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Testing for Parameter Stability in DSGE Models. The Cases of France, Germany, Italy, and Spain

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Testing for Parameter Stability in DSGE Models. The Cases of France, Germany, Italy, and Spain¹

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Abstract

We estimate a New Keynesian DSGE model on French, German, Italian, and Spanish data. The main aim of this paper is to check for the respective sets of parameters that are stable over time, making use of the ESS procedure („Estimate of Set of Stable parameters“) developed by Inoue and Rossi (2011). This new econometric technique allows to address the stability properties of each single parameter in a DSGE model separately. In the case of France, Germany, and Italy our results point to structural breaks after the beginning of the second stage of EMU in the mid-nineties, while the estimates for Spain show a significant break just before the start of the third stage in 1998. Specifically, there are significant changes in monetary policy behavior for France, Italy, and Spain, while monetary policy in Germany seems to be stable over time.

Keywords: DSGE, EMU, Monetary Policy, Structural Breaks

JEL Classification E31, E32, E52

1 Introduction

Dynamic stochastic general equilibrium (DSGE) models have become a standard tool of modern macroeconometrics. The attractiveness of this class of models lies in the symbiosis of theoretical models and the forefront of macroeconomic analysis. As outlined e.g. in DeJong and Dave (2007) and Fernández-Villaverde (2010) the combination of rich structural models, novel solution algorithms and powerful simulation and estimation techniques lead to a very active and progressive discipline changing the way we think about macroeconomic modeling and economic policy advice. In this paper, we contribute to this area of research by employing an econometric technique, recently introduced by Inoue and Rossi (2011), to test for parameter stability in a New Keynesian model estimated for the four largest countries of the European Monetary Union (EMU): France, Germany, Italy, and Spain. By doing so, we add to a vast literature that developed around the topic of economic integration within Europe. One of the important aspects of this ongoing and gradual integration process was the introduction of a common monetary policy in the EMU. Evaluating the overall macroeconomic performance in 2008, the European Commission (2008) summarizes that the record after almost one decade of the EMU looks quite favorable. More detailed analyses of European economic integration can be grouped into four distinct strands of literature. The first looks at the implications of a common currency for other economic institutions like regulation or wage setting; see e.g. von Hagen (1999), Cukierman and Lippi (2001), Jerger (2002) and Fratzscher and Stracca (2009). A second one analyzes the (change of) different transmission channels of monetary policy (van Aarle et al., 2001; Angeloni and Ehrmann, 2006; Jarocinski, 2010; Hughes Hallett and Richter, 2009). Thirdly, the availability of micro data, especially for loans and prices, led to a large literature that usually identifies statistically and economically significant convergence across countries due to monetary union (Beck and Weber, 2005; Popov and Ongena, 2011). A fourth and relatively recent literature uses dynamic stochastic general equilibrium (DSGE) models to characterize the euro area or the economies in this region within some well-defined theoretical framework (see, e.g., Lee, 2009; Milani, 2009; Reis, 2009).

Here, we contribute to the last strand and add the dimensions parameter stability over time and cross country comparisons. To do so we employ the ESS procedure („Estimate of Set of Stable parameters“) introduced by Inoue and Rossi (2011). This allows to pin down the subset of parameters of a model that are stable for an unknown break date. Following Inoue and Rossi (2011, p. 9), „... our analysis focuses on the

situation in which there is a single, unanticipated and once for all shift in some of the parameters of the structural model at an unknown time, and in which there is an immediate convergence to a rational-expectations equilibrium after the regime change.“

In the case of France, Germany, and Italy our results point to structural breaks after the beginning of the second stage of EMU in the mid-nineties, while the estimates for Spain show a significant break just before the start of the third stage in 1998. Specifically, there are significant changes in monetary policy behavior for France, Italy, and Spain, while monetary policy in Germany seems to be stable over time. We also find significant declines in capital and price adjustment costs in France, Italy, and Spain.

The rest of the paper is structured as follows. Section 2 presents the model. Data issues are discussed in section 3, whereas the ESS procedure is outlined in section 4. The results are presented and interpreted in section 5. Section 6 concludes.

2 The Model

2.1 Overview

The model we use for France, Germany, Italy, and Spain is similar to the standard closed-economy New Keynesian framework developed in Ireland (2003). The model economy features a representative household, a representative finished goods-producing firm, a continuum of intermediate goods-producing firms indexed by $i \in [0, 1]$, and a monetary policy authority. During each period $t = 0, 1, 2, \dots$, the intermediate goods producing firms produce a distinct, perishable intermediate good, also indexed by $i \in [0, 1]$. The solution requires these firms to be treated symmetrically.

Before describing the model it is necessary to comment on the fact that we apply a closed-economy model to indisputably open economies. The most important reason is the obvious fact that we get around the notorious difficulties of modeling exchange rates and their implications for bilateral trade flows. In the present context, we are not particularly interested in those, since the exchange rate consequences of EMU on member states are pretty clear. Furthermore, openness makes it very difficult to characterize the process of capital formation that is a central part of the present model; see also the discussion by DiCecio and Nelson (2007) who apply a closed-economy model to the UK as well as the remarks of Obstfeld (2002) and Neiss and Nelson (2003) concerning closed-economy models.

We now proceed to characterize the decisions taken by households and firms before

looking at the behavior of the monetary authority and sketching the solution of the model.

