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Downward wage rigidity and business cycle asymmetries

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ABSTRACT

The growth rates of wages, unemployment and output of a number of OECD countries have a strongly skewed distribution. In this paper we analyze to what extent downward wage rigidities can explain these empirical business cycle asymmetries. To this aim, we introduce asymmetric wage adjustment costs in a New-Keynesian DSGE model with search and matching frictions in the labor market. Increasing wages is less costly than cutting them. It follows that wages increase relatively fast and thus limit vacancy posting and employment creation, but they decline more slowly, leading to a strong reduction in vacancies and employment. The presence of downward wage rigidities strongly improves the fit of the model to the observed skewness of labor market variables and the relative length of expansions and contractions in the output and the employment cycles. The asymmetry also explains the differing transmission of positive and negative monetary policy shocks from wages to inflation.

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1. Introduction

Many variables exhibit asymmetric adjustments around their long-run trend. Nominal wages tend to adjust faster upwards than downwards, and so does unemployment; on the other hand, employment and GDP tend to contract faster than to expand. This paper investigates how downward nominal wage rigidity (DNWR) shapes the adjustment of other variables over the business cycle and how it affects the relative length and violence of recessions and expansions. We introduce DNWR in an otherwise standard New-Keynesian business cycle model with labor market frictions. We find that asymmetric nominal wage dynamics not only are at the core of labor market asymmetries in unemployment and real wages, but also shape the asymmetries of prices, output and investment.

Our empirical analysis for France, Germany, the United Kingdom, the United States and the Euro Area reveals that changes in nominal and real wages, the GDP deflator and unemployment are right (positively) skewed, whereas employment, investment and GDP are left (negatively) skewed and tend to fall more rapidly than to increase. Furthermore, we show that contractionary phases in GDP and employment tend to be shorter but more violent than expansionary phases.

Our findings on the asymmetric adjustment of wages using aggregate series echo the ample microeconometric evidence on the importance of downward nominal and real wage rigidity. In the context of the International Wage Flexibility Project, Dickens et al. (2007) use micro data on individual wage changes to show that asymmetries in wage settings are widespread in industrialized countries. This finding has been confirmed, updated and further quantified for a number of European countries by Messina et al. (2010) in the context of the Eurosystem Wage Dynamics Network. Kaur (2012) finds evidence of downward nominal wage rigidity even in casual daily agricultural labor markets in 500 Indian districts that strongly

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resemble spot markets for labor.[1] Notice however that downward wage rigidities at the micro level do not necessarily translate into asymmetric wage adjustment at the macro level, as the wage asymmetry at the individual level may be mitigated by alternative possibilities of adjustments or by composition effects at the firm or sector level. Indeed, Babecký et al. (2010) find that bonus payments and skill composition serve as important additional margins of cost adjustment. But despite these mitigation effects, Holden and Wulfsberg (2009) still detect nominal and real downward wage rigidities at the industry level for many OECD countries. This indicates that alternative margins of adjustment do not fully absorb the wage asymmetry stemming from the individual level.

We introduce asymmetric wage adjustment costs similar to Kim and Ruge-Murcia (2009) into a standard New-Keynesian framework with frictional labor markets. The convex adjustment cost function exhibits larger costs for cutting nominal wages than for increasing them by the same size. This modelling device captures in a simple but effective manner the evidence at the micro level and makes it possible to study the macroeconomic implications of asymmetric wage adjustments for labor markets, inflation, monetary policy and output.[2]

The main contribution of our paper is to explain the asymmetry in business cycle fluctuations observed in the data by referring solely to DNWR. We show that models with symmetric wage adjustment costs are unable to generate asymmetries and even tend towards the opposite direction of what we observe in the data. On the other hand, DNWR correctly captures the direction of asymmetries and matches quantitative results on skewness measures quite well for nominal as well as for real labor market variables.

The effect of downward wage rigidities depends on the sources of business cycle fluctuations. Following positive productivity shocks, nominal wages grow with few frictions, leading to nominal and real wage increases which limit vacancy posting and employment creation. Instead, during periods in which real wages should fall, DNWR inhibits the adjustment through nominal wage cuts, which leads to a stronger decline in vacancy posting and employment than in the absence of DNWR.

Following demand shocks, the asymmetric effect of DNWR is even stronger. We consider two types of demand shocks, a standard monetary policy shock and a risk premium shock, modelled as a wedge between the return on assets held by households and the policy rate controlled by central banks. In both cases, contractionary shocks induce a strong decline in prices, but nominal wages do not follow suit because of DNWR. As a result, real wages may even increase during the downturn, with strong detrimental effects on employment, investment and output. This mechanism implies that symmetric monetary policy shocks have asymmetric effects on labor markets, output and inflation: expansionary shocks lead mainly to increases in wage and price inflation; contractionary shocks affect more strongly the real side of the economy.

A similar framework of DNWR has been proposed by Kim and Ruge-Murcia (2009) in a model with monopolistic labor supply and wage setters based on Erceg et al. (2000). Their paper studies the question of how much inflation is necessary to “grease the wheels” of the labor market when wages are downwardly rigid. Fahr and Smets (2010) extend the setup to a monetary union to show that downward real wage rigidity have strong detrimental effects for the competitiveness of the country in a currency union. Benigno and Ricci (2011) model the greasing effects of positive inflation in an extreme manner whereby wages can never be cut and they highlight the implications for the slope of the long-run Phillips curve.

The paper most closely related to ours is McKay and Reis (2008), subsequently referred to as MR08. Using US data from 1948q1 to 2005q1, the authors find that contractions in employment are shorter and more violent than expansions, whereas this asymmetry is not present for output. To explain the empirical finding MR08 introduce asymmetric labor adjustment costs and endogenous technology adoption in a real business cycle model.

Our work differs from MR08 on both empirical and theoretical grounds. On the empirical side, using turning points and skewness of growth rates to assess asymmetry, we find stronger evidence for asymmetry in US real GDP than MR08 find. The difference mainly stems from the sample periods considered. 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 11.4% in 1950q3, a period strongly influenced by the Korean war which we would consider as outlier. Excluding these observations leads to stronger evidence for negative skewness in US real GDP growth: indeed, the skewness of GDP in a sample starting in 1952q1 is virtually identical and of very similar significance to the one obtained in a sample starting in 1970q1. The choice of 1970q1 to 2011q2 for our sample period is made to compare in a coherent manner a larger set of variables across five countries. The empirical evidence indicates 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.

On the theoretical side, we propose a different explanation for the asymmetries of the data. Our model with nominal frictions and DNWR accounts for the observed asymmetric dynamics of both nominal and real variables allowing for

[1] A plethora of theoretical models has been developed to explain the phenomenon of downward wage rigidity, covering institutional features, efficiency wages, implicit contracts and insider–outsider models (see e.g. Bewley, 2004).

