulative growth rates	
	Cycle	Exp.	Rec.	Exp.	Rec.	Exp.	Rec.	Exp.	Rec.
FR	19.2	15.6	3.8	2.34	-1.71	0.69	-3.36	9.1	-1.6
DE	24.5	19.8	4.4	2.95	-2.00	1.26	-3.69	14.6	-2.2
UK	35.1	30.0	5.0	3.48	-3.75	1.73	-5.50	26.1	-4.7
US	19.5	14.6	4.6	3.17	-2.68	1.71	-4.14	11.6	-3.0
EA	22.5	18.8	3.7	2.38	-2.31	0.78	-3.91	11.2	-2.1

Table 2: Turning point analysis for four selected countries and the euro area for the output per capita 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 algorithm using the code by James Engel.

[10] See McKay and Reis (2008) and Barnichon (2009) for a similar approach. We perform the turning point analysis using the dating algorithm (modified BBQ) made available by James Engle on the site: http://www.ncer.edu.au/data/. The algorithm can be described as follows:

1) Smooth the reference serie y_t with a series of filters in order to eliminate outliers, high frequency or irregular variations. Call y_t^{sm} the smoothed series. 2) Use a dating rule to determine a potential set of turning points. The rule we have used is: $\triangle^2 y_t^{sm} > 0\ (< 0)$, $\triangle y_t^{sm} > 0\ (< 0)$, $\triangle y_{t+1}^{sm} < 0\ (> 0)$, $\triangle^2 y_{t+1}^{sm} < 0\ (> 0)$. 3) Use a censuring rule to ensure that peaks and throughs alternate and that the duration and the amplitude of phases is meaningful.

Table 2 indicates that the average length of the business cycle across countries, measured by GDP per working age population[11], varies between just under 5 years and just over 6 years, except for the UK where it is slightly longer. Expansions are four to six times longer than recessions.[12] The differences in the length of the business cycles are mainly explained by differences in expansions. The average annualized growth rate during expansions is 2.4% in the euro area and 3.2% in the US, whereas GDP declines by 2.3% during recessions in the euro area, and by 2.7% in the US. The asymmetry in growth rates becomes more apparent in deviations from mean growth rate, presented in the third column, where the the mean growth rate over the entire sample has been subtracted from the average growth rate during expansionary and recessionary phases. It appears that the euro area grows 0.8% more strongly during expansions than on average, but during recessions the growth rate is 3.9% lower than on average.

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 the HP(1600)–detrended GDP and employment rate series[13], which is illustrated in Table 3.[14]

HP(1600)–detrended	Duration (quarters)			Growth rates (annualized)		Cumulative growth rates	
	Cycle	Exp.	Rec.	Exp.	Rec.	Exp.	Rec.
Output per capita							
FR	12.3	7.2	5.0	1.15	-1.64	2.07	2.05
DE	15.1	8.2	6.6	1.90	-2.37	3.90	3.91
UK	10.7	5.6	5.1	2.64	-2.38	3.70	3.03
US	12.8	7.2	5.7	2.20	-2.39	3.96	3.41
EA	15.2	9.0	5.9	1.10	-1.51	2.48	2.23
Employment rate							
FR	10.6	5.8	5.0	0.98	-1.25	1.42	-156
DE	13.7	6.6	7.1	0.88	-0.90	1.45	-1.60
UK	13.8	7.5	6.2	0.75	-0.92	1.41	-1.43
US	13.3	8.1	5.8	0.98	-1.41	1.98	-2.04
EA	21.2	13.1	8.0	0.60	-0.95	1.97	-1.90

Table 3: Turning point analysis for HP(1600)-detrended output and employment per capita. See caption of Table 2.

Removing the trend from the data does not remove the asymmetries between expansions and recessions, although they are considerably reduced (compare to Table 2). Despite large cross–country differences on cycle duration, expansions in output and employment are always longer than recessions, except for the employment rate in Germany, where the opposite is true. In addition, recessions are more violent (except for the UK output series).[15] Recessions are hence shorter than expansions and the variable drops faster than it increases during expansions. As we

[11] We apply the algorithm to GDP per capita instead of to raw GDP to abstract from possible population dynamics either through varying fertility and mortality rates or migration flows. This also facilitates the comparison with the model, which abstract from population dynamics.

[12] The underlying trends in population growth are very different across countries and an analysis in GDP levels would earn longer cycles for European countries.

[13] See McKay and Reis (2008) for a discussion of the advantages of applying the Bry-Boschan algorithm to detrended series.

[14] Applying a Band-Pass filter with cycle length of 8-32 quarters earns similar results.

[15] Small differences in the cumulative growth rates for expansions and contractions may be due to the situation of the business cycle at the beginning and the end of the sample.

show in Section 5.3, these remaining asymmetries in the detrended series can not be captured in linear models with trend, they require the introduction of asymmetric features.

3 The Model

In order to capture the asymmetric features of the labor market we introduce asymmetric wage adjustment costs in a New Keynesian model with frictional labor markets. The aim is to develop a parsimonious model revealing the mechanism through which downwardly rigid wages affect different variables over the business cycle.

3.1 The labor market

Workers and firms need to match in the labor market to become productive. Their number depends on the measure of vacancies v_t and job seekers u_t following a constant returns to scale matching technology:

$$m_t = \bar{m} u_t^{\vartheta} v_t^{1-\vartheta},$$

with $\bar{m} > 0$, $\vartheta \in (0, 1)$. The probability q_t for a firm to fill an open vacancy and the probability s_t for a worker to find a job are respectively

$$q_t = \frac{m_t}{v_t} = \bar{m}\theta_t^{-\vartheta} \quad \text{and} \quad s_t = \frac{m_t}{u_t} = \theta_t q_t,$$

where $\theta_t = v_t/u_t$ denotes labor market tightness. Employment evolves according to a law of motion including job matches and exogenous job destructions. A constant fraction ρ of employment relationships is destroyed in every period and the number of matches m_t becomes operative in the same period reflecting contemporaneous hiring endogenous job destruction is not considered in this model:

$$n_t = (1 - \rho)\, n_{t-1} + m_t \tag{1}$$

We define *unemployment* in period t as the fraction of workers without employment after hiring has taken place in a given period: $ur_t = 1 - n$ and $u_t = 1 - (1 - \rho)\, n_{t-1}$ the number of *job-searching workers* at the beginning of period t.

3.2 Household optimization

Each household is thought of as a large extended family with a continuum of members on the unit interval. Consumption is pooled inside the family and family members perfectly insure each other against employment fluctuations. The representative household maximizes a time–separable lifetime utility, including consumption and disutility of work, compatible with trend growth:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t F_t \left[\log C_t - \chi \frac{h_t^{1+\phi}}{1+\phi} n_t \right]$$

where F_t is a preference shifter affecting the discount rate and hence intertemporal allocation of consumption, as in Smets and Wouters (2003) and Kim and Ruge-Murcia (2009).

Households own the firms in the economy and face a per period budget constraint

$$C_t + \frac{B_t}{P_t R_t} = w_t^R h_t n_t + b_t\,(1 - n_t) + \frac{B_{t-1}}{P_t} + D_t,$$

where C_t represents a Dixit–Stiglitz consumption bundle, w_t^R the real wage and R_t the gross nominal risk-free interest rate of the nominal bond B_t, and P_t is the aggregate price level. Total real household income is the sum of the hourly wage income w_t^R earned by employed family members n_t working h_t hours and the income by unemployed $b_t = b\gamma^t$, growing with the deterministic growth rate in the economy γ. In addition, the household earns the family share of aggregate profits from retailers and wholesalers D_t.

The first–order conditions deliver a standard Euler equation determining the intertemporal condition for consumption

$$\lambda_t = \frac{F_t}{C_t} = \beta R_t \mathbb{E}_t \left[\frac{F_{t+1}}{C_{t+1}\Pi_{t+1}} \right],$$

with λ_t being the Lagrange multiplier associated with the budget constraint. The value of employment for the family $\tilde{N}_t$ is

$$\tilde{N}_t = w_t^R h_t - b_t - F_t \frac{\chi}{\lambda_t} \frac{h_t^{1+\phi}}{1+\phi} + (1-\rho)\, \mathbb{E}_t \left[\beta_{t+1} \left(1 - s_{t+1}\right) \tilde{N}_{t+1} \right], \tag{2}$$

where $\beta_{t+1} = \beta\left(\lambda_{t+1}/\lambda_t\right)$ is the stochastic period–per–period discount factor of households. The net value of an additional employed worker in the family is the income from working h_t hours net of the disutility of working h_t hours, and net of the unemployment benefits that would be received otherwise, plus the expected continuation value from the employment relationship.