2.2 Households

The representative household enters period t holding M_{t-1} , B_{t-1} , and K_t units of money, one-period bonds, and physical capital rented to the intermediate goods sector, respectively. In addition to this endowment, the household receives a lump sum transfer T_t from the monetary authority at the beginning of period t . The household receives $W_t h_t$ units of labor income, with W_t denoting the nominal wage rate and h_t working hours; $K_t Q_t$ in capital income, where Q_t represents the rental rate for capital and K_t household's capital supply; and a nominal dividend D_t from the intermediate goods producing firm. Each source of income is measured in units of money.

The household uses its funds to purchase new bonds at the nominal cost B_t/r_t , where r_t denotes the gross nominal interest rate between time periods, or output from the final goods sector at price P_t . This good can be used for consumption C_t or investment I_t . In the latter case, quadratic capital adjustment cost given by

$$\frac{\phi_K}{2} \left(\frac{K_{t+1}}{K_t} - 1 \right)^2 K_t \quad (1)$$

accrue to the household, where $\phi_K \geq 0$ governs the size of these adjustment costs. The capital accumulation process is given by

$$K_{t+1} = (1 - \delta)K_t + x_t I_t,$$

with $0 < \delta < 1$ denoting the rate of depreciation and x_t representing a shock to the efficiency of investment. This shock is specified as

$$\ln(x_t) = \rho_x \ln(x_{t-1}) + \varepsilon_{xt}, \quad (2)$$

with $0 < \rho_x < 1$ and $\varepsilon_{xt} \sim N(0, \sigma_x^2)$ as introduced by Greenwood, Hercowitz and Huffman (1988).

The budget constraint of the representative household is given by

$$\frac{M_{t-1} + T_t + B_{t-1} + W_t h_t + Q_t K_t + D_t}{P_t} \geq C_t + I_t + \frac{\phi_K}{2} \left(\frac{K_{t+1}}{K_t} - 1 \right)^2 K_t + \frac{B_t/r_t + M_t}{P_t}.$$

Facing this constraint, the household maximizes the stream of expected utility

$$E \sum_{t=0}^{\infty} \beta^t \{a_t [\gamma / (\gamma - 1)] \ln [C_t^{(\gamma-1)/\gamma} + e_t^{1/\gamma} (M_t/P_t)^{(\gamma-1)/\gamma}] + \eta \ln(1 - h_t)\}, \quad (3)$$

where $0 < \beta < 1$ is a discount factor and $\eta > 0$ measures the relative weight of leisure. Further, it can be easily shown that $-\gamma$ is the interest rate elasticity of money demand. The utility function (3) contains two preference shocks, which are both assumed to follow an autoregressive process. More specifically,

$$\ln(a_t) = \rho_a \ln(a_{t-1}) + \varepsilon_{at}, \quad (4)$$

with $0 < \rho_a < 1$ and $\varepsilon_{at} \sim N(0, \sigma_a^2)$ denotes an IS shock (McCallum and Nelson, 1999), whereas

$$\ln(e_t) = (1 - \rho_e) \ln(e) + \rho_e \ln(e_{t-1}) + \varepsilon_{et} \quad (5)$$

with $0 < \rho_e < 1, e > 0$ and $\varepsilon_{et} \sim N(0, \sigma_e^2)$ represents a money demand shock.

2.3 Firms

The final good Y_t is produced by a firm acting in a perfectly competitive market, which combines the intermediate goods $Y_t(i)$ according to

$$Y_t \leq \left[\int_0^1 Y_t(i)^{(\theta-1)/\theta} di \right]^{\theta/(\theta-1)},$$

where $\theta > 1$ represents the elasticity of substitution between intermediate goods $Y_t(i)$. With $P_t(i)$ denoting the price of intermediate good i , profit maximization leads to the following demand function for intermediate goods

$$Y_t(i) = \left[\frac{P_t(i)}{P_t} \right]^{-\theta} Y_t, \quad (6)$$

where

$$P_t = \left[\int_0^1 P_t(i)^{1-\theta} di \right]^{1/(1-\theta)}.$$

Each intermediate good i is produced by a single monopolistically competitive firm

according to the constant returns to scale technology

$$Y_t(i) \leq K_t(i)^\alpha [z_t h_t(i)]^{1-\alpha},$$

where $1 > \alpha > 0$ represents the elasticity of output with respect to capital. The technology shock z_t follows the autoregressive process

$$\ln(z_t) = (1 - \rho_z) \ln(z) + \rho_z \ln(z_{t-1}) + \varepsilon_{zt} \quad (7)$$

with $1 > \rho_z > 0$, $z > 0$, and $\varepsilon_{zt} \sim N(0, \sigma_z^2)$. As it is clear from (6), each firm i exerts some market power, but is assumed to act as a price taker in the factor markets. Furthermore, the adjustment of its nominal price $P_t(i)$ is assumed to be costly, where the cost function is convex in the size of the price adjustment. More specifically, following Rotemberg (1982), these costs are specified as

$$\frac{\phi_P}{2} \left[\frac{P_t(i)}{\pi P_{t-1}(i)} - 1 \right]^2 Y_t, \quad (8)$$

where $\phi_P \geq 0$ governs the size of price adjustment costs and π denotes the gross steady-state rate of inflation targeted by the monetary authority (described below). Due to the convexity of (8), the firm's problem becomes dynamic. It chooses $h_t(i)$, $K_t(i)$, $Y_t(i)$, and $P_t(i)$ to maximize its total market value

$$E \sum_{t=0}^{\infty} \beta^t \lambda_t [D_t(i)/P_t],$$

where λ_t measures the period t marginal utility to the representative household provided by an additional euro of profits. These are distributed to the household as dividends, defined in real terms by

$$\frac{D_t(i)}{P_t} = \left[\frac{P_t(i)}{P_t} \right] Y_t(i) - \frac{W_t h_t(i) + Q_t K_t(i)}{P_t} - \frac{\phi_P}{2} \left[\frac{P_t(i)}{\pi P_{t-1}(i)} - 1 \right]^2 Y_t.$$