[2] In the model we assume that the wages of new hires are tied to those of similarly productive existing workers. Recently Pissarides (2009) and Haefke et al. (2008) show that wages in new matches, which are the relevant wages for the hiring decisions, are more volatile than wages in existing matches. Gertler and Trigari (2009), however, argue that the high relative cyclicality of new hires' wages may reflect cyclical composition effects as opposed to differences of wage flexibility within a firm between new and existing workers. Moreover, a different strand of the literature has found that wages tend to be downwardly rigid even when workers become unemployed (see e.g. Addison et al., 2009; Krueger and Mueller, 2011). See also Pissarides (2009, p. 1362), for the discussion of further evidence on the asymmetric influence of the outside labor market conditions on wage negotiations.

productivity shocks and demand shocks. In contrast, in MR08 the drivers of business cycles are only productivity shocks and the model does not make it possible to analyse the behaviour of nominal and real wages.

In order to assess if asymmetric employment and investment adjustment costs could account for the observed asymmetries in wage and inflation data, we incorporate these frictions in separate versions of our model. We find that models with asymmetric employment or investment adjustment costs are equally able to reproduce the negative asymmetry of employment, investment and output, but cannot explain the positive asymmetry of inflation and nominal and real wages. We therefore conclude that DNWR is a friction which is consistent with a larger set of macroeconomic variables than asymmetric employment or investment adjustment costs.

The remainder of the paper is structured as follows. Section 2 presents the evidence on asymmetries. Section 3 derives the New-Keynesian model with frictional labor markets and asymmetric adjustment costs. Section 4 discusses the baseline calibration, and Sections 5 and 6 respectively contain our main results and conclusions.

2. Business cycle asymmetries

This section documents business cycle facts on asymmetries for France (FR), Germany (DE), the United Kingdom (UK), the United States (US) and the Euro Area (EA) based on two methodologies. The first one uses skewness in annual growth rates of macroeconomic series and the second one analyses turning points following the Bry and Boschan (1971) and Harding and Pagan (2002) approach, which allows to compare the length and violence of expansions and recessions.[3]

2.1. The skewness of macroeconomic variables

Macroeconomic variables are very differently skewed. Table 1 documents the skewness of annual growth rates of a large number of variables for DE, FR, UK, US and EA using quarterly data from 1970q1 to 2011q2.[4] The significance is assessed on the basis of the asymptotic test for skewness by Bai and Ng (2005). The technical Appendix provides additional tests based on bootstrap methods which lead to broadly similar results.

For all the countries considered, growth in nominal wages is strongly positively skewed.[5] Positive skewness indicates that nominal wages rise fast above their mean whereas reductions below the mean occur in small steps. Price inflation, measured as the annual growth rate of the GDP deflator, is also positively skewed. The growth in real wages, computed as nominal compensation divided by the GDP deflator, is positively skewed as well, suggesting that the nominal wage asymmetry dominates over the price asymmetry. The statistical significance varies across countries and variables, and is particularly strong for real wages (except for the UK).

In addition to the asymmetries in the distribution of wage and price inflation, the growth rates of quantities are also skewed. Unemployment is strongly and significantly positively skewed, whereas the employment rate, measured as employment over working age population, is negatively skewed. On the side of labor demand, the vacancy rate gives less clear-cut results, but it is prone to the largest measurement errors and we therefore can draw less inference.

Asymmetries are not confined to labor market variables. In fact, output growth (measured as GDP per capita) and investment also exhibit a strong negative skewness.

Many potential explanations exist for these asymmetries, including differing speed of hiring or firing of workers, lumpiness in investment, or endogenous borrowing constraints that require the build-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 observed in the data.

2.2. Turning point analysis

An alternative possibility for analyzing business cycle asymmetries is to identify turning points in 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. The procedure focusses on duration, amplitude and cumulative changes during expansions and contractions.[6] We compute the following statistics:

- *Average cycle duration*: average between peak-to-peak and trough-to-trough of a variable's time series.

[3] See the technical Appendix for details on the methodologies and on the robustness of the findings.

[4] The skewness is computed on annual growth rates of selected macroeconomic variables, $x_t/x_{t-4}-1$. 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. The mean of the distributions captures implicitly trend components, such as productivity growth or mean inflation, but does not affect the skewness.

[5] The nominal wage series used is the nominal compensation rate per person which includes bonuses and social contributions in addition to the base wage. The use of alternative nominal wage series delivers a similar picture.

[6] See McKay and Reis (2008) and Barnichon (2012) 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) filter the original series y_t to obtain the smoothed series y_t^{sm} and to eliminate outliers, high frequency or irregular variations. (2) Use a dating rule to determine a potential set of turning points. The rule we have used is $\Delta^2 y_t^{sm}>0$ (<0), $\Delta y_t^{sm}>0$ (<0), $\Delta y_{t+1}^{sm}<0$ (>0), $\Delta^2 y_{t+1}^{sm}<0$ (>0). (3) Use a censuring rule to ensure that peaks and troughs alternate and that the duration and the amplitude of phases are meaningful.

Table 1
Skewness of annual growth rates for selected variables, based on original data corrected for outliers, defined as observations deviating more than 3.5 standard deviations from the median value. *p*-Values are obtained from the test for skewness by Bai and Ng (2005) with Parzen kernel and pre-whitened errors. Data source for the series is the OECD Economic Outlook covering 1970q1–2011q2. 'Nominal wages' is the series for nominal compensation per employee, 'Prices' is the GDP deflator, 'Real wages' are nominal wages divided by the GDP deflator, 'Employment' is the total employment divided by working age population, 'Unemployment' is the unemployment rate series, 'Vacancies' is the total number of vacancies divided by working age population, 'Real GDP' is the real GDP series divided by working age population and 'Investment' is total capital formation divided by working age population.

Skewness of annual growth rates	DE	FR	UK	US	EA
Nominal wages	**0.89**	**0.83**	**1.02**	**0.29**	**0.78**
p-val	0.00	0.30	0.08	0.24	0.17
Prices	**0.69**	**0.84**	**1.41**	**1.16**	**0.67**
p-val	0.12	0.37	0.08	0.06	0.40
Real wages	**0.86**	**0.92**	**0.23**	**0.56**	**0.95**
p-val	0.00	0.01	0.15	0.06	0.00
Employment	**−0.47**	**0.01**	**−0.38**	**−0.77**	**−0.28**
p-val	0.24	0.51	0.24	0.12	0.34
Unemployment	**1.48**	**0.68**	**0.99**	**1.38**	**0.74**
p-val	0.04	0.13	0.01	0.01	0.03
Vacancies	**−0.24**	**−0.10**	**0.31**	**0.15**	**n.a.**
p-val	0.30	0.41	0.71	0.65	n.a.
Investment	**−0.39**	**−0.41**	**−0.23**	**−0.58**	**−0.76**
p-val	0.05	0.17	0.34	0.14	0.05
Output	**−0.36**	**−0.31**	**−0.82**	**−0.77**	**−0.66**
p-val	0.07	0.24	0.12	0.08	0.06

- *Average duration of expansions and recessions*: average duration from troughs to peaks (expansions) and 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*: annualized growth rates from troughs to peaks (expansions) and from peaks to troughs (recessions).