3.3 Firms

The economy consists of two sectors of production. Firms in the wholesale sector produce the intermediate homogeneous good in competitive markets using labor and capital. Their output is sold to the final good sector (retailers) who are monopolistically competitive and transform the homogeneous goods one for one into differentiated goods at no extra cost and apply a mark–up. Convex adjustment costs for prices arise in the retail sector, whereas search frictions together with convex wage adjustment costs exist in the intermediate goods sector.

3.3.1 Final good firms

A measure one of monopolistic retailers produces differentiated goods with identical technology transforming one unit of intermediate goods $Y_t(z)$ into one unit of differentiated final goods, $Y_t^F(z) = Y_t(z)$. These are aggregated in a Dixit–Stiglitz fashion with elasticity ϵ to the final composite good $Y_t = \left[\int_0^1 Y_t^F(z)^{(\epsilon-1)/\epsilon}\right]^{\epsilon/(\epsilon-1)}$. The demand function for the retailer's products is

$$Y_t^F(z) = \left(p_t(z)/P_t\right)^{-\epsilon} Y_t, \tag{3}$$

where $P_t = \left[\int_0^1 p_t(z)^{1-\epsilon}\right]^{1/(1-\epsilon)}$. Retailers maximize profits by purchasing intermediate goods at price $P_t\varphi_t$ from intermediates and setting the price $p_t(z)$ for the differentiated final good

$$\max_{p_t(z)} \; E_0 \sum_{t=0}^{\infty} \beta_t \left[\frac{p_t(z) - P_t\varphi_t}{P_t} - \Gamma_t \left(\frac{p_t(z)}{p_{t-1}(z)} \right) \right] Y_t^F(z),$$

subject to the demand function (3) and a price adjustment cost function $\Gamma_t\left(p_t(z)/p_{t-1}(z)\right) = \phi^p \left(p_t(z)/p_{t-1}(z) - \Pi^*\right)^2/2$, where Π^* is trend inflation. The first order condition for the retail firm earns a Philips curve:

$$\Gamma_t' \Pi_t = \epsilon_t \left(\varphi_t + \Gamma_t\right) - \left(\epsilon_t - 1\right) + \mathbb{E}_t \left[\beta_{t+1} \frac{Y_{t+1}}{Y_t} \Gamma_{t+1}' \Pi_{t+1} \right], \tag{4}$$

where $\Pi_t = p_t(z)/p_{t-1}(z) = P_t/P_{t-1}$ as all retailers operate with identical technology and set the same price in equilibrium.[16] The two–tier production setup implies that the price setting of retail firms is independent of labor hiring by wholesale firms, but instead depends exclusively on the relative cost of intermediate goods φ_t and on the price adjustment costs Γ_t.

3.3.2 Wholesale firms

Firms in the intermediate goods sector use employment and capital as inputs in a constant returns to scale production function[17]

$$Y_t = Z_t \left(\gamma^t n_t h_t\right)^{\alpha} K_t^{1-\alpha}$$

where γ represents the labor–augmenting deterministic growth rate in the economy, K_t is the aggregate capital stock and Z_t is an AR(1) total factor productivity process.[18]

The representative firm chooses vacancy posting and investment to maximize the expected sum of discounted profits

$$\max_{v_t, I_t} \mathbb{E}_t \left\{ \sum_{t=0}^{\infty} \beta_t \left[\varphi_t Y_t - w_t^R h_t n_t \left(1 + c_t^w\right) - \kappa_t v_t - I_t - T\left(I_t, K_{t-1}\right) \right] \right\}$$

subject to the law of motion of employment (1) and capital $K_t = (1-\delta) K_{t-1} + I_t$. The vacancy posting costs are $\kappa_t = \kappa/\lambda_t$ and are consistent with balanced growth. $T\left(I_t, K_{t-1}\right) = \Theta\left(I_t/K_{t-1} - \delta'\right)^2 K_{t-1}/2$ represents a quadratic adjustment cost on investment, with $\delta' = \gamma - (1-\delta)$ being the growth-adjusted depreciation rate. Wages and hours are determined in a bilateral bargaining between the firm and the worker, described below in Section 3.4.

The first order conditions for the wholesale firms deliver

$$Q_t = 1 + \frac{\partial T_t}{\partial I_t} = (1-\alpha)\varphi_t \frac{Y_t}{K_t} + \mathbb{E}_t \beta_{t+1} \left\{ (1-\delta)\left(1 + \frac{\partial T_{t+1}}{\partial I_{t+1}}\right) - \frac{\partial T_{t+1}}{\partial K_t} \right\} \quad (5)$$

$$J_t = \frac{\kappa_t}{q_t} = \alpha \varphi_t \frac{Y_t}{n_t} - w_t^R h_t \left(1 + c_t^w\right) + (1-\rho)\, \mathbb{E}_t \left[\beta_{t+1} \frac{\kappa_{t+1}}{q_{t+1}} \right] \quad (6)$$

The first equation describes Tobin's Q for investment decisions, which equates the marginal cost of investment to its expected benefit, consisting of the marginal product of capital, plus the expected continuation value of the capital unit and the expected savings in investment adjustment costs due to an increase in capital $(-\partial T_{t+1}/\partial K_t)$. Equation (6) is the free–entry condition for vacancies in equilibrium which equates expected vacancy posting costs to the value from a filled vacancy. It consists of the revenues from output, net of wages and their adjustment costs, and the expected continuation value of the job next period, accounting for the probability of separation.

The wage adjustment cost function is convex and may be asymmetric, indicating that wages can be more easily increased than cut. We assume the functional form

[16] Under flexible prices, $\Gamma_t = \Gamma_t' = 0$, optimal price setting leads to $p_t(z)/P_t = \epsilon/(\epsilon-1)\varphi_t$ and as all retail firms are identical in equilibrium, firms choose prices to maintain a constant mark-up μ_p over the marginal cost $\varphi_t = (\epsilon-1)/\epsilon = 1/\mu_p$.

[17] In equilibrium all firms are identical, we therefore avoid firm specific subscripts to simplify notation.

[18] The production may be re-written as $Y_t = Z_t \left(A_t h_t\right)^{\alpha} k_t^{1-\alpha} n_t$, where $k_t = K_t/n_t$ is capital per employee, which implies that returns are constant with respect to employment once taking capital per employee into account. In order to circumvent the problem of intra-firm bargaining as described by Cahuc et al. (2008), we follow di Pace and Faccini (2010) by assuming that vacancy openings, hirings, wage bargaining as well as capital decisions occur simultaneously. Given that the quantitative effects of intrafirm bargaining are found to be small (see Krause and Lubik (2007), and Faccini and Ortigueira (2010)) this assumption should alter only marginally the effects of downward wage rigidities on business cycle fluctuations.