2.4 Monetary policy

Similar to Ireland (2001) monetary policy is represented by a generalized Taylor rule of the form

$$\ln(r_t/r) = \omega_\mu \ln(\mu_t/\mu) + \omega_\pi \ln(\pi_t/\pi) + \omega_y \ln(y_t/y) + \ln(v_t), \quad (9)$$

encompassing the standard Taylor (1993) rule (when $\omega_\mu = 0$), where the monetary authority changes interest rates in response to inflation and output deviations. If ω_μ is non-zero, monetary policy can be considered to influence a linear combination of the interest rate r_t and money growth $\mu_t = M_t/M_{t-1}$ in response to deviations of inflation π_t and detrended output y_t from their steady-state values. Two alternative interpretations are that the central bank may simply respond to money growth because a) it wishes to protect the economy from the effects of money demand shocks or b) because money growth is a predictor of future inflation; see Christensen and Dib (2008).

The monetary policy shock v_t follows the autoregressive process

$$\ln(v_t) = \rho_v \ln(v_{t-1}) + \varepsilon_{vt}, \quad (10)$$

where $0 < \rho_v < 1$ and $\varepsilon_{vt} \sim N(0, \sigma_v^2)$.

It is important to note that this characterization of the monetary authority does not even ask the question of optimal monetary policy. Being aware that there are a lot of alternative specifications of monetary reaction functions and that it might be doubtful to assume an identical specification of the monetary policy function for the four economies under consideration we would like to stress that we are much more interested in examining the statistical relationship between short term interest rates, inflation, money growth and the output gap in four different countries than in issues regarding the specification of monetary policy.

2.5 Solution and Estimation

The model is characterized by a set of nonlinear difference equations, namely the first-order conditions for the three agents' problems, the laws of motion for the five exogenous shocks (2), (4), (5), (7), and (10) and the monetary policy rule (9). Two additional steps are required to close the model. First, in order to get from sectoral to aggregate variables, symmetric behavior within the intermediate sector is assumed, implying

$P_t(i) = P_t$, $Y_t(i) = Y_t$, $h_t(i) = h_t$, $K_t(i) = K_t$, and $D_t(i) = D_t$ for all $i \in [0, 1]$. Second, the market clearing conditions for both the money market $M_t = M_{t-1} + T_t$ and the bond market $B_t = B_{t-1} = 0$ must hold for all $t = 0, 1, 2, \dots$

Since the model is nonlinear, no exact closed-form solution exists in general. An approximate one is obtained by calculating the stationary representation of the model, computing the steady state, log-linearizing the system around the steady state, and then applying the method of Blanchard and Kahn (1980) to solve linear difference models under rational expectations. The solution takes on the form of a state space representation with a state equation

$$\mathbf{s}_t = \mathbf{A}\mathbf{s}_{t-1} + \mathbf{B}\boldsymbol{\varepsilon}_t$$

and an observation equation

$$\mathbf{f}_t = \mathbf{C}\mathbf{s}_t,$$

where \mathbf{s}_t contains the model's state variables including the current capital stock, lagged real balances, and the five exogenous shocks. The vector $\boldsymbol{\varepsilon}_t$ consists of the mutually as well as serially uncorrelated innovations ε_{at} , ε_{et} , ε_{xt} , ε_{zt} , ε_{vt} and \mathbf{f}_t comprises the model's flow variables including current values of consumption, investment, inflation and the nominal interest rate. The matrices \mathbf{A} , \mathbf{B} , and \mathbf{C} contain (functions of) the „deep“ as well as the policy rule parameters of the model. These parameters are estimated using maximum likelihood. As outlined in Canova (2007, p. 123), „... the likelihood function of a state space model can be conveniently expressed in terms of one-step-ahead forecast errors, conditional on the initial observations, and of their recursive variance, both of which can be obtained with the Kalman filter.“ Because likelihoods can have several peaks we use multiple starting values as well as different numerical search algorithms¹ to circumvent stalling at a local peak.

3 Data

To estimate the structural parameters of the model we use French, German, Italian, and Spanish quarterly (seasonally adjusted) data for consumption, investment, money balances, inflation and the interest rate. While French, German, and Italian time series

¹Therefore, we implement Christopher Sims' hybrid optimization algorithm „csminwel“, which combines the derivative-based BFGS method with a simplex algorithm. The „csminwel“ program is available at <http://sims.princeton.edu/yftp/optimize/>.

data run from 1980:Q1 to 2008:Q3, we decided to follow Burriel et al. (2010) and drop the data before 1987:Q1 for Spain because the changes in the structure of the Spanish economy were too substantial in the early eighties. Consumption and investment are measured by real personal consumption and real gross fixed capital formation in per capita terms. Real money balances are constructed by dividing the monetary aggregate M3 (again per capita) by the consumer price index that is also used for our measure of inflation. The interest rate is measured by the three month money market rate. The data sources are detailed in the appendix.