Although the methodology may be applied to trending and de-trended series alike, the presence of longer expansions and shorter recessions with trending data may merely stem from the trend-cycle combination and does not by itself call for an asymmetric model. In fact, as noted by Harding and Pagan (2002), a symmetric 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 HP(1600)-de-trended GDP and employment rate series.[7]

The results are summarized in Table 2. Despite large cross-country differences in the length of the cycle, we find that expansions in output and employment are longer than recessions, except for the employment rate in Germany, where expansions and recessions are of the same length. Moreover, recessions are more violent than expansions, as the decline of the economy during recessions is stronger than the increase in expansions (except for the UK output series). By computing the relative length of expansions to recessions (see column entitled "ratio"), it appears that the employment cycle is more asymmetric than the output cycle only for the US, whereas for the other countries the ratios are often very similar.

2.3. The behaviour of wages in recessions

To analyse the behaviour of wages and employment during recessions, Fig. 1 plots the cumulative log deviations of the employment rate, of real wages and of real wages from their trend for the official recessions in the US and the EA since 1970.[8] While employment declines in every recession, the surprising fact is that de-trended real wages do not always decline during recessions. In fact, the 1980 and 1991 recessions in the euro area have not seen real wages fall below their trend. Similarly for the US, where detrended real wages did not decline in the three recessions from 1979 to 1991, and were still growing above trend five quarters from the beginning of the Great Recession.[9] This disconnect between employment and real wages is reflected in the low contemporaneous correlation between the two variables, which is 0.25 for the US and 0.13 for the EA.

[7] See also McKay and Reis (2008) for a discussion of the advantages of applying the dating algorithm to detrended series. Applying a Band-Pass filter with cycle length of 8–32 quarters earns similar results. See the Appendix for details.

[8] This exercise follows in spirit Elsby et al. (2010), who study the evolution of employment, unemployment, labor force participation and hours during recessions. The official business cycle dates are taken from the NBER for the US, and from the CEPR for the EA. Notice that, following Elsby et al. (2010), the recession dates used for constructing Fig. 1 differ slightly from the official recession dates, as they correspond to the quarters around the recession dates over which employment is observed to decline. Using the official business cycle dates, or the dates corresponding to the detrended output or employment cycle gives a similar picture.

[9] The measure of real wages is real compensation per employee. Given that hours worked per employee generally decline in recessions, an hourly real wage measure would exacerbate these results.

Table 2
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 the Harding–Pagan methodology using the code by James Engel. The length of expansions and recessions may not add up to the overall cycle length due to rounding errors.

Turning point analysis	Duration (quarters)			Ratio	Growth rates (annualized)		Cumulative growth rates	
HP(1600)-detrended	Cycle	Exp.	Rec.		Exp.	Rec.	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

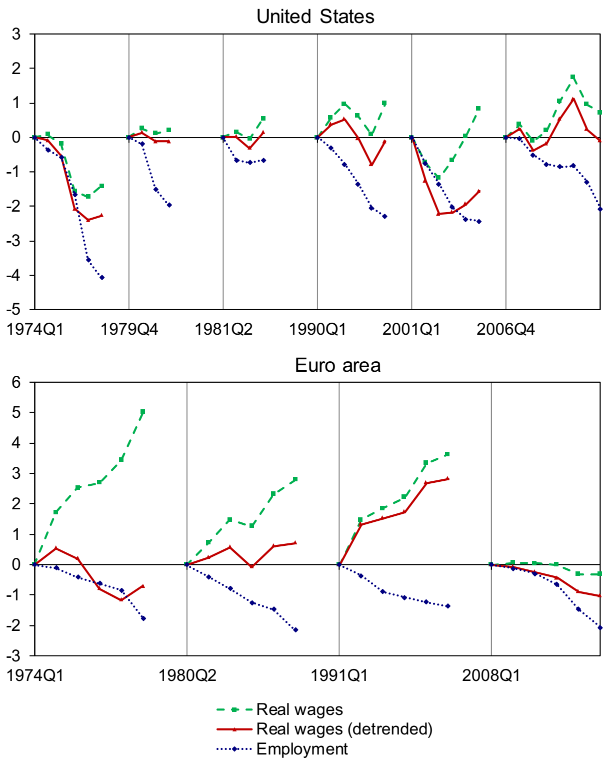

Fig. 1. Cumulative log change of employment, real compensation, and real compensation in deviation from HP(1600)-trend during recessions (in percentage points).

One possible explanation for the low cyclicality of real wages is the presence of counter-cyclical composition biases, as low-skilled workers are more likely to lose their jobs in time of recession (see e.g. Abraham and Haltiwanger, 1995; Solon et al., 1994). But it seems unlikely that the composition bias alone can explain the large disconnect between real wages and employment that we observe in the data, especially for the Euro Area.[10]

We show in this paper that, in the presence of DNWR, the behaviour of real wages in recessions crucially depends on the source of business cycle fluctuations. If the downturn is caused by a negative technology shock, real wages decrease mildly together with employment, because the increase in inflation due to lower productivity supports the adjustment of real

[10] See Shimer (2005) for a similar argument related to the weak procyclicality of labor productivity.

wages. Conversely, if the downturn is caused by an adverse demand shock, prices decline faster than nominal wages, which leads to an increase in real wages. Our model is thus consistent with minor or no real wage adjustments in recessions, something that a real business cycle model may have difficulties to explain.

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 search and matching frictions in the labor market.

3.1. The labor market

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

$$m_t = \overline{m} u_t^{\zeta} v_t^{1-\zeta}$$

where $\overline{m} > 0$, $\zeta \in (0,1)$. The job-finding and the job-filling rates are defined respectively as $f_t = m_t/u_t$ and $q_t = m_t/v_t$.

We assume contemporaneous hiring, which implies that job matches increase employment in the same period:

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

where s is a constant exogenous job destruction rate.

Unemployment is the fraction of workers without employment *after* hiring has taken place in a given period, $ur_t = 1 - n_t$, while the number of *job-searching workers* at the beginning of a period is defined as $u_t = 1-(1-s)n_{t-1}$.

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 members perfectly insure each other against employment fluctuations. The representative household maximizes a time-separable lifetime utility

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \log C_t$$

subject to the per period budget constraint

$$C_t + \frac{B_t}{P_t R_t \varepsilon_t^b} = n_t w_t + (1-n_t) b_t + \frac{B_{t-1}}{P_t} + D_t, \tag{2}$$

where C_t represents a Dixit–Stiglitz consumption bundle, P_t is the aggregate price level, $w_t = W_t/P_t$ the real wage and R_t the gross nominal risk-free interest rate of a nominal bond B_t. Total real household income is the sum of the wage income earned by employed family members and the income of unemployed $b_t = b\gamma^t$, where γ denotes the deterministic productivity trend of the economy. Aggregate profits from retailers and wholesalers D_t are distributed to the households. ε_t^b denotes a serially correlated shock to the risk premium as specified in Smets and Wouters (2007).

The Euler equation determines the intertemporal condition for consumption

$$\lambda_t = 1/C_t = \beta R_t \varepsilon_t^b \mathbb{E}_t(\lambda_{t+1}/\Pi_{t+1})$$

with λ_t being the Lagrange multiplier associated with the budget constraint (2) and $\Pi_{t+1} \equiv P_{t+1}/P_t$ being the gross inflation rate. The value of employment for the family $\tilde{N}_t$ is

$$\tilde{N}_t = w_t - b_t + (1-s)\mathbb{E}_t[\beta_{t,t+1}(1-f_{t+1})(\tilde{N}_{t+1})],$$

where $\beta_{t,t+1} = \beta(\lambda_{t+1}/\lambda_t)$ is the stochastic period-per-period discount factor of households. The net value of an additional employed worker in the family is the wage net of unemployment benefits, plus the expected continuation value from the employment relationship.