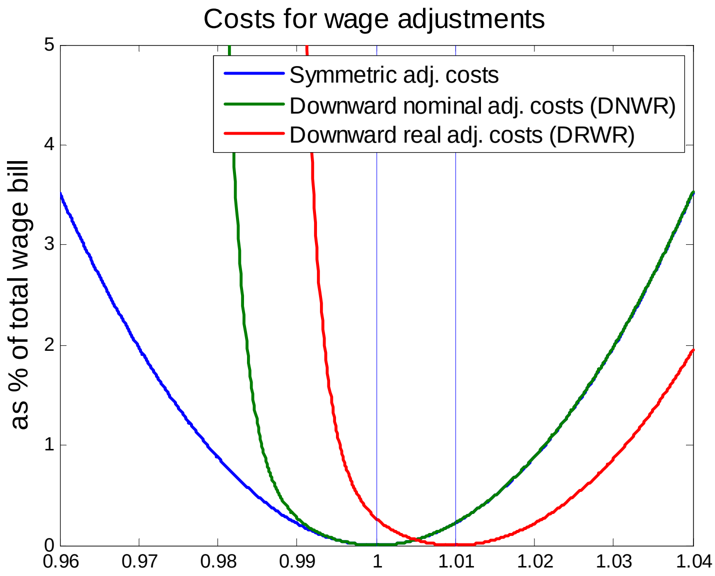

Figure 4: Different specifications of adjustment cost curves. The horizontal axis depicts gross inflation. Dotted line: symmetric adjustment cost function as used for prices, dashed line: asymmetric cost function for downward nominal wage rigidity, continuous line: downward real wage rigidity with underlying inflation of 1% as example.

$$c_t^w\left(\Omega_t^{ind}\right) = \frac{\phi^w - 1}{2}\left(\Omega_t^{ind} - \gamma\right)^2 + \frac{1}{\psi^2}\left\{\exp\left[-\psi\left(\Omega_t^{ind} - \gamma\right)\right] + \psi\left(\Omega_t^{ind} - \gamma\right) - 1\right\} \quad (7)$$

with $\Omega_t^{ind} = W_t / \left(W_{t-1}\Pi_t^{\nu}\right)$. $\nu \in [0,1]$ captures the degree of indexation to the gross inflation rate Π_t. The parameter ϕ^w determines the degree of convexity and ψ the degree of asymmetry in adjustment costs around Ω_t^{ind}. This specification nests the quadratic adjustment cost function à la Rotemberg: $\lim_{\psi \to 0} c_t^w\left(\Omega_t^{ind}\right) = \phi^w\left(\Omega_t^{ind} - \gamma\right)^2/2$. Figure 4 offers a visual impression and a comparison between different specifications. We distinguish three main cases. In the absence of indexation, $\nu = 0$, wage adjustment costs are set around the (gross) steady state nominal wage inflation rate. If we combine $\nu = 0$ with $\psi > 0$, wage adjustment costs for increases above the economy 's growth rate are smaller than those for adjustments below that rate. This captures downward nominal wage rigidity (DNWR), the main focus in this paper. If $\nu = 1$ and $\psi > 0$ the asymmetry is around the growth–adjusted inflation rate chosen for indexation and the wage adjustment function (7) allows one to capture the essence of downward real wage rigidity (DRWR).

3.4 Wage and hour negotiation

Nominal wages and hours are determined through a Nash bargaining scheme between workers and employers who maximize the joint surplus of employment by choosing hours worked and nominal wages.

$$\arg\max_{\{W_t, h_t\}}\left[J_t^{1-\eta}\tilde{N}_t^{\eta}\right]$$

with η representing the exogenous part of the worker's bargaining power. $\tilde{N}_t$ and J_t are the value of a job for the firm and the household, as specified in (2) and (6). The only difference from the standard setup is the presence of wage adjustment costs in J_t. Bargaining over the nominal wage yields an optimal sharing rule similar to the standard Nash bargaining solution:[19]

$$\omega_t J_t = (1-\omega_t)\,\tilde{N}_t \tag{8}$$

with ω_t being the *effective* time–varying bargaining power of the worker

$$\omega_t = \frac{\eta}{\eta + (1-\eta)\,\tau_{t,t+1}} \tag{9}$$

where $\tau_{t,t+1}$ is a term reflecting the evolution of current and expected wage adjustment costs:

$$\tau_{t,t+1} = 1 + c_t^w + \frac{\partial c_t^w}{\partial W_t} W_t + (1-\rho)\,\mathbb{E}_t \beta_{t+1} \frac{h_{t+1}}{h_t} \left(\frac{\partial c_{t+1}^w}{\partial W_t} \right) \frac{W_{t+1}}{\Pi_{t+1}} \tag{10}$$

In the absence of adjustment costs, $\tau_{t,t+1}$ is equal to 1, and we obtain the constant sharing rule with $\omega_t = \eta$. With adjustment costs the bargaining power becomes state-dependent. During periods of rising wages, $\partial c_t^W / \partial W_t > 0$, the effective bargaining power of workers decline. During periods of declining wages, the bargaining power of workers increase. The asymmetry in the wage adjustment cost function magnifies this tendency, i.e. the bargaining power is increased by more in recessions than it is reduced in expansions.

The result from the wage bargaining for wages is

$$\begin{aligned} w_t^R h_t &= \omega_t \left(\overline{w_t^R h_t} \right) + (1-\omega_t) \left(\underline{w_t^R h_t} \right) \\ &= \omega_t \left(\varphi_t Y'_{n,t} - c_t^w w_t^R h_t + (1-\rho)\,\mathbb{E}_t \left[\beta_{t+1} J_{t+1} \right] \right) \\ &\quad + (1-\omega_t) \left(b_t + F_t \frac{\chi}{\lambda_t} \frac{h_t^{1+\phi}}{1+\phi} - (1-\rho)\,\mathbb{E}_t \left[\beta_{t+1} (1-s_{t+1})\,\tilde{N}_{t+1} \right] \right) \end{aligned}$$

where $\overline{w_t^R h_t}$ and $\underline{w_t^R h_t}$ are the boundaries of the wage bargaining set.

Wage adjustment costs affect the bargained wage bill in two main ways. First, a deadweight loss component reduces the value of a job for the firm and thus the bargained wage. This effect, captured by the term $\omega_t c_t^w w_t^R h_t$, reduces wages independently of the direction of wage adjustments they reduce the overall surplus generated by the match. Second, wage adjustment costs affect the wage through the effective bargaining weight ω_t of the worker. In situations where flexible wages would increase, higher adjustment costs reduce the effective bargaining weight of workers ω_t. The reduction of ω_t, in turn, counteracts and dampens the wage increase by reducing the weight on the productive part of the wage, and instead increases the weight on the worker's lower outside option. Similarly, a shock exerting negative pressures on wages increases the relative bargaining power of workers and maintains wages higher than in the flexible setup.

This mechanism highlights that, although adjustment costs are incurred by the firm, they are shared between firms and workers through the bargaining setup. Times of wage contractions are thus episodes in which the relative bargaining power of workers increase, even though wages decline, and periods of wage increases reduce the worker's bargaining power. Through the movements of ω_t, wage adjustment costs have thus a dampening effect on fluctuations in the wage bill; this dampening effect is larger, the more convex wage adjustment costs are.

[19] This follows the derivations by Arseneau and Chugh (2008) in the context of optimal monetary policy with rigid wages.

The number of hours worked per worker are set to maximize the joint surplus of the match and satisfy

$$(1+\underbrace{c_t^w}_{\text{Loss}})mrs_t = \varphi_t mpl_t + \underbrace{\mathbb{E}_t\left[(\tau_{t,t+1}-1-c_t^w)\left(w_t^R - mrs_t\right)\right]}_{\text{Intertemporal}} \tag{11}$$

where the marginal rate of substitution between consumption and hours worked is $mrs_t = F_t \frac{\chi}{\lambda_t} h_t^{\phi}$, and $mpl_t = \partial^2 Y_t / (\partial n_t \partial h_t)$ is the marginal product of a marginal hour of work for the firm and the second term on the right captures the change in costs due to current and expected wage changes using $\tau_{t,t+1}$ from equation (10).

In the absence of wage adjustment costs, we obtain that the marginal rate of substitution equates the marginal product of labor, adjusted for the relative price. The introduction of adjustment costs alters the amount of hours worked in two ways. First, they reduce hours worked through the reduction in net productivity, and thereby introduce a wedge between the marginal rate of substitution and the marginal productivity as captured on the left hand side. The marginal product of labor needs to be higher than in the flexible wage case to compensate for the deadweight loss of the adjustment costs. A second effect leads to an intertemporal reallocation of hours worked, whereby hours increase when wages are larger than the marginal rate of substitution and wages are growing.

3.5 Monetary Policy and Resource constraint

The monetary authority sets the short term nominal interest rate by reacting to inflation and output growth. More specifically, the central bank adopts an augmented Taylor type rule for the nominal interest rate with a certain degree ω_r of interest rate smoothing.[20]

$$r_t = r_{t-1}^{\omega_r}\left[\left(\frac{\Pi_t}{\Pi^*}\right)^{\omega_\pi}\left(\frac{Y_t}{Y_{t-1}}\right)^{\omega_{\Delta y}}\right]^{1-\omega_r}\varepsilon_t^m.$$

The parameters ω_π and $\omega_{\Delta y}$ are the response coefficients to deviations from target inflation and to output growth. The term ε_t^m captures an i.i.d. monetary policy shock.