Following Fagan, Henry and Mestre (2005), we deal with the break in the series for Germany due to re-unification by re-scaling the West German series for consumption, investment and money prior to re-unification by the ratio of the values for West Germany and Germany at re-unification. The time series for (logs of) consumption, investment and M3 are detrended using the Hodrick-Prescott (H-P) filter.²

Despite its relative simplicity, the model contains a large number of parameters that are difficult to estimate precisely on only five time series. Hence, a number of parameters had to be fixed prior to estimation. More specifically, η is set to 1.5 which implies that the representative household's labor supply in the steady state amounts to one-third of its time. In addition, the depreciation rate δ is set to 0.025, corresponding to an annual depreciation rate of about 10 percent and θ is fixed at 6, implying a steady state markup of prices over marginal cost of 20 percent. Lastly, we set the elasticities of output with respect to capital of each country equal to their respective average capital income share, calculated from OECD data. The steady state money growth rate of each country is set equal to the average rate of inflation for the whole sample under consideration.

4 Estimating the Set of Stable Parameters: The ESS Procedure

In this section we outline the ESS („Estimate of Set of Stable parameters“) procedure developed by Inoue and Rossi (2011), that allows to identify the subset of parameters of a model that are stable over time. They propose the following recursive procedure. First, test the joint null hypothesis that all parameters are stable, using a consistent

²To facilitate the process of parameter estimation, we follow DeJong and Dave (2007, Chapter 11.2.5) and perform further data alignment by scaling the filtered series using their (relative) means.

test for structural breaks. Following Inoue and Rossi, we employ Andrews' (1993) QLR stability test. If the null is not rejected, then all the parameters belong to the set of stable parameters. If it is, the p-values of the individual test statistics are calculated in order to test whether each of the parameters is stable. Then the parameter with the lowest p-value is eliminated from the set of stable parameters, since this is the one that is most likely to be unstable. Second, it is tested whether the *remaining* parameters are jointly stable. If they are, then the set of stable parameters includes those parameters; otherwise, eliminate the parameter with the second lowest p-value from the set, and continue this procedure until the joint test on the remaining parameters does not reject stability.

Two specific features of the ESS procedure have to be emphasized:

- (i) The individual tests do not rely on the assumption that the other parameters are constant over time. If these parameters are in fact time-varying, a “one at a time approach” might lead to invalid results.
- (ii) The ESS approach overcomes the problem of size distortions, which arises “... in existing tests for structural breaks when used repeatedly to test structural changes in more than one subset of parameters” (Inoue and Rossi, 2011, p. 1203).³

5 Results

5.1 Full Sample Estimates

Here we first report the estimates for the whole sample before moving to the identification of parameter instabilities in section 5.2.

For each country table 1 presents the full sample maximum likelihood estimates of the parameters as well as the standard errors. The latter are computed using a parametric bootstrapping technique as in Cho and Moreno (2006) or Ireland (2007). According to Ireland (2007), this procedure simulates the estimated model for each country to generate 1000 samples of artificial data for real personal consumption, real gross fixed capital formation, real money balances, inflation, and the short term interest rate, each containing the same number of observations as the original samples of the

³For a more detailed description of the methodology, including a formal description of the algorithm and proofs, we refer to Inoue and Rossi (2011) as well as to their not-for-publication appendix; see <http://econ.duke.edu/~brossi/NotforPublicationAppendixInoueRossi2009.pdf>.

four EMU countries, and then re-estimates the model 1000 times using these artificial data sets. For a detailed description of the parametric bootstrapping analysis we refer to Efron and Tibshirani (1993). The absolute value of the maximized log likelihood function is indicated by $|L|$.

Parameter	France		Germany		Italy		Spain	
	Estimate	Std. Error	Estimate	Std. Error	Estimate	Std. Error	Estimate	Std. Error
β	0.9905	0.0112	0.9921	0.0014	0.9998	0.0410	0.9932	0.0277
γ	0.0152	0.0091	0.0738	0.0116	0.0067	0.0157	0.0366	0.0334
ϕ_P	10.2132	2.7778	14.0161	0.4214	46.7997	14.2531	27.0936	6.9245
ϕ_K	26.5408	4.1028	30.2300	0.4423	35.4014	6.2435	20.5672	3.4103
ω_μ	0.2009	0.0411	0.4362	0.0136	0.5647	0.1378	0.3163	0.0832
ω_π	0.9391	0.1491	1.6001	0.0037	1.0750	0.4163	0.8161	0.0901
ω_y	-0.1011	0.0842	-0.0025	0.0084	-0.1673	0.1378	-0.0711	0.0495
e	4.1884	0.0202	2.9638	0.0002	3.7456	0.9409	4.3559	0.0056
z	4214.3794	0.0001	4184.4742	0.0001	3189.9297	0.0080	1866.9879	0.0001
ρ_a	0.9678	0.0357	0.9002	0.0056	0.8587	0.0782	0.9731	0.0221
ρ_e	0.8778	0.0552	0.9001	0.0022	0.9877	0.0350	0.9360	0.0373
ρ_x	0.9615	0.0381	0.9001	0.0011	0.9873	0.0386	0.9294	0.1063
ρ_z	0.9125	0.0318	0.9005	0.0074	0.9871	0.0626	0.9210	0.0518
ρ_v	0.4826	0.0096	0.2994	0.0083	0.1425	0.3356	0.3818	0.0121
σ_a	0.0124	0.0012	0.0155	0.0011	0.0258	0.0178	0.0189	0.0020
σ_e	0.0096	0.0007	0.0145	0.0014	0.0135	0.0030	0.0102	0.0003
σ_x	0.0236	0.0201	0.0821	0.0082	0.2162	0.1450	0.0182	0.0094
σ_z	0.0090	0.0012	0.0135	0.0010	0.0334	0.0052	0.0140	0.0014
σ_v	0.0041	0.0007	0.0071	0.0005	0.0105	0.0028	0.0069	0.0008
$ L $	2195.2950		2037.3376		1891.2450		1553.1251	