3.3. Firms

Firms in the wholesale sector produce homogeneous intermediate goods in competitive markets using labor and capital. Their output is sold to the final good sector which transforms the homogeneous goods one for one into differentiated goods at no extra cost and applies a mark-up due to monopolistic competition. Symmetric convex adjustment costs for prices arise in the retail sector, whereas search frictions together with convex wage adjustment costs exist in the wholesale goods sector.

3.3.1. Final good and wholesale firms

A measure one of the monopolistic retailers produce differentiated goods $Y_t^F(z)$ from intermediate goods $Y_t(z)$, with identical technology $Y_t^F(z) = Y_t(z)$. Retailers maximize profits by purchasing intermediate goods at price $P_t\varphi_t$ from wholesalers and setting the price $p_t(z)$ for the differentiated final good

$$\max_{p_t(z)} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \frac{\lambda_t}{\lambda_0} \left[\frac{p_t(z) - P_t\varphi_t}{P_t} - \Gamma\left(\frac{p_t(z)}{p_{t-1}(z)} \right) \right] Y_t^F(z)$$

subject to price adjustment costs $\Gamma_t = \phi^p (p_t(z)/p_{t-1}(z) - 1)^2/2$ and to the Dixit–Stiglitz demand function faced by each retailer. In equilibrium, the first order conditions for retail firms earn a Phillips curve:

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

where ϵ is the elasticity of substitution between varieties.[11]

Firms in the wholesale sector use employment and capital as inputs in a constant return to scale production function $Y_t = Z_t(\gamma^t n_t)^{\alpha}(K_t)^{1-\alpha}$, where γ is the labor-augmenting deterministic growth rate in the economy, K_t is the aggregate capital stock and Z_t is the total factor productivity, following an AR(1) process.

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

$$\max_{v_t, I_t} \mathbb{E}_0 \left\{ \sum_{t=0}^{\infty} \beta^t \frac{\lambda_t}{\lambda_0} \left[\varphi_t Y_t - w_t n_t (1 + c_t^w) - \frac{\kappa}{\lambda_t} v_t - I_t(1 + T(I_t, I_{t-1})) \right] \right\}$$

subject to the law of motion of employment (1) and capital $K_t = (1-\delta)K_{t-1} + I_t$. Posting v_t comes at a utility cost for the management given by κv_t. Investment adjustment costs are quadratic:

$$T(I_t, I_{t-1}) = \frac{\Theta_I}{2} \left(\frac{I_t}{\gamma I_{t-1}} - 1 \right)^2 \tag{3}$$

The first order conditions regarding investment, capital and labor demand by wholesale firms deliver

$$Q_t = 1 + T_t + \frac{\partial T_t}{\partial I_t} I_t + \mathbb{E}_t \beta_{t,t+1} \frac{\partial T_{t+1}}{\partial I_t} I_{t+1} \tag{4}$$

$$Q_t = (1-\alpha)\varphi_t \frac{Y_t}{K_t} + \mathbb{E}_t \beta_{t,t+1} \{ Q_{t+1}(1-\delta) \} \tag{5}$$

$$J_t = \frac{\kappa}{\lambda_t q_t} = \alpha \varphi_t \frac{Y_t}{n_t} - w_t(1 + c_t^w) + (1-s)\mathbb{E}_t \left[\beta_{t,t+1} \frac{\kappa}{\lambda_{t+1} q_{t+1}} \right] \tag{6}$$

The first equation equates the marginal value of investment to its expected cost. The former consists, according to Eq. (5), of the marginal product of capital and the expected continuation value of the invested capital unit. Eq. (6) is the job creation condition for vacancies, which equates expected vacancy posting costs to the value of a filled vacancy. This consists of the revenues from output, net of wages and their adjustment costs, and the expected continuation value of the job next period.

3.4. Asymmetric wage adjustment costs

Wholesale firms face wage adjustment costs c_t^w, which are proportional to the overall wage bill of firms. This is in line with the empirical fact of stronger intermediation for wage bargaining in larger firms. The wage and the wage adjustment costs are identical for newly hired workers and workers in ongoing job relationships. This is clearly a simplifying assumption, but reflects the idea that wage agreements between specific subgroups of workers are extended to larger groups of the workforce. The wage adjustment cost function is convex and may be asymmetric, indicating that it can be more costly to cut than to increase wages. This captures DNWR, the main focus of this paper. We assume the same functional form of Fahr and Smets (2010):

$$c_t^w(\pi_t^w) = \frac{\phi^w - 1}{2}(\pi_t^w - \gamma)^2 + \frac{1}{\psi^2} \{ \exp[-\psi(\pi_t^w - \gamma)] + \psi(\pi_t^w - \gamma) - 1 \} \tag{7}$$

where $\pi_t^w = W_t/W_{t-1}$ is the gross wage inflation rate. The parameter ϕ^w determines the degree of convexity and ψ the degree of asymmetry in adjustment costs around the steady state wage inflation γ. With $\psi > 0$ adjustment costs for wage increases above the economy's growth rate are smaller than those for wage adjustments below that rate. With $\psi \to 0$, the specification nests the quadratic adjustment cost function: $\lim_{\psi \to 0} c_t^w(\pi_t^w) = \phi^w(\pi_t^w - 1)^2/2$. Fig. 2 displays a comparison between different specifications.[12]

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

[12] The choice of convex adjustment costs is dictated by two considerations. First, even if non-convexities in wage adjustments may exist at the individual level, the existence of alternative adjustment margins may "convexify" the adjustment costs at the aggregate level. Second, we solve and simulate the model by

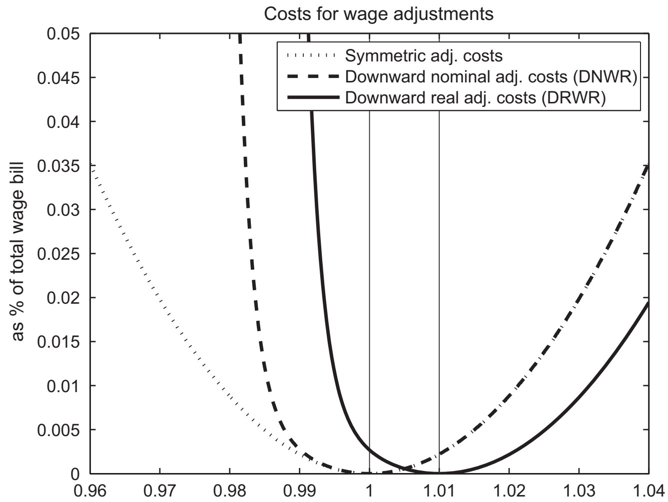

Fig. 2. Different specifications of adjustment cost curves. The horizontal axis depicts gross inflation. Dotted line: symmetric adjustment cost function as used for prices, dashed line: asymmetric cost function for downward nominal wage rigidity, continuous line: downward real wage rigidity with underlying inflation of 1% as example.