3.5.1 Resource constraint

Final output may either be used for consumption or investment, else it is used to cover for price, wage and investment adjustment costs or for vacancy posting.

$$C_t + I_t = Y_t(1-\Gamma_t) - \kappa_t v_t - c_t^w w_t^R h_t n_t - T(I_t, K_{t-1}).$$

4 Calibration

In the baseline calibration the parameters are set to capture the main structural features of the euro area. Time is measured in quarters.

Preferences. The discount factor β is set to 0.992 in order to obtain a real interest rate of about 3.3%. The value of the curvature of disutility of work ϕ is set to 4, a value in line with empirical micro estimates.[21] The price mark-up charged by firms is assumed to amount to 20% which implies an elasticity of substitution of intermediate goods of $\epsilon = 6$ and is well in the range of the estimates of Christopoulou and Vermeulen (2008). The steady state number of hours worked is normalized to 1, which pins down the relative weight of the disutility of working χ through steady state relationships.

[20] See, e.g, Clarida et al. (1999).

[21] See Trigari (2009) for a brief discussion.

Parameter	Value	
Real business cycle		
Discount rate β	0.992	Annual real interest rate of 3.3%
Elasticity of labor disutility ϕ	4	Trigari (2009), Christoffel et al. (2009)
Elasticity of product substitution ϵ	6	Mark–up on differentiated goods 1.2
Production function α	0.3	Capital ratio of 30%
Capital depreciation rate δ	0.025	Smets and Wouters (2003)
Labour market		
Job finding rate s	0.35	Elsby et al. (2009)
Job separation rate ρ	0.053	Reconciles unemployment rate $u = 9\%$ and $s = 0.35$
Unemployment benefits	0.85	Unemployment benefits relative to wages $b/wh = 0.66$
Elasticity in matching fct, ϑ	0.4	Christoffel et al. (2009)
Bargaining power η	0.4	Chosen such that Hosios' condition holds
Price rigidity ϕ^p	22.7	Conversion of Calvo estimate of 0.63 (SW07)
Wage rigidity ϕ^w	25	Wage Dynamics evidence of more rigid wages than prices
Wage asymmetry ψ	35000	Targets $cor\left(\pi, \pi^W\right) \simeq 0.42$
Monetary policy		
Response to inflation	1.5	Conventional value for Taylor rules
Interest rate smoothing coefficient	0.85	Conventional value for Taylor rules
Shocks		
Std. deviation interest rate shock σ_z	0.115%	Christoffel et al. (2008)
Autocorr. of productivity shocks ρ_z	0.95	Sahuc and Smets (2008)
Std. deviation productivity shock σ_z	0.54%	Sahuc and Smets (2008)
Autocorr. of preference shocks ρ_F	0.85	Smets and Wouters (2003)
Std. deviation preference shocks σ_F	1.2%	Targets $std(y) \simeq 1.26$ as in data

Table 4: The table reports calibrated parameter values.

Production. The elasticity of output with respect to total hours is set to $\alpha = 0.7$ reflecting a capital share of 30%. The quarterly depreciation rate of capital is set to $\delta = 0.025$ for an annual depreciation rate of 10%, while the investment adjustment cost is calibrated to roughly match the relative standard deviation of investment over GDP. Specifically, we set $\Theta = 6$, a value similar to the one used in Moyen and Sahuc (2005).

Labor market. In the baseline calibration, the labor market is calibrated setting the steady state unemployment to $u = 9\%$ and the job finding rate per quarter to 0.35, a value consistent with the empirical analysis by Elsby et al. (2009) for a number of continental European countries. Combining these two values with a constant participation rate normalized to 1, the separation rate per quarter is $\rho = 0.053$. This reflects the relatively rigid labor markets in Europe compared to the US, where instead a job–finding rate of 0.70 is more plausible and average unemployment is 5%, ultimately also leading to a higher job separation rate. The job filling rate q is set to 0.9, which implies that the efficiency parameter in the matching function is $\bar{m} = 0.62$. The unemployment benefits parameter is set to $b = 0.85$ to match in steady state a replacement ratio $b/(wh) = 0.66$. We specify the elasticity of job matches with respect to job seekers to $\vartheta = 0.4$, in line with Petrongolo and Pissarides (2001)'s estimation of matching functions. The workers' relative bargaining power η is also set to 0.4.

Price and wage rigidities. Under symmetric adjustment, the parameters governing the degree of price and wage rigidities are respectively ϕ^p and ϕ^w. For the convexity parameter of price adjustments we pick a value of $\phi^p = 22.7$, which is consistent with a Calvo parameter of $\zeta = 0.63$ and a mean duration of about three quarters as found in the estimated Phillips curve relationships by Smets and Wouters (2007). The parameter on symmetric wage rigidity is set to $\phi^w = 25$. This is consistent with the empirical evidence showing that the rigidity in wages is slightly higher than the one in prices, as confirmed also in the context of the Wage Dynamics Network by Druant et al. (2009). To set the parameter ψ, which governs the degree of wage asymmetry, we use the fact that the correlation of nominal wage inflation and price inflation is monotonically decreasing in ψ. We choose $\psi = 35000$, which gives a correlation between price and wage inflation of 0.40, similar to the value of $corr\left(\pi_t, \pi_t^W\right) \simeq 0.42$ found in the data. The degree of wage indexation ν is set to 0 to focus on nominal wage rigidity. The combined presence of price and wage rigidities implicitly leads to real wage rigidity.

Shocks and monetary policy. The average quarterly growth rate is $g_a = 1.004$, implying an annual average growth rate of 1.6%, a value which is in line with the average growth rate of labor productivity and GDP per person in the euro area. The persistence and standard deviation of the transitory productivity shock z_t are set to $\rho_a = 0.95$ and $\sigma_a = 0.0054$, as in the estimates of Sahuc and Smets (2008) for the euro area. The persistence of the preference shock F_t is set to $\rho_F = 0.85$, as estimated by Smets and Wouters (2003) while its standard deviation is set such that the baseline model predictions replicate the standard deviation of output, which is 1.25 in the Euro area. We get a value of $\sigma_F = 0.012$.

For the monetary policy we use a simple rule reacting to inflation with an elasticity ω_π of 1.5 and a persistence in interest rates $\omega_R = 0.85$. Regarding the shock processes, we set the standard deviation of monetary policy shocks to 0.115 percent, consistent with the estimates by Christoffel et al. (2008).

Table 5 compares the second moments of the data with the ones obtained in the model under the assumption of symmetric and asymmetric wage adjustment costs, denoted by "Sym" and "DNWR" respectively. The asymmetric model overestimates the relative standard deviation of wages and hours compared to the data. At the same time it does not generate sufficient employment volatility, which is known as the volatility puzzle, first described in Shimer (2005). For the remaining variables, however, the model appears to capture both the relative standard deviations and the co–movement in the data reasonably well. We do not intend to contribute or resolve the volatility puzzle in this context.

Euro area	$\sigma(x)$			$\sigma(x)/\sigma(y)$			$\rho(x,y)$		
	Data	Sym	DNWR	Data	Sym	DNWR	Data	Sym	DNWR
Nom. wage inflation W_t	0.61	0.32	0.82	0.49	0.27	0.65	0.29	0.74	0.16
Inflation p_t	0.36	0.47	0.47	0.29	0.40	0.38	0.30	0.49	0.39
Real wages w_t^R	0.55	0.50	0.93	0.44	0.43	0.74	0.06	0.39	-0.11
Unemployment u_t	6.55	3.94	4.59	5.24	3.38	3.76	-0.82	-0.83	-0.83
Hours worked h_t	0.24	0.70	0.83	0.19	0.60	0.62	0.07	0.68	0.73
Employment n_t	0.72	0.39	0.47	0.58	0.33	0.37	0.81	0.83	0.83
Vacancies v_t	n.a.	8.97	10.67	n.a.	7.70	8.45	n.a.	0.74	0.75
Investment I_t	3.41	3.60	3.81	2.73	3.08	3.02	0.93	0.65	0.69
Output y_t	1.25	1.17	1.26	1.00	1.00	1.00	1.00	1.00	1.00

Table 5: The table reports second moments of HP-detrended series in the data and two model specifications, one with symmetric wage adjustment costs (Sym), the second with asymmetric adjustment costs, i.e. with Downward Nominal Wage Rigidity (DNWR). The computations for the data were performed on the sample 1970:Q1 to 2010:Q1.