Table 1: Maximum Likelihood Estimates: Full Samples.

To compare parameter estimates of the full samples across countries, we employ the Andrews and Fair (1988) Wald test. The Wald statistic can be written as

$$W = \frac{(a_i - a_j)^2}{\sigma_{a_i}^2 + \sigma_{a_j}^2},$$

where a and σ_a denote the point estimate of a parameter and the associated bootstrapped standard deviation, respectively, for country $i, j \in \{\text{France, Germany, Italy, Spain}\}$, $i \neq j$. The test statistic W follows a $\chi^2(1)$ distribution under the null hypothesis of $a_i = a_j$. For a detailed discussion on the use of the bootstrap in hypothesis testing we refer to Cameron and Trivedi (2005).⁴

Turning to our results, we first note that the estimates for the discount factor β are below unity, but exceed 0.99 for all of the four economies.

⁴A full set of the test statistics is available from the authors upon request.

The money demand equation derived from the household's optimization problem implies an interest elasticity for real money holdings of $-\gamma$. We find small values of this elasticity with the correct sign for all regions, although the estimates for Italy and Spain turn out to be statistically insignificant. These results are in line with a large empirical literature detecting small interest rate elasticities of (broad) money demand (see Browne et al., 2005).

Next, we turn to the estimates for the rigidity parameters. For all countries, both the adjustment cost parameters for capital ϕ_K defined in subsection 2.2 and prices ϕ_P defined in subsection 2.3 are significant. The latter is significantly higher in Italy and Spain compared to France and Germany at the 5% and 10% level, respectively.

To gauge the plausibility of the price adjustment parameters, we adopt the approach of Keen and Wang (2007) and translate the estimates of ϕ_P into an average duration of quoted prices. For France and Germany we get an average duration of prices between six and seven months, respectively. The findings are supported for France by the results of Baudry et al. (2004) using French consumer price index (CPI) micro-data. Spain shows a higher degree of price stickiness implying an average of eight to nine months between price adjustments. This is in line with international micro evidence as reported in de Walque et al. (2006). In the case of Italy we find an average duration of consumer prices of ten to eleven months, which is consistent with the evidence from Italian CPI micro-data reported in Fabiani et al. (2010). Our findings are also confirmed by the result of analysis on consumer price changes conducted by Dhyne et al. (2006), who identify Italy to have the lowest incidence of price changes, whereas France shows the highest frequency of price changes among the four regions.

Turning to the monetary policy reaction function, our estimates of ω_π and ω_μ are non-zero for all four countries, allowing at least for two possible interpretations of monetary policy (see subsection 2.4). Compared to France and Spain ω_π is significantly higher in Germany (at the 1% level). This result might reflect the well-documented higher pre-occupation with inflation in this country. The point estimate of ω_π for Italy is also well below the estimate for Germany, although insignificantly so. Concerning the positive estimates of ω_μ our results are consistent with the findings of Andrés et al. (2006) for the euro area. It is important to note that for each of the four countries the estimates of ω_μ and ω_π sum up to a value greater than unity. Hence, the monetary policy rule is consistent with a unique rational expectations equilibrium (see Clarida et al., 2000). For all countries the estimates of ω_y are negative. However, they are insignificant, which makes it difficult to interpret this result as a hint for the presence

of an endogenous money channel.

The estimates of e and z are not interesting from an economic policy point of view; they simply allow the steady state values of real balances and output in the model to match the average values of these variables in the data (see Ireland, 1997).

The estimates of ρ_a , ρ_e , ρ_x , ρ_z , and ρ_v indicate a high persistence of the first four shocks, whereas the monetary policy shock is less persistent and even statistically insignificant for Italy. In the case of France, Germany, and Italy, the estimated standard deviations of the innovations are dominated by the ones of the investment shock, although the estimate of σ_x turns out to be insignificant for Italy. This result is consistent with the findings of Justiniano et al. (2010) for the US. Hence, the marginal efficiency of investment shock is identified as the most important driver of business cycle fluctuations. For Spain the preference shock is the most volatile followed by the marginal efficiency of investment shock.