3.5. Wage determination

Nominal wages are determined through a Nash bargaining scheme between workers and employers who maximize the joint surplus of an employment relationship. The only difference from the standard setup is the presence of wage adjustment costs in the value of the job for the firm. Bargaining over the nominal wage yields the optimal sharing rule[13]

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

with ω_t being the *effective* bargaining power of the worker

$$\omega_t = \frac{\eta}{\eta+(1-\eta)\tau_{t,t+1}}, \tag{8}$$

η represents the exogenous part of the worker's bargaining power and $\tau_{t,t+1}$ is a time-varying term reflecting the evolution of current and expected wage adjustment costs

$$\tau_{t,t+1} = 1 + c_t^w + \frac{\partial c_t^w}{\partial W_t} W_t + (1-s)\mathbb{E}_t \beta_{t,t+1} \left(\frac{\partial c_{t+1}^w}{\partial W_t} \right) \frac{W_{t+1}}{\Pi_{t+1}}. \tag{9}$$

In the absence of adjustment costs we obtain the constant sharing rule, $\omega_t = \eta$. With adjustment costs, the bargaining power becomes state dependent. During periods of rising wages, since $\partial c_t^W / \partial W_t > 0$, the effective bargaining power of workers declines, while the opposite occurs with periods of declining wages, as the effective bargaining power of workers increases. 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. These endogenous movements of ω_t are at the core of the transmission of downward wage rigidities to the economy.

The result from the wage bargaining for wages is

$$w_t = \omega_t \left(\alpha \varphi_t \frac{Y_t}{n_t} - c_t^w w_t + (1-s)\mathbb{E}_t[\beta_{t,t+1} J_{t+1}] \right) + (1-\omega_t)(b_t - (1-s)\mathbb{E}_t[\beta_{t,t+1}(1-f_{t+1})\tilde{N}_{t+1}]).$$

Wage adjustment costs affect the bargained wage in two main ways. First, a deadweight loss component, captured by $\omega_t c_t^w w_t$, reduces the value of a job for the firm and hence the bargained wage. Second, wage adjustment costs affect the bargained wage through the effective bargaining weight of the worker ω_t, as discussed before. This mechanism highlights further that, although adjustment costs are incurred by the firm, they are shared between firms and workers through the bargaining setup. In the presence of DNWR, when wages decline workers capture a larger fraction of the joint surplus between firms and workers, even though this surplus is smaller. Overall, through the movements of ω_t wage adjustment costs have a dampening effect on fluctuations in the wage bill and the asymmetric adjustment cost ensures that the effective bargaining power of workers increases by more during declining wages than it falls when wages increase.

(*footnote continued*)
perturbations with a 2nd-order approximation, including the pruning option for stability, using DYNARE ver. 4. This requires a differentiable adjustment cost at the steady state.

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

3.6. Monetary policy and resource constraint

The central bank adopts an augmented Taylor type rule for the nominal interest rate with interest rate smoothing parameter ω_r:

$$r_t = r_{t-1}^{\omega_r}\left[r\left(\frac{\Pi_t}{\Pi^*}\right)^{\omega_\pi}\left(\frac{Y_t}{\gamma Y_{t-1}}\right)^{\omega_{\Delta y}}\right]^{1-\omega_r}\varepsilon_t^m. \tag{10}$$

The parameters ω_π and $\omega_{\Delta y}$ are the response coefficients to deviations of inflation from its target $\Pi^* = 1$ and of output growth from trend growth. The term ε_t^m captures an i.i.d. monetary policy shock.

Final output may either be used for consumption or investment, or it is used to cover for price, wage and investment adjustment costs[14]

$$C_t + I_t = Y_t(1-\Gamma_t) - c_t^w w_t n_t - T(I_t, I_{t-1})I_t.$$

4. Calibration

In the baseline calibration the parameters are set to capture the main structural features of the euro area.

Wage and price rigidities. The parameter on symmetric wage rigidity, ϕ^w, and the parameter that governs the degree of wage asymmetry, ψ, are chosen to match the observed volatility and skewness of nominal wage inflation, i.e. $\sigma(\pi^W) = 0.60$ and $\gamma^1(\pi^W) = 0.78$. The result is $\phi^w = 37.6$ and $\psi = 24100$. The degree of price rigidities, ϕ^p, is set to 60.5, consistent with a Calvo parameter of 0.67 which represents a mean price duration of about 3 quarters.[15]

Preferences. The discount factor β is set to 0.992. The elasticity of substitution of retail goods is $\epsilon = 11$, as in Christoffel et al. (2009), and implies a gross mark-up of 10%.

Production. The elasticity of output with respect to employment is $\alpha = 0.7$, reflecting a capital share of 30%. The quarterly capital depreciation rate is $\delta = 0.03$, corresponding to an annual depreciation rate of 12%, while the investment adjustment cost is set to $\Theta_I = 0.67$, in order to match the relative standard deviation of investment to GDP.

Labor market. The steady state unemployment rate is set to 10% and the quarterly job finding rate to 0.35, consistent with the empirical analysis by Elsby et al. (2009) for a number of continental European countries. Taken together, these values imply a quarterly separation rate of $s = 0.06$. The job filling rate q is set to 0.9 as in Ravenna and Walsh (2011), which implies $\overline{m} = 0.56$. Job posting costs are chosen such that aggregate hiring costs are 1% of steady state output, as in Blanchard and Galí (2010) and Walsh (2005). The sum of unemployment benefits, home production and disutility of work is determined by steady state relationships, resulting in $b = 1.25$. The elasticity of job matches with respect to job seekers is $\zeta = 0.5$, in line with matching function estimations by Petrongolo and Pissarides (2001). The workers' relative bargaining power η is set to 0.5, as in Blanchard and Galí (2010).

Shocks and monetary policy. The average quarterly growth rate is $g_a = 1.004$, implying an annual average growth rate of 1.6%, which is in line with average annual labor productivity growth in the euro area. The persistence of the neutral productivity shock is set to $\rho_z = 0.95$, while its volatility is $\sigma_z = 0.0064$, as estimated by Smets and Wouters (2003). The persistence of the risk premium shock is $\rho_R = 0.8$, as estimated by Christoffel et al. (2009), while its standard deviation is set such that the baseline model replicates the standard deviation of output, i.e. $\sigma_R = 0.001$.

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 $\omega_r = 0.85$. In the baseline calibration, the reaction to output growth, $\omega_{\Delta y}$, is set to zero, capturing a strict inflation targeting central bank.[16] The standard deviation of monetary policy shocks is set to 0.1%, consistent with the estimates by Christoffel et al. (2009).

The model is solved by second-order perturbation methods and applies pruning following Kim et al. (2008). The methodology approximates the model around its steady state using a second-order Taylor approximation instead of a linear approximation and is thereby able to generate asymmetric responses to positive and negative shocks. To obtain the simulated moments the model is simulated 1000 times for 166 periods. In order to have different starting points, we simulate an additional 400 periods as pre-sample which are not included for the computation of the moments.

5. The asymmetric effects of downward wage rigidities

5.1. Impulse responses

In order to study the effects of downward wage rigidities on the aggregate economy, we first analyze the dynamic responses of different macro variables to three shocks: a productivity shock, a monetary policy shock and a risk premium shock.