5 The asymmetric effects of downward wage rigidities

Asymmetric wage adjustments at the firm level transmit to other variables either directly, through production costs or through intertemporal considerations in adjusting wages, or indirectly, through the general equilibrium responses of other variables.

5.1 Impulse responses

How strong are the effects of downward wage rigidities on other macroeconomic variables? Do they absorb and counteract the asymmetry from wage adjustments or do they reinforce it? To address these questions, we analyze the dynamic responses of different macro variables to three shocks: a productivity shock, a monetary policy shock and a time preference shock.

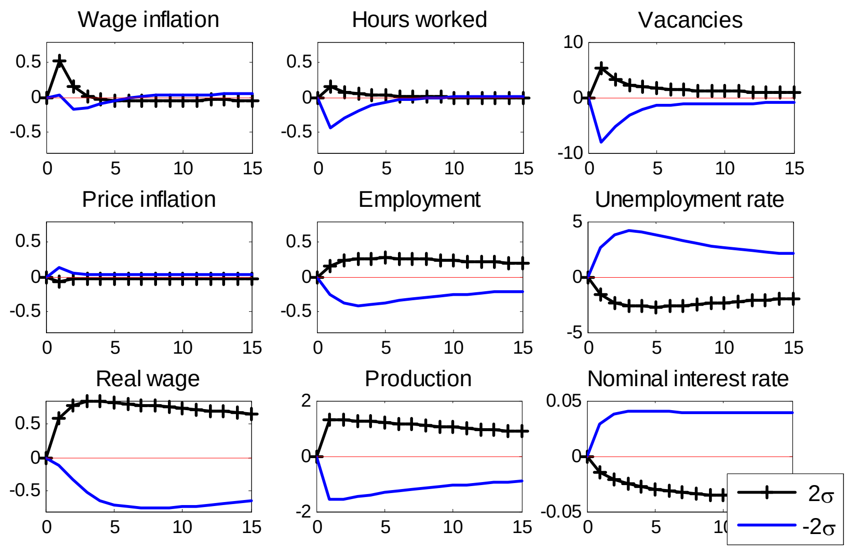

Figure 5: Impulse responses following positive and negative technology shocks of 2 standard deviations.

We first consider a technology shock. A positive shock leads to an increase in the productivity

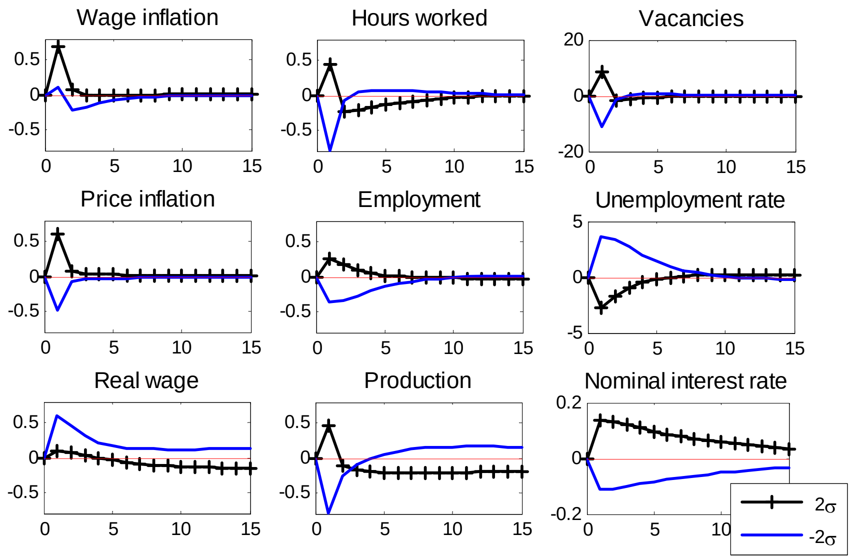

Figure 6: Impulse responses following positive and negative preference shocks of 2 standard deviations.

of employed workers that causes a simultaneous increase in nominal and real wages, supported by a fall in prices due to lower marginal costs for firms, as depicted in Figure 5. The adjustment of wages is much stronger than the one for prices due to the relative rigidities in prices and wages and due to monetary policy stabilizing inflation. The extensive and the intensive margins of labor input, employment and hours per employee, initially co-move. Hours worked increase due to intertemporal substitution, as firms and households exploit the initially higher productivity of the existing workforce. In addition, firms engage in stronger hiring activity through vacancy posting to increase employment. The persistence of hours worked and employment is very different. While hours worked return to their steady state values already after few quarters, employment deviates for a prolonged period of time. Three reasons exist for this phenomenon. First, changes in employment are effectively subject to an adjustment cost, the vacancy posting costs, whereas hours worked are not, which eases the adjustment. Second, the persistence of the shock leads to a prolonged increase in the value for firms of a filled job, when compared to the steady state. This makes the payment of the vacancy posting cost worthwhile instead of recurring to an increase in hours worked. Finally, the optimality condition for hours worked, equation (11), relates the marginal rate of substitution by households to the marginal product of an hour worked, altered by a term from wage adjustment costs. Once the initial strong nominal wage adjustments have taken place, the additional term reduces to zero and hours worked is determined by the equation of marginal rate of substitution and the marginal product of labor. As the adjustment of nominal wages is relatively fast this additional effect through the relative bargaining power also quickly returns to zero.

A comparison with a negative shock illustrates the importance of the asymmetries generated by downward wage rigidities. Following a negative technology shock, nominal wage inflation decreases only slowly and mildly and real wages are slower to adjust than following a positive shock. The slow decline in real wages reduces firms' profits strongly. This, in turn reduces the incentives for hiring new workers. Ultimately, hours worked and employment exhibit a stronger response than after a positive shock, whereas wages have seen a smaller response. Overall, unless transitory technology shocks are big, they induce only small asymmetries on the dynamics of other variables.

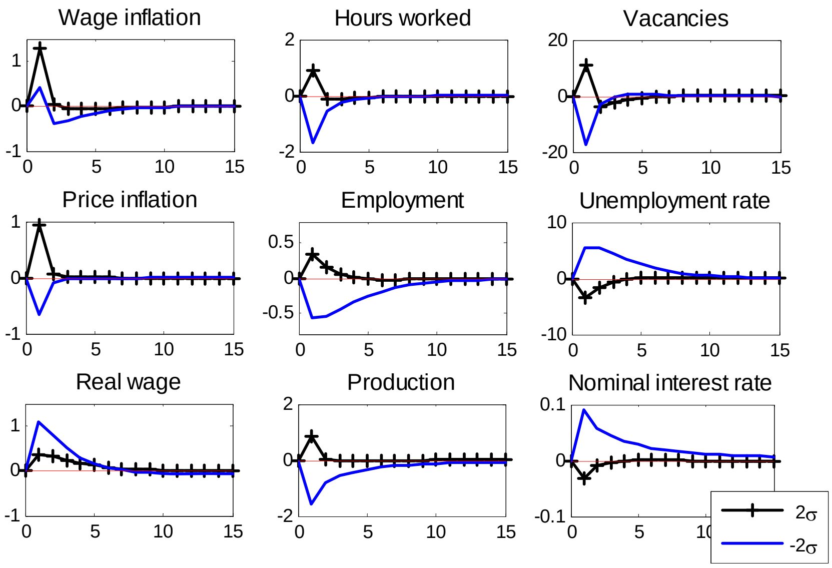

Figure 7: Impulse responses following positive and negative monetary policy shocks of 2 standard deviations.