5.2 Testing for Parameter Instability

For each country tables 2 – 5 report the parameter estimates and standard deviations in both sub-samples, while tables 6 – 9 show the p-values of the QLR test on individual parameters as well as the p-values at each step of the ESS procedure. The set of stable parameters at the 10% significance level is denoted by \mathcal{S} . To structure the following discussion, it is useful to divide the parameters into three groups:

- (i) private sector parameters: $\beta, \gamma, \phi_P, \phi_K$;
- (ii) monetary policy parameters: $\omega_\mu, \omega_\pi, \omega_y$;
- (iii) shock parameters: $e, z, \rho_a, \rho_e, \rho_x, \rho_z, \rho_v, \sigma_a, \sigma_e, \sigma_x, \sigma_z$ and σ_v .

In the case of France, the QLR stability test indicates a significant break in 1994:Q3. Concerning the private sector parameters, table 6 reports instabilities of γ and ϕ_P . The estimates of γ are lower in both sub-samples than in the full sample, the estimate for the 1980:Q1 to 1994:Q2 period is insignificant, however. Table 2 shows a sharp decline of the price rigidity parameter ϕ_P . Further, we find significant changes in the monetary policy parameters ω_y and ω_π , both increasing in absolute values. Concerning the shock

parameters, the ESS procedure identifies only the technology shock to be stable with respect to both persistence and volatility. The direction of change in the persistence of the remaining shocks is ambiguous, while we find an overall decline in the volatilities $\sigma_a, \sigma_e, \sigma_x$, and σ_v .

For Germany we locate a break in 1994:Q2.⁵ As reported in table 7, the set of stable parameters \mathcal{S} contains $(\sigma_x, \omega_\mu, \sigma_e, \omega_\pi, \rho_e, \rho_a, \rho_z, \omega_y, \rho_x)$. Most interestingly, we find monetary policy to be constant over time. This result suggests no discernible difference between the monetary policy conducted in the 1980:Q2 to 1994:Q1 period by the German Bundesbank and the 1994:Q2 to 2008:Q3 period, although the latter is affected by the inception of EMU and the monetary policy strategy of the ECB. Further, we find instabilities in all of the private sector parameters, as well as the persistence of the monetary policy shock and the volatilities of the preference shock a_t , the technology shock z_t and the monetary policy shock v_t . Concerning the direction of change, only the volatility of the monetary policy shock increases, while the volatilities of the other shocks decline or stay constant over time.

We detect a significant break in 1994:Q4 for Italy. With respect to the private sector parameters, table 8 shows instabilities of γ , ϕ_P , and ϕ_K . According to table 4 the interest elasticity of money demand turns out to increase over time, while we find a significant decline in capital and price adjustment costs after the break. Concerning the monetary policy parameters, ω_y appears to be stable over time, whereas ω_μ and ω_π both change significantly. More specifically, table 4 presents a sharp decline of ω_μ and a substantial increase of ω_π in the 1994:Q4 to 2008:Q3 period. With exception of ρ_x , we find the persistence parameters to be unstable. While ρ_a and ρ_v increase, ρ_e and ρ_z turn out to decrease after the break. Regarding the volatilities of the five shocks, the ESS procedure identifies σ_a and σ_e to be stable, whereas σ_v , σ_x and σ_z decrease over time.

Turning to Spain, we find a significant break in 1998:Q1. Moreover, we detect instabilities in the private sector parameters (γ, ϕ_P, ϕ_K) , the monetary policy parameters (ω_μ, ω_π) and the shock parameters $(e, z, \rho_z, \rho_v, \sigma_a, \sigma_e, \sigma_x, \sigma_z$ and $\sigma_v)$. While ω_μ decreases, ω_π is significantly higher after the break (see table 5). Furthermore, we observe a sharp decline in capital and price adjustment costs. Regarding the persistence of the technology shock and the money policy shock, table 5 shows a decrease in both, while the latter declines sharply after the break. With the exception of the money

⁵We cannot rule out a test bias due to the treatment of re-unification outlined in section 3.

demand shock, we also find a decrease in the volatilities of the shocks a_t , x_t , z_t , and v_t .

6 Conclusions

Despite some scepticism voiced in the literature, DSGE models became a cornerstone of modern macroeconometrics leading to a high acceptance both in academia and central banking; see Tovar (2009). Being firmly rooted in microeconomic foundations, this class of models is able to identify structural characteristics of economies that are not easily recovered from a necessarily parsimonious set of macroeconomic time series. Apart from their frequent use as a tool for the description and evaluation of monetary policy, DSGE models enable cross-country comparisons of such characteristics without having to resort to micro data (see Smets and Wouters, 2005).

In this paper, we apply a New Keynesian model to French, German, Italian, and Spanish data and formally test for parameter stability over time. Parameter instabilities are detected by making use of the ESS procedure („Estimate of Set of Stable parameters“) developed by Inoue and Rossi (2011). This procedure allows to identify the parameters of the model that have changed at an unknown break date. In the cases of France, Germany, and Italy our results point to structural breaks in the mid-nineties after the beginning of the second stage of EMU, while the estimates for Spain show a significant break just before the start of the third stage of EMU in 1998. The most interesting result is that France, Italy, and Spain show significant changes in monetary policy behavior after the break dates, while monetary policy in Germany is found to be stable over time. Furthermore, France, Italy, and Spain show a significant decline in capital and price adjustment costs after the break. Moreover, we find at least four out of the five shocks to be either constant or declining after the break date for all economies under consideration.