[14] Notice that, following Thomas (2008), vacancy posting costs are defined in terms of utils and thus do not enter the aggregate constraint.
[15] See Table 1 in Khan (2005) for converting the convexity parameter into a Calvo parameter.
[16] In a robustness exercise, we analyse the effects of adopting a monetary rule with some weight on output stabilization. See the Appendix for details.

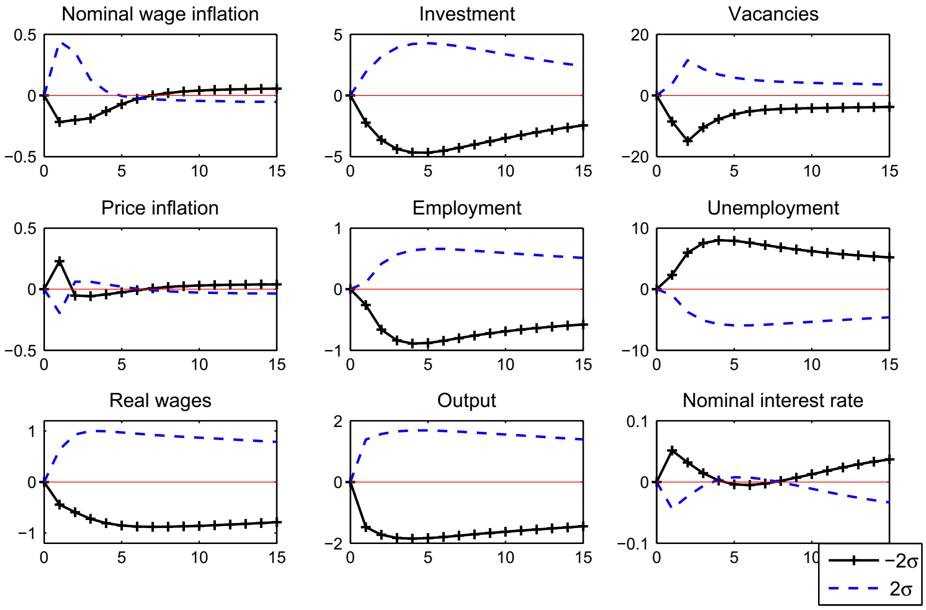

Fig. 3. Dynamic response following positive and negative neutral technology shocks of 2 standard deviations.

Consider first a positive technology shock, as shown in Fig. 3. Following the increase in productivity, the value of a worker for the firm increases, which leads firms to engage in stronger hiring activity to increase employment. Nominal and real wages increase simultaneously, partially reducing the incentives for firms to open new vacancies. The increases in productivity, employment and investment lead to a strong and persistent increase in production.

A comparison with a negative shock illustrates the effect of downward wage rigidities. Following a negative technology shock, nominal wage inflation decreases only slowly because of the presence of DNWR. Real wages decrease mainly because of higher price inflation and adjust more slowly than after a positive shock. The slow decline in real wages reduces firms' profits strongly, which reduces the incentives for hiring new workers. As a result, employment exhibits a stronger response than after a positive shock, whereas wages exhibit a smaller response. Technology shocks do not seem to generate strong asymmetries on output and investment, mainly because the dynamics of these variables are dominated by the direct effect of the technology shock.

Consider now a risk premium shock, which represents a wedge between the return on assets held by households and the interest rate controlled by the central bank. The responses are presented in Fig. 4.[17] A decrease in the risk premium reduces the required return on assets and increases consumption. At the same time, it lowers the cost of capital and encourages investment. The strong increase in demand leads firms to post more vacancies and increase hiring and production. Price and wage inflation rise relatively fast, while real wages increase mildly. Monetary policy reacts to the reduction in the risk premium by increasing the policy rate, which helps to reduce the effects of the shock.

Following an increase in the risk premium, the results change considerably. The presence of DNWR implies that wage inflation remains almost constant. At the same time, the reduction in demand induces a strong contraction in price inflation, which now tends to move in a destabilizing way. Taken together, a lack of adjustment in nominal wages and a decline in prices translate into a strong increase in real wages. The fact that real wages *increase* during a downturn leads to a strong contraction in vacancy posting, employment, investment and production.

Finally, the effect of monetary policy is depicted in Fig. 5. The impulse responses of the monetary policy shock are qualitatively very similar to the ones of the risk premium shock. The main difference lies in the behaviour of the policy rate, which is counteracting the exogenous increase in the return on assets following a risk premium shock, while it is the underlying cause for the economic fluctuations under a monetary policy shock. A monetary policy shock can have strongly asymmetric effects in the presence of DNWR. An expansionary monetary policy mainly affects wage and price inflation, while the effects on real variables are relatively small. In contrast, a contractionary monetary policy shock has a much stronger effect on real variables (real wages, investment and employment) than on nominal variables. Taken together, this seems to suggest that active monetary policy itself may be a source of business cycle asymmetries.

[17] The difference between a risk premium shock and a discount factor shock lies in the response of investment. In contrast to a discount factor shock, the risk premium shock helps explaining the comovement of consumption and investment. See Smets and Wouters (2007) for a discussion.

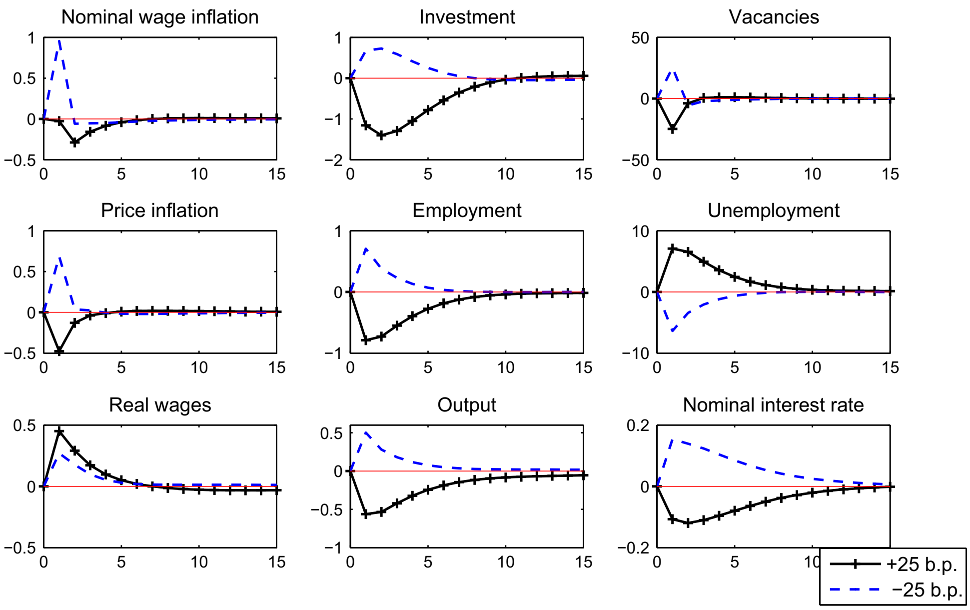

Fig. 4. Dynamic response following positive and negative risk premium shocks of 25 bps, representing 2.5 standard deviations.