A positive preference shock, as illustrated in Figure 6, increases the discount rate of households, shifting consumption to the current period. This needs to be met by increases in production. This is made possible by the positive adjustment in hours worked and the assumption of contemporaneous hiring, which leads to an immediate increase in employment. Similar to the technology shock, hours worked have a much lower persistence, due to their dependence on intertemporal considerations. Beyond the rationale within the single equations, a complementarity exists between hours worked and employment. The higher the amount of hours worked by a single worker, the more attractive it is to hire workers for firms, as this reduces the effective hiring cost for a worker's input. Turning to wages, three factors are key for their adjustment. First, as hiring intensity increases, the outside option for workers improves due to higher job-finding rates, putting upward pressures on wages; second, the higher contemporaneous production increases marginal costs, due to decreasing returns in production combined with the hiring activity, which raises prices. Workers want to be compensated for this loss in purchasing power and demand higher nominal wages. In fact, nominal wage growth is nearly as strong as price inflation inducing only small changes in real wages. Third, the existence of wage adjustment costs shifts the effective bargaining power of workers ω_t temporarily downward, dampening the increase slightly.

Following a negative shock, the presence of DNWR leads effectively to an almost constant nominal wage growth. The reduction in demand induces a strong contraction in price inflation. And both effects combined translate into a strong increase in real hourly wages, with stronger detrimental effects on employment and hours than after a positive shock. Monetary policy plays an important role in shaping the specific path of the adjustment. In our case is primarily on inflation stabilization, which reduces the role inflation dynamics may play to support the adjustment of real wages and to dampen the real side effects of the shock. Indeed, as can be seen in response to a negative shock, it is the faster adjustment of prices compared to the nominal wage adjustment, that increases real wages following a negative preference shock. A monetary policy with stronger output stabilization induces less strong effects on real wages as becomes evident in Section 5.4.

A third exercise involves a monetary policy shock, with a positive shock defined as being looser than the Taylor rule would imply and therefore expansionary. As captured in Figure

7), following an expansionary shock nominal wage and price inflation increase because marginal production costs increase and the firms passes these costs on to the consumers in form of higher prices. With nominal wage increases being stronger than inflation, real wages increase. On the quantity side the expansionary monetary policy is made possible by increasing employment and hours worked.

When monetary policy is contractionary, instead, aggregate demand declines and inflation decreases almost symmetrically to the expansionary shock. But the response of wages is very much muted and consequently, due to the decline in inflation, real wages increase. The inherent asymmetry of real hourly wages following a contractionary policy shock has strong repercussions on vacancies, hours and employment. The response of employment is particularly strong. Overall, we find that in the presence of DNWR expansionary monetary policy mainly affects nominal variables (inflation, wage inflation), whereas contractionary monetary policy affects real variables (real wages, employment). It may thereby be that monetary policy is itself contributing to business cycle asymmetries.

5.2 Skewness

In this section we analyze the effects of asymmetric adjustment costs on third moments in growth rates of different variables . Two guiding questions structure this section. First, are asymmetric features, beyond those already incorporated in standard models, necessary to generate the asymmetries observed in the data? Second, do downward wage rigidities improve the match between the moments of the data and those of the model? To this aim we simulate the model with and without asymmetries in wage adjustment costs to obtain simulated statistics comparable to those in the empirical part.[22] Table 6 gives answers to the two posed questions by comparing the skewness of annual log changes from the model and the data (first column). Output, employment, vacancies and investment all fall faster than they rise, implying negative skewness, whereas unemployment, prices, nominal and real wages increase faster than they fall. As illustrated in the second column of Table 6, these basic features of the data cannot be captured with symmetric adjustment costs. Most of the skewness of the variables generated with the model are close to zero and even the direction of skewness in the case of real wages and unemployment / employment are pointing in the opposite direction of their empirical counterparts. The little skewness observed in the model stems from non–linearities in the production and utility function.[23]

By introducing asymmetric wage adjustment costs (column 3), and thereby accounting for downward rigidity in the wage negotiation process, the model not only corrects for the wrong direction of skewness of the symmetric model, but is also able to capture the degree of skewness of labor market variables relatively well. As the source of the asymmetry lies in the wage bargaining process, nominal wage growth is characterized by the strongest asymmetries. These asymmetries are transmitted to real wages, but less strongly. In fact, inflation, which is also characterized by positive skewness, is absorbing part of the adjustment in real labor costs. The reason is that in situations where real wages are required to decline but nominal wages resist to adjust, stronger positive price inflation facilitates the required downward real wage adjustment. Inflation is forced to adjust upward more strongly than it declines.

The effects on real variables stemming from DNWR are most apparent for vacancies and transmits thereby to employment.[24] Following a shock requiring cuts in wages, downward rigid-

[22] The model was simulated for 100,000 periods using the shocks as calibrated before.

[23] These asymmetries are obtained with a second-order approximation. With a linear approximation even these small asymmetries vanish, and the skewness of all variables would be zero.

[24] The model series of vacancies is not taken in first differences due to the flow nature of the variable. Firms need to post vacancies every period to renew the vacancy of the former period. Most of the data series take stock variables of vacancies, as they often stem from administrative sources. To make the model compatible with the

	EA data	Symm. model	**DNWR (ψ=35000)**	DNWR (ψ=50000)
Wage inflation ΔW_t^N	**1.45**	0.04	**1.06**	0.99
Price inflation Δp_t	**0.58**	0.09	**0.48**	0.63
Real wages Δw_t	**0.41**	-0.01	**0.12**	0.21
Unemployment Δu_t	**0.67**	-0.05	**0.54**	0.65
Hours Δh_t	**n.a.**	0.00	**-0.06**	-0.11
Employment Δn_t	**-0.56**	0.05	**-0.56**	-0.68
Vacancies Δv_t	**n.a.**	0.04	**-0.59**	-0.87
Investment Δinv_t	**-1.23**	-0.02	**-0.08**	-0.13
Output Δy_t	**-1.15**	0.00	**-0.36**	-0.48

Table 6: Skewness of annual growth rates of different variables. The table reports the skewness of the annual growth rates for selected variables in the data and three model specifications, one with symmetric adjustment costs (Symm), one with wage asymmetries ($\psi = 35000$) and one with very strong wage asymmetries ($\psi = 50000$).

ity reduces the adjustment compared to the flexible case, which reduces the incentives for opening vacancies. In contrast, a faster increase in nominal wages implies that more of the additional surplus is attributed to the worker, which attenuates the increase in vacancies. The skewness of vacancies and employment is similar because of the assumption of contemporaneous hiring; the differences are due to differencing labor market tightness at the moment of opening vacancies. In turn, unemployment is defined as the complementary part to employment and is therefore the mirror image of employment in terms of asymmetry. Hours worked exhibit a less clear cut pattern, similar to what has been observed in the data for different countries. The reasons are mainly due to the short-lived deviations from steady state values even following large shocks. One can thereby clearly distinguish between short-term labor adjustment through hours capturing the intertemporal shifts over few quarters, whereas employment reflects an investment with in-built persistence and stronger skewness.

Finally, the effects on aggregate output are muted, which reflects time lags between the different input components and the buffering effects of consumption smoothing. total production is either used for consumption, investment or for adjustment costs. In periods of large adjustment, the costs of adjusting absorb part of the asymmetries. On the empirical side, a lower degree of asymmetry for output may be due to additional buffer mechanisms such as trade as well as the inventory cycle.

Overall, the model with downward wage rigidities indicates in the right direction for explaining the skewness in many macroeconomic variables. However, the model falls slightly short in explaining the large negative skewness in output per capita and in investment that we observe in the data. Indeed, increasing the degree of downward wage rigidities to $\psi = 50000$ helps to increase the skewness of real wages to more realistic levels, but is still not enough to reach the skewness of investment and output. This clearly indicates that other sources of asymmetry may be present, probably located in the adjustment of capital.

5.3 Turning point analysis

Can asymmetries in the wage setting process also affect the length of employment cycle, where expansion are long and smooth and contractions short and violent? To address this question, we apply the Bry and Boschan algorithm for turning points to the simulated data generated by our model.

The first result on Turning Points in Table 7 relates to the fact that trending models with

data, the series needs to be taken in levels for the model (flow) and in growth rates for the data (stock).

symmetric adjustment costs can indeed explain asymmetries in the output level, as had already been noted by Harding and Pagan (2002). With trend growth output increases most of the time, and expansionary phases are mechanically longer than recessionary periods. Introducing downward wage rigidity has only a small effect on the asymmetric length in this case. It slightly lengthens the expansionary periods, but generates an important effect on the violence of recessions. The cumulative loss of output per capita in a recession increases from −1.9% in the symmetric model, to −2.6% with the baseline degree of DNWR ($\psi = 35000$) and −3.0% with large DNWR ($\psi = 50000$).