On a methodological level, we could show that the use of DSGE models is able to shed some interesting light on the ongoing process of economic integration in Europe by allowing to look at the stability of structural and policy parameters both across countries and across time. This process yields numerous explanations for changes of allegedly „deep“ parameters. We empirically show that it is indeed important to take such potential changes into account and formally test for them.

Appendix: Data sources

- France:
 - Real personal consumption: EUROSTAT
 - Gross fixed capital formation: EUROSTAT
 - Money balances (M3): Banque de France
 - Consumer price index: OECD
 - Interest rate (Pibor): OECD
 - Population: National Institute for Statistics and Economic Studies (INSEE)
- Germany:
 - Real personal consumption: Federal Statistics Office
 - Gross fixed capital formation: Federal Statistical Office
 - Money balances (M3): Deutsche Bundesbank
 - Consumer price index: OECD
 - Interest rate (Fibor): OECD
 - Population: Federal Statistical Office
- Italy:
 - Real personal consumption: Oxford Economics
 - Gross fixed capital formation: Oxford Economics
 - Money balances (M3): Oxford Economics
 - Consumer price index: Oxford Economics
 - Interest rate (three-month money market rate): Oxford Economics
 - Population: Oxford Economics
- Spain:
 - Real personal consumption: EUROSTAT
 - Gross fixed capital formation: EUROSTAT
 - Money balances (M3): Banco de España
 - Consumer price index: OECD
 - Interest rate (three-month money market rate): OECD
 - Population: EUROSTAT

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Parameter	1980:Q1 - 1994:Q2		1994:Q3 - 2008:Q3	
	Estimate	Std. Error	Estimate	Std. Error
β	0.9906	0.0013	0.9913	0.0024
γ	0.0000	0.0007	0.0043	0.0014
ϕ_P	10.3880	0.5796	3.2691	0.3101
ϕ_K	30.0492	0.5400	28.8285	2.1778
ω_μ	0.2980	0.0081	0.2792	0.0188
ω_π	1.1974	0.0095	1.4680	0.0807
ω_y	-0.0075	0.0115	-0.1417	0.0605
e	4.4410	0.0006	4.3587	0.0115
z	4185.6183	0.0001	4181.1612	0.0001
ρ_a	0.8963	0.0065	0.8507	0.0137
ρ_e	0.9000	0.0071	0.8132	0.0128
ρ_x	0.9011	0.0078	0.9817	0.0067
ρ_z	0.8995	0.0188	0.9222	0.0061
ρ_v	0.4999	0.0076	0.1976	0.0249
σ_a	0.0202	0.0004	0.0082	0.0002
σ_e	0.0096	0.0001	0.0089	0.0001
σ_x	0.0554	0.0069	0.0324	0.0021
σ_z	0.0080	0.0003	0.0082	0.0002
σ_v	0.0057	0.0001	0.0044	0.0003

Table 2: Maximum Likelihood Estimates: France.

Parameter	1980:Q1 - 1994:Q1		1994:Q2 - 2008:Q3	
	Estimate	Std. Error	Estimate	Std. Error
β	0.9918	0.0001	0.9925	0.0001
γ	0.0739	0.0001	0.0751	0.0001
ϕ_P	13.9897	0.0131	14.0370	0.0159
ϕ_K	29.9417	0.1895	30.4771	0.1227
ω_μ	0.4368	0.0006	0.4353	0.0009
ω_π	1.5998	0.0006	1.6005	0.0001
ω_y	-0.0025	0.0007	-0.0026	0.0008
e	2.9639	0.0001	2.9635	0.0001
z	4196.6065	0.0001	4160.1370	0.0001
ρ_a	0.9000	0.0007	0.9002	0.0005
ρ_e	0.9000	0.0005	0.9004	0.0004
ρ_x	0.9001	0.0006	0.9001	0.0004
ρ_z	0.9004	0.0007	0.9006	0.0004
ρ_v	0.2999	0.0002	0.2984	0.0002
σ_a	0.0185	0.0011	0.0107	0.0008
σ_e	0.0150	0.0009	0.0135	0.0007
σ_x	0.0852	0.0034	0.0784	0.0030
σ_z	0.0161	0.0008	0.0109	0.0006
σ_v	0.0063	0.0001	0.0076	0.0001

Table 3: Maximum Likelihood Estimates: Germany.

Parameter	1980:Q1 - 1994:Q3		1994:Q4 - 2008:Q3	
	Estimate	Std. Error	Estimate	Std. Error
β	0.9992	0.0100	0.9975	0.0036
γ	0.0054	0.0057	0.0350	0.0057
ϕ_P	64.6013	4.7897	31.7841	1.8189
ϕ_K	33.1134	0.8700	14.5576	1.4126
ω_μ	0.6722	0.0287	0.0538	0.0096
ω_π	0.8736	0.0287	1.6598	0.2561
ω_y	-0.1286	0.0302	-0.1627	0.0832
e	3.9728	0.0855	3.2327	0.5237
z	3343.6115	0.0006	3336.9033	0.0013
ρ_a	0.8379	0.0108	0.9935	0.0142
ρ_e	0.9929	0.0093	0.9093	0.0119
ρ_x	0.9952	0.0085	0.9891	0.0077
ρ_z	0.9953	0.0195	0.8519	0.0062
ρ_v	0.0899	0.0662	0.5551	0.0022
σ_a	0.0291	0.0076	0.0119	0.0005
σ_e	0.0153	0.0021	0.0110	0.0001
σ_x	0.2501	0.0364	0.0192	0.0017
σ_z	0.0533	0.0017	0.0101	0.0003
σ_v	0.0128	0.0015	0.0034	0.0006

Table 4: Maximum Likelihood Estimates: Italy.