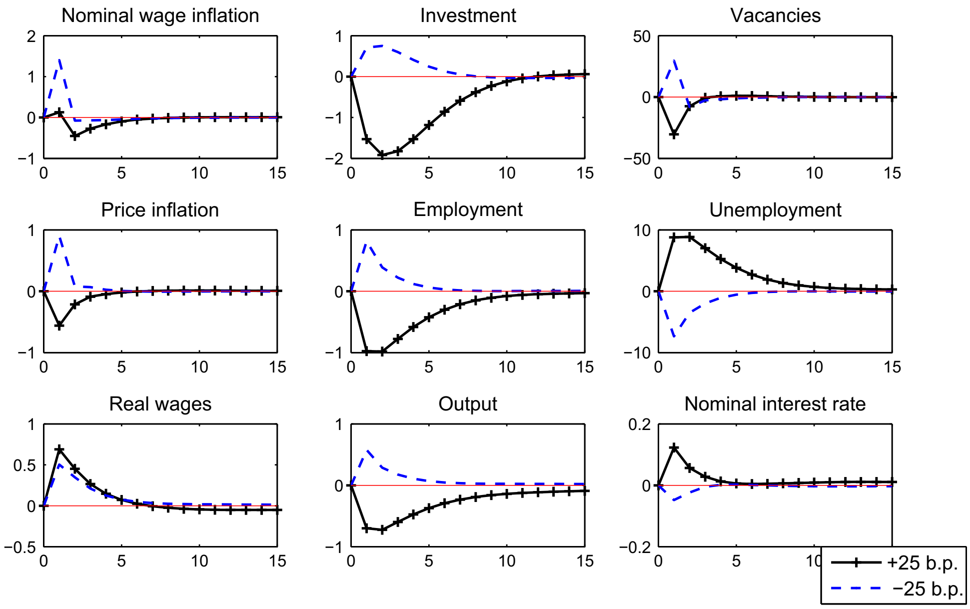

Fig. 5. Dynamic response following positive and negative monetary policy shocks of 25 bps, representing 2.5 standard deviations.

5.2. Second moments

Table 3 compares the second moments of the data with those obtained in the model under the assumption of symmetric and asymmetric wage adjustment costs, denoted by "Sym" and "DNWR" respectively. Notice that in order to be consistent with the calibration strategy across models, the wage adjustment cost in the symmetric model is reset to match the nominal wage volatility, which implies a value for the wage convexity parameter of $\phi^w = 10.9$.

Both the symmetric and the DNWR model capture the standard deviation of the variables remarkably well. The DNWR model tends to slightly overestimate the volatility of real wages and price inflation, but results are generally very close to the data. Except for price inflation, volatility in the symmetric model is lower compared to the DNWR model, confirming the idea that DNWR may increase the violence of business cycle fluctuations.

Table 3
The table reports second moments of HP (1600)-detrended quarterly series in the data for the sample 1970q1–2011q2 and two model specifications, one with symmetric wage adjustment costs (Sym), the second with asymmetric wage adjustment costs, capturing Downward Nominal Wage Rigidity (DNWR). To be consistent with the calibration strategy across models, the wage adjustment cost is reset to match the nominal wage volatility.

2nd moments	$\sigma(x)$			$\sigma(x)/\sigma(y)$			$\rho(x,y)$		
	Data	DNWR	Sym	Data	DNWR	Sym	Data	DNWR	Sym
Nominal wages	0.60	0.60	0.60	0.51	0.51	0.56	0.23	0.36	0.40
Prices	0.33	0.39	0.40	0.28	0.33	0.37	0.31	0.25	0.25
Real wages	0.50	0.68	0.61	0.42	0.58	0.55	0.27	0.60	0.98
Employment	0.66	0.77	0.61	0.55	0.65	0.56	0.77	0.78	0.75
Unemployment	6.34	6.63	5.35	5.34	5.61	4.91	−0.85	−0.77	−0.74
Vacancies	n.a.	19.46	15.19	n.a.	16.50	13.96	n.a.	0.51	0.49
Investment	2.96	3.06	2.76	2.49	2.57	2.51	0.92	0.95	0.94
Output	1.19	1.19	1.10	1.00	1.00	1.00	1.00	1.00	1.00

Table 4
Skewness of annual growth rates for selected variables in the data and different model specifications. The symmetric model is calibrated assuming symmetric investment and wage adjustment costs. The skewness obtained from simulations with symmetric adjustment costs stems from other non-linearities in the model, such as the curvature in the production and utility functions. The DNWR model assumes asymmetric adjustment costs on nominal wages. The column on robustness summarizes skewness in models with asymmetric employment adjustment costs (EACs) or with asymmetric investment adjustment costs (IACs), as described in Section 5.5.

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

Looking only at relative standard deviations, there is no reason why one should prefer a model with DNWR with respect to the symmetric model, as the performances of the two models are very similar. However, when considering cross-correlations, the presence of DNWR strongly improves the fit with the data, in particular the correlation of nominal and real wages with output. The symmetric model generates a very strong co-movement between real wages and output of 0.98. The presence of DNWR is able to break this tight link and reduces the correlation to 0.60, much closer to the value of 0.27 observed in the data. Moreover, the introduction of DNWR also reduces the co-movement between price and wage inflation in the model to 0.58, very close to the observed correlation of 0.53, whereas the symmetric model generates a correlation between price and wage inflation of 0.81.

5.3. Skewness

To assess whether DNWR improves the match between the empirical third moments and their model counterpart, we simulate the model with and without asymmetries in wage adjustment costs to obtain simulated statistics to be compared to those in the empirical part. Table 4 summarizes the results.

The symmetric model is unable to reproduce the skewness observed in the data. In fact, the skewness for most variables generated with the symmetric model is close to zero and, if anything, point in the wrong direction in the case of employment, investment and output.[18]

By introducing asymmetric wage adjustment costs, the model not only corrects for the wrong direction of skewness of the symmetric model, but also captures the degree of skewness of labor market variables relatively well. As expected, the strongest asymmetry is found in nominal wages as it is the source of the asymmetry within the model. The calibration targets the skewness observed in the data in order to allow using the remaining variables for the evaluation

[18] The skewness obtained from simulations with symmetric adjustment costs stems from other existing non-linearities of the model, such as the curvature in the production and utility functions.

Table 5
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 different model specifications. The symmetric model is calibrated assuming symmetric investment and wage adjustment costs. The DNWR model assumes asymmetric wage adjustment costs. The rows on robustness summarize the results from models with asymmetric employment adjustment costs (EACs) or with asymmetric investment adjustment costs (IACs), as described in Section 5.5. The length of expansions and recessions may not add up to the overall cycle length due to rounding errors.

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

of the model. This asymmetry is transmitted to real wages, but less strongly. Inflation is also characterized by positive skewness, mainly because it is absorbing part of the adjustment in real labor costs. In situations where real wages are required to decline but nominal wages resist adjustment, stronger positive price inflation facilitates the required downward real wage adjustment. Inflation is thus forced to adjust more strongly upward than downward. The model nevertheless falls somewhat short of the empirical asymmetry in price inflation, partly due to a relatively aggressive monetary policy rule.