Output per capita	Duration (quarters)			Growth Rates		Cumulative Growth Rates	
	Cycle	Exp.	Rec.	Exp.	Rec.	Exp.	Rec.
EA Data	**22.5**	**18.8**	**3.7**	**2.3**	**-2.3**	**11.2**	**-2.1**
Symmetric model	18.8	15.2	3.6	2.4	-2.1	9.0	-1.9
DNWR (ψ=35000)	**19.4**	**15.8**	**3.5**	**2.4**	**-2.9**	**9.5**	**-2.6**
DNWR (ψ=50000)	19.0	15.5	3.5	2.4	-3.5	9.4	-3.0

Table 7: Turning Point Analysis for the output per capita series in levels. The table reports the turning point analysis performed on the data and three model specifications, one with symmetric adjustment costs (Symm), one with wage asymmetries ($\psi = 35000$) and one with very strong wage asymmetries ($\psi = 50000$).

Table 8 shows the results obtained when the dating algorithm is applied to the *detrended* output and employment rate series. It is apparent that once the trend has been removed the symmetric model is unable to generate any degree of asymmetry in the duration between expansionary and recessionary phases found in detrended data. Introducing asymmetric adjustment costs leads to longer cycles driven by longer expansionary periods. Overall, though, the asymmetry generated by the model falls short of the empirically observed one, both for output and for employment.

Detrended Series	Duration (quarters)			Growth rate (annualized)		Cumulative growth rate	
	Cycle	Exp.	Rec.	Exp.	Rec.	Exp.	Rec.
Output per capita							
EA Data	**15.2**	**9.0**	**5.9**	**1.1**	**-1.5**	**2.5**	**-2.2**
Symmetric model	14.3	7.2	7.2	1.8	-1.8	3.2	-3.1
DNWR(ψ= 35000)	**14.3**	**7.7**	**6.6**	**1.7**	**-2.1**	**3.2**	**-3.5**
DNWR(ψ= 50000)	14.2	7.8	6.4	1.7	-2.3	3.3	-3.7
Employment rate							
EA Data	**21.2**	**13.1**	**8.0**	**0.6**	**-1.0**	**2.0**	**-1.9**
Symmetric model	13.3	6.5	6.8	0.6	-0.6	1.0	-1.0
DNWR(ψ= 35000)	**13.4**	**7.4**	**5.9**	**0.6**	**-0.8**	**1.0**	**-1.2**
DNWR(ψ= 50000)	13.5	7.7	5.8	0.6	-1.0	1.1	-1.3

Table 8: Turning point analysis for the detrended output per capita and employment rate series. The table reports the turning point analysis performed on the data and three model specifications, one with symmetric adjustment costs (Symm), one with wage asymmetries ($\psi = 35000$) and one with very strong wage asymmetries ($\psi = 50000$).

Regarding the violence of recessions, measured by the negative growth rates during these periods, asymmetric wages do indeed generate more violent downturns, with growth rates that are larger than in the data in the case of output. Nevertheless, the ratio in growth rates between expansionary and contractionary phases still falls short of the empirical observation. For the employment cycle, growth rates are more muted than for output, as observed in the data, but only with an unrealistically high asymmetry of $\psi = 50000$, the growth rate can be matched to the data.

5.4 The role of labor market institutions and monetary policy

In order to better understand the relevance of labor market institutions and the role of monetary policy for the skewness of different variables, we compare the previous results to two alternative calibrations. In the first one, meant to capture a more flexible US labor market, we set the quarterly job finding rate in steady state to 0.7 and lower the unemployment rate to 5%.[25] In the second alternative calibration, meant to capture a more accommodative monetary policy rule, we increase the weight on output stabilization to $\omega_{\Delta y} = 0.5$, while the labor market calibration follows the one used in the baseline. The results are summarized in Table 9.

The differences between the European and the US calibration do not generate large differences in skewness. In the US-style calibration the skewness of employment and vacancies is reduced, while it is slightly increased for inflation and hours per employee.

Comparing the baseline calibration with the accommodative monetary policy calibration, we notice that giving some weight to output growth stabilization lowers the skewness of basically all macroeconomic variables. The new monetary rule, by taking into account possible effects on employment and output in addition to inflation, smooths the asymmetries of the business cycle. The presence of different monetary policies may thus explain why different countries present different degrees of labor market and output asymmetries. In both alternative calibrations, the model with DNWR falls short of matching the output asymmetry observed in the data.

Skewness of variables in ann. growth rates	**EA data**	EA calib. s=0.35 u=0.09	US calib. s=0.7 u=0.05	Monetary policy $\omega_{\Delta y} = 0.5$
Wage inflation ΔW_t^N	**1.45**	1.06	1.02	1.04
Price inflation Δp_t	**0.58**	0.48	0.66	0.42
Real wages Δw_t	**0.41**	0.12	0.13	0.17
Unemployment Δu_t	**0.67**	0.54	0.37	0.42
Hours Δh_t	**n.a.**	-0.06	-0.14	-0.02
Employment Δn_t	**-0.56**	-0.56	-0.29	-0.43
Vacancies v_t	**n.a.**	-0.59	-0.43	-0.60
Investment Δinv_t	**-1.23**	-0.08	-0.12	-0.06
Output Δy_t	**-1.15**	-0.36	-0.38	-0.24

Table 9: Interaction of downward wage rigidities with different labour market institutions and different monetary policy regimes. The table represents the skewness of annual growth rates of different variables under different calibration (see text).

To complete the picture, Table 10 presents the sensitivity of the turning point analysis on the detrended GDP cycle to the two alternative calibrations. The higher turnover implicit in the US–style calibration does not affect the average length of business cycles, but reduces the asymmetry between expansionary and recessionary phases. Moreover, business cycles become much more violent, due to the stronger responsiveness of employment and output to positive and negative shocks.

Under a monetary policy rule taking into account accelerating output growth, the degree of asymmetry between expansionary and contractionary phases is reduced, reflecting more equilibrated periods of recessions and expansions, while the length and violence of business cycles are

[25] Notice that this calibration implies simultaneously a higher separation rate in order to be internally consistent.

only weakly affected.

Output per capita detrended	Duration (quarters)			Growth Rates		Cumulative Growth Rates	
	Cycle	Exp.	Rec.	Exp.	Rec.	Exp.	Rec.
EA Data	**15.2**	**9.0**	**5.9**	**1.10**	**-1.51**	**2.5**	**-2.2**
EA Calibration s=0.35u=0.09	14.3	7.7	6.6	1.68	-2.12	3.2	-3.5
US calibration s=0.7u=0.05	14.1	7.3	6.8	2.28	-2.80	4.2	-4.6
Monetary policy $\omega_{\Delta y}$=0.5	14.5	7.5	7.1	1.84	-2.16	3.4	-3.6

Table 10: Turning point analysis on the detrended GDP per capita series. Sensitivity to different calibrations (see text).

6 Conclusions

Downward wage rigidities are important for shaping the dynamics of the business cycle. Symmetric models have focused on second moments, but cannot capture numerous facts of third moments, strongly present especially in labor markets. Accounting for asymmetries in the adjustment of wages allows understanding asymmetries, both in terms of growth rates and in business cycle turning points, where long and smooth expansions are followed by shorter but more violent contractions. We introduced downward wage rigidities into a New Keynesian framework with a Mortensen-Pissarides matching model for the labor market. The asymmetric adjustment cost in the wage bargaining process makes wage increases less costly and thereby faster than wage cuts. This core asymmetry in wage dynamics directly affects the incentives for creating vacancies on the side of the firm and influences the decision of hours per employee. During an expansion the fast increase in wages mutes vacancy creation and hence employment compared to a situation with symmetric rigidity. During a recession the effects on the real side are stronger: real wages increase due to inflation rates below steady state, combined with nominal wages that have difficulties to fall. Here vacancy creation responds with a steep fall leading to strong increases in unemployment.

The overall mechanism is present particularly for demand shocks, such as monetary policy or preference shocks. In fact, a contractionary monetary policy acts primarily on real variables, whereas an expansionary policy appears to affect more strongly nominal variables, such as price and wage inflation, leaving the adjustment of real variables muted.