Parameter	1987:Q1 - 1997:Q4		1998:Q1 - 2008:Q3	
	Estimate	Std. Error	Estimate	Std. Error
β	0.9929	0.0067	0.9957	0.0020
γ	0.0189	0.0069	0.0518	0.0075
ϕ_P	66.9756	3.5472	2.7164	0.3119
ϕ_K	26.8170	0.7038	7.4710	0.4382
ω_μ	0.4707	0.0313	0.2367	0.0171
ω_π	0.6868	0.0339	1.2448	0.0480
ω_y	-0.0646	0.0098	-0.1006	0.0140
e	4.6627	0.0034	4.1651	0.0035
z	1932.4221	0.0001	1771.8852	0.0001
ρ_a	0.9542	0.0123	0.9411	0.0147
ρ_e	0.9440	0.0098	0.9648	0.0071
ρ_x	0.9625	0.0142	0.9903	0.0122
ρ_z	0.9477	0.0122	0.7833	0.0173
ρ_v	0.4565	0.0027	0.0333	0.0025
σ_a	0.0235	0.0006	0.0079	0.0002
σ_e	0.0084	0.0001	0.0107	0.0002
σ_x	0.0389	0.0086	0.0083	0.0004
σ_z	0.0227	0.0008	0.0073	0.0002
σ_v	0.0071	0.0003	0.0054	0.0002

Table 5: Maximum Likelihood Estimates: Spain.

Model Parameters	Individual p-value	ESS p-value
z	0	0
σ_a	0	0
ρ_v	0	0
ϕ_P	0	0
ρ_x	0	0
e	0	0
ρ_e	0	0
σ_v	0	0
σ_e	0	0
ω_π	0.0503	0
σ_x	0.0723	0
ρ_a	0.1106	0
γ	0.2181	0
ω_y	0.5459	0
ρ_z	1	1
ω_μ	1	1
σ_z	1	1
ϕ_K	1	1
β	1	1

Set of stable parameters (90% probability level):

$$\mathcal{S} = \{\rho_z, \omega_\mu, \sigma_z, \phi_K, \beta\}$$

Table 6: The table shows the p-values of Andrews'(1993) QLR test on individual parameters for France. In addition the set of stable parameters is reported as well as the p-values at each step of Inoue and Rossi's (2011) ESS procedure.

Model Parameters	Individual p-value	ESS p-value
z	0	0
γ	0	0
σ_v	0	0
β	0	0
e	0	0
σ_a	0	0
ρ_v	0	0
σ_z	0	0
ϕ_K	0.4175	0
ϕ_P	0.4615	0
σ_x	1	1
ω_μ	1	0.8630
σ_e	1	0.7592
ω_π	1	1
ρ_e	1	1
ρ_a	1	1
ρ_z	1	1
ω_y	1	1
ρ_x	1	1

Set of stable parameters (90% probability level):

$$\mathcal{S} = \{\sigma_x, \omega_\mu, \sigma_e, \omega_\pi, \rho_e, \rho_a, \rho_z, \omega_y, \rho_x\}$$

Table 7: The table shows the p-values of Andrews'(1993) QLR test on individual parameters for Germany. In addition the set of stable parameters is reported as well as the p-values at each step of Inoue and Rossi's (2011) ESS procedure.

Model Parameters	Individual p-value	ESS p-value
z	0	0
σ_z	0	0
ω_μ	0	0
ϕ_K	0	0
ρ_a	0	0
ρ_v	0	0
ρ_z	0	0
ϕ_P	0	0
σ_x	0	0
σ_v	0	0
ρ_e	0	0
γ	0.0180	0
ω_π	0.1498	0
σ_a	0.4892	0.6207
σ_e	0.6370	0.7320
e	1	1
ρ_x	1	1
ω_y	1	1
β	1	1

Set of stable parameters (90% probability level):

$$\mathcal{S} = \{\sigma_a, \sigma_e, e, \rho_x, \omega_y, \beta\}$$

Table 8: The table shows the p-values of Andrews'(1993) QLR test on individual parameters for Italy. In addition the set of stable parameters is reported as well as the p-values at each step of Inoue and Rossi's (2011) ESS procedure.

Model Parameters	Individual p-value	ESS p-value
z	0	0
ρ_v	0	0
e	0	0
σ_a	0	0
ϕ_K	0	0
σ_z	0	0
ϕ_P	0	0
σ_e	0	0
ω_π	0	0
ρ_z	0	0
ω_μ	0	0
σ_v	0	0
σ_x	0.0249	0
γ	0.0066	0
ω_y	0.5959	0.6288
ρ_e	0.8332	1
ρ_x	1	1
ρ_a	1	1
β	1	1

Set of stable parameters (90% probability level):

$$\mathcal{S} = \{\omega_y, \rho_e, \rho_x, \rho_a, \beta\}$$

Table 9: The table shows the p-values of Andrews'(1993) QLR test on individual parameters for Spain. In addition the set of stable parameters is reported as well as the p-values at each step of Inoue and Rossi's (2011) ESS procedure.