The effects on real variables stemming from DNWR first affect vacancies. This is a jump variable and exhibits low persistence.[19] When cuts in wages are necessary, the presence of DNWR strongly amplifies the decline of the firms' surplus of the match and thus reduces the incentives for opening new vacancies. This leads to the negative skewness of employment and the positive skewness of unemployment, which capture surprisingly well the skewness in the data.

Downward wage rigidity also affects the asymmetry of investment and output, though to a less degree. Capital is complementary to employment as it raises or reduces the production frontier in step with employment, which explains the negative skewness of investment. The overall effects on output asymmetry are driven by three factors: productivity, capital and employment. Productivity shocks are symmetric in the model, hence not contributing to output asymmetry. The overall asymmetry of output is thus the result of the negative skewness of employment and investment.

Overall, we find that the introduction of DNWR helps to explain the skewness in macroeconomic variables, even though the model falls short in explaining the negative skewness in output per capita and investment. Complementarities with alternative sources of asymmetry may exist. The explanation by McKay and Reis (2008) invoking asymmetric adjustment costs for employment represents in this context a short-cut to theories that generate this asymmetry in employment endogenously. DNWR provides such a rationale. Endogenous job separations as in den Haan et al. (2000) would provide an alternative explanation, but generate counterfactual positive correlations between unemployment and vacancies which contradict the robust fact of the Beveridge curve. Alternative explanations include asymmetries in the adjustment of imports or exports or in the inventory cycle.

Robustness exercises in the technical Appendix reveal that the structure of the labor market and the monetary policy rule have only a limited influence on the results. A higher labor turnover, as for example in the US, reduces the skewness of employment and vacancies somewhat, while it slightly increases those of inflation. A monetary policy with stronger weight on output growth stabilization lowers the skewness of macroeconomic variables because its more balanced rule takes possible effects of output into account. The presence of different monetary policy specification may thus explain why different countries present different degrees of labor market and output asymmetries.

[19] The model series of vacancies is not taken in growth rates 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 data, the series needs to be taken in levels for the model (flow) and in growth rates for the data (stock).

5.4. Turning point analysis

Table 5 shows the results when applying the Bry–Boschan dating algorithm for turning points to the de-trended output and employment rate series generated by the model.

The model replicates well the length of the output cycle, while the employment rate cycle is shorter than in the data. The presence of downward wage rigidities does not affect the overall length of the cycle, which is the same in the symmetric and asymmetric model, but affects the relative length and violence of expansions and recessions.

The symmetric model is unable to generate any degree of asymmetry in the duration or in the violence of expansions and recessions. Introducing asymmetric wage adjustment costs, the model is able to generate asymmetries in the right direction, as long and smooth expansions are followed by shorter but more violent contractions. The reason why DNWR generates discrepancies in the relative length of expansions and recessions is due to the sharp decline in employment when wages fail to adjust downward. Once employment is far below trend, a slow recovery phase starts bringing employment back to steady state. As was expected, the degree of asymmetry is larger for the employment cycle than for the output cycle, consistent with the idea of an asymmetry that takes place in the adjustment of wages, which translates into asymmetric labor market dynamics and then affects the wider economy. Overall, though, the asymmetry generated by the model falls short of the empirically observed one, both for output and for employment.[20]

5.5. Robustness: employment and investment adjustment costs as alternative sources for asymmetries?

The presence of downward wage rigidities is only one of the possible explanations of the asymmetries found in the data. To assess if other frictions could account for the observed asymmetries in wages and unemployment, we incorporate in the model asymmetric employment and investment adjustment costs.

Asymmetric employment adjustment costs are introduced by assuming that, on top of the vacancy posting costs already described, firms face additional hiring and training costs that are asymmetric in employment growth (n_t/n_{t-1}).[21] Asymmetric investment adjustment costs are modelled by replacing the quadratic investment adjustment costs (3) with an asymmetric function. In both cases, the functional form is identical to wage adjustment costs in Eq. (7) and is calibrated such that increasing employment or investment is more costly than reducing them below trend.

The simulations are carried out by shutting off wage asymmetries ($\psi = 0$) and the parameters of the employment (investment) cost functions are calibrated to match its target variable: the observed relative volatility of employment (investment) to output, and the skewness of annual growth rates of employment (investment). All other parameters are set at their baseline values. The technical Appendix offers a more detailed description of the exercise.

The volatilities of the two alternative 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 volatilities and correlations relative to output, however, remain close to the ones of the model with DNWR. The main difference with the DNWR model is the correlation of real wages with output, which remains extremely and counterfactually high in the models with EAC or IAC, while it is lowered to more reasonable values in the DNWR model. This confirms our hypothesis that downward wage rigidities may be an important factor to explain the low cyclicality of real wages.[22] Moreover, we find that the three models are equally able to explain, at least qualitatively, the fact that contractions are shorter but more violent than expansions (see Table 5).

When it comes to skewness, the EAC and IAC models yield different results (see the last two columns in Table 4). The EAC and IAC models, in fact, capture the negative skewness of employment and GDP, but fail to capture the positive skewness of inflation and nominal and real wages. In fact, skewness of real wage growth is positive in the data, but negative in both the IAC and EAC models.

To understand the reason behind this discrepancy, consider for instance a technology shock.[23] A positive technology shock induces an increase in employment, investment and wages. The presence of asymmetric EAC and IAC, however, not only limits employment and investment increases, but also reduces the surplus generated by the firm. This in turn limits the wage increase. Conversely, 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.

Overall, 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 nominal and real wages that are consistent with the data.

[20] Robustness exercises in the technical Appendix reveal that the structure of the labor market and the policy rule have only a limited influence on the results of the turning point analysis.

[21] The advantage of this modelling strategy is that it nests our baseline model, which can be obtained by simply setting the parameters of the adjustment cost function to 0. Asymmetric employment adjustment costs can be justified, for example, by noting that hiring workers involves training them, which is subject to strong decreasing returns to scale. See also McKay and Reis (2008).

[22] See the Appendix for details.

[23] A similar reasoning applies to demand shocks.

6. Conclusion

In this paper we study to what extent the presence of downward wage rigidities can explain the business cycle asymmetries that characterize the data. Trying to match third order moments, in addition to second order moments, gives additional discipline to the analysis, which may contain important information about the structural features that are essential for explaining business cycle dynamics.

We introduce 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 firm's incentives for creating vacancies and employment. During an expansion the fast increase in wages mutes vacancy creation and employment creation compared to a situation with symmetric rigidity. During a recession the effects on the real side are much stronger, especially after a demand shock, because the reduction in prices, combined with nominal wages that have difficulties to fall, may actually lead to an increase of real wages during a downturn. In this case vacancy creation responds with a steep fall leading to strong increases in unemployment.

We show that downward wage rigidities are important for shaping the adjustment of macroeconomic variables. Symmetric models have focused on second moments, but cannot capture numerous facts of third order moments. Accounting for asymmetries in the adjustment of wages improves the overall fit of the model to the skewness of macroeconomic variables and to the relative length and violence of expansions and recessions.

Downward wage rigidities are only one of the possible sources of business cycle asymmetries. Extensions building upon complementarities between the labor market and other variables may further improve the fit of the model with the data. 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 a helpful way to amplify the asymmetries of the model and match the third order moments of the data.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.jmoneco.2013.08.001.

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