Regarding asymmetries in the length of expansionary and contractionary phases, downward wage rigidity affects the length of expansionary phases more than the length of contractionary ones, but at the same time increases output drops during recessions. The sclerotic nature in European labor markets shields employment, but due to the presence of downward wage rigidity hours worked need to adjust by more. Downward wage rigidities are only one source for asymmetries over the cycle, with only limited influence on the length of the cycle when comparing to the data. It appears that complementarities with other parts of the economy exist and amplify asymmetries. Hence, extensions building upon complementarities between the labor market and other variables may further improve the fit of the model with the data on the issue of asymmetries. In this respect a more detailed modelling of capital accumulation, as already advocated by den Haan et al. (2000) in the context of a model with job destruction, may be an helpful way to amplify the asymmetries and match the third moments of the model with the ones of the data.

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7 Appendix

7.1 Appendix 1: Empirical moments in growth rates

The following tables report the moments of the annual growth rates of key macro variables for five countries: France, Germany, the UK, the US and the Euro Area. The original data is quarterly and covers the period from 1970:Q1 to 2010:Q1. All series are taken from the OECD. The series on vacancies have been compared with other nationally available series with no major differences.

EA	Mean	Median	St.Dev.	Skew	Kurt
ΔW_t	2.83	2.68	1.23	1.45	6.22
Δp_t	4.90	4.20	3.21	0.58	2.04
Δw_t^R	0.40	0.29	0.86	0.48	5.72
Δu_t	4.19	2.21	10.33	0.67	3.22
Δh_t	-0.38	-0.30	0.40	-0.35	2.77
Δn_t	0.03	0.25	1.14	-0.56	3.03
Δv_t	n.a.	n.a.	n.a.	n.a.	n.a.
Δinv_t	1.13	2.08	4.80	-1.23	4.47
Δy_t	1.60	1.83	1.95	-1.15	5.07

Fra	Mean	Median	St.Dev	Skew	Kurt	**DE**	Mean	Median	St.Dev	Skew	Kurt
ΔW_t	6.25	3.62	4.76	0.83	2.27	ΔW_t	3.92	2.91	3.27	0.91	2.91
Δp_t	4.67	2.61	3.78	0.77	2.21	Δp_t	2.71	2.31	2.01	0.64	2.79
Δw_t^R	1.58	1.21	1.48	0.95	3.64	Δw_t^R	1.22	0.87	1.78	0.80	3.00
Δu_t	3.79	3.15	9.94	0.72	4.60	Δu_t	7.54	2.42	21.30	1.11	3.48
Δh_t	-0.72	-0.76	1.56	0.37	3.31	Δh_t	-0.81	-0.89	0.71	0.63	4.02
Δn_t	-0.20	-0.19	1.12	-0.03	2.58	Δn_t	0.16	0.30	1.27	-0.40	2.35
Δv_t	1.58	4.72	22.39	-0.87	5.69	Δv_t	-1.27	3.91	25.08	-0.76	3.71
Δinv_t	1.43	2.31	4.75	-0.60	2.59	Δinv_t	1.73	3.02	5.85	-1.06	3.73
Δy_t	1.65	1.59	1.87	-0.43	3.58	Δy_t	1.69	1.91	2.08	-0.67	4.00

UK	Mean	Median	St.Dev	Skew	Kurt	**US**	Mean	Median	St.Dev	Skew	Kurt
ΔW_t	7.68	6.93	5.40	1.19	4.66	ΔW_t	4.93	4.43	2.07	0.31	2.42
Δp_t	6.27	4.62	5.21	1.62	5.42	Δp_t	3.84	3.13	2.35	1.09	3.26
Δw_t^R	1.70	1.81	1.95	0.03	3.80	Δw_t^R	0.56	0.74	1.74	-0.67	3.30
Δu_t	2.04	-0.29	13.57	0.77	3.35	Δu_t	1.71	-3.71	16.78	1.15	4.00
Δh_t	-0.44	-0.42	1.36	0.04	4.24	Δh_t	-0.18	-0.13	0.58	-0.06	2.71
Δn_t	-0.01	0.25	1.41	-0.39	3.37	Δn_t	0.07	0.43	1.57	-0.86	4.08
Δv_t	0.92	6.92	28.39	-0.80	5.01	Δv_t	-4.61	-0.85	20.72	-0.38	2.83
Δinv_t	1.75	2.43	7.86	-0.73	5.76	Δinv_t	1.72	3.33	7.85	-0.86	3.77
Δy_t	1.75	1.94	2.38	-0.97	5.53	Δy_t	1.46	1.80	2.25	-0.69	3.59

7.2 Appendix 2: Second moments in log deviation from HP trend

EA	$\sigma(x)$	$\sigma(x)/\sigma(y)$	$\rho(x,y)$
$\hat{y}_t$	1.25	1.00	1.00
$\hat{R}_t$	n.a.	n.a.	n.a.
$\hat{\pi}_t$	0.36	0.29	0.30
$\hat{\pi}_t^W$	0.61	0.49	0.29
$\hat{w}_t$	0.55	0.44	0.06
$\hat{n}_t$	0.72	0.58	0.81
$\hat{v}_t$	n.a.	n.a.	n.a.
$\hat{h}_t$	0.24	0.19	0.07
$\hat{u}_t$	6.55	5.24	-0.82
$\hat{\imath}_t$	3.41	2.73	0.93

Fra	$\sigma(x)$	$\sigma(x)/\sigma(y)$	$\rho(x,y)$	DE	$\sigma(x)$	$\sigma(x)/\sigma(y)$	$\rho(x,y)$
$\hat{y}_t$	1.13	1.00	1.00	$\hat{y}_t$	1.46	1.00	1.00
$\hat{R}_t$	0.37	0.33	0.47	$\hat{R}_t$	0.40	0.27	0.48
$\hat{\pi}_t$	0.46	0.40	0.15	$\hat{\pi}_t$	0.56	0.38	0.17
$\hat{\pi}_t^W$	0.47	0.41	0.21	$\hat{\pi}_t^W$	0.94	0.64	0.28
$\hat{w}_t$	0.59	0.52	0.02	$\hat{w}_t$	0.86	0.58	0.35
$\hat{n}_t$	0.72	0.64	0.50	$\hat{n}_t$	0.88	0.60	0.67
$\hat{v}_t$	14.75	13.09	0.58	$\hat{v}_t$	17.87	12.21	0.71
$\hat{h}_t$	0.98	0.87	0.00	$\hat{h}_t$	0.40	0.27	0.09
$\hat{u}_t$	6.23	5.53	-0.78	$\hat{u}_t$	14.70	10.05	-0.68
$\hat{\imath}_t$	3.38	3.00	0.89	$\hat{\imath}_t$	4.31	2.95	0.75

UK	$\sigma(x)$	$\sigma(x)/\sigma(y)$	$\rho(x,y)$	US	$\sigma(x)$	$\sigma(x)/\sigma(y)$	$\rho(x,y)$
$\hat{y}_t$	1.52	1.00	1.00	$\hat{y}_t$	1.55	1.00	1.00
$\hat{R}_t$	0.45	0.30	0.29	$\hat{R}_t$	0.42	0.27	0.36
$\hat{\pi}_t$	0.99	0.65	0.00	$\hat{\pi}_t$	0.31	0.20	0.11
$\hat{\pi}_t^W$	1.05	0.69	0.15	$\hat{\pi}_t^W$	0.65	0.42	0.04
$\hat{w}_t$	1.22	0.80	0.18	$\hat{w}_t$	0.80	0.52	0.39
$\hat{n}_t$	0.97	0.64	0.59	$\hat{n}_t$	1.08	0.70	0.83
$\hat{v}_t$	20.16	13.24	0.76	$\hat{v}_t$	13.81	8.89	0.89
$\hat{h}_t$	0.81	0.53	0.55	$\hat{h}_t$	0.40	0.26	0.71
$\hat{u}_t$	8.59	5.64	-0.73	$\hat{u}_t$	11.88	7.65	-0.86
$\hat{\imath}_t$	5.13	3.37	0.63	$\hat{\imath}_t$	5.43	3.50	0.93