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Testing for Parameter Stability in DSGE Models. The Cases of France, Germany and Spain[1]

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Abstract

We estimate a New Keynesian DSGE model on French, German 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 and Germany 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 and Spain, while monetary policy in Germany seems to be stable over time.

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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 macroeconometric 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 modelling 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 France, Germany 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 European Monetary Union (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 looks at the (change of) different transmission channels of monetary policy (van Aarle et al. (2001), Angeloni and Ehrmann (2006), Jarocinski (2008) and 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), Ongena and Popov (2010)). 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 (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 and Germany 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 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 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 and Spain is similar to the one developed and applied to US data in Ireland (2003). It is a standard closed-economy New Keynesian setting featuring 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 $t = 0, 1, 2, ...$, 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-1} 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

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

accrue to the household. g denotes the steady state growth rate of the capital stock. $\phi_K \geq 0$ 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

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

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

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

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

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

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

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

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

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

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 firms acting in a perfectly competitive market by combining the intermediate goods $Y_t(i)$ according to

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

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

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

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

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

where g denotes the gross rate of labor-augmenting technological progress and $1 > \alpha > 0$ represents the elasticity of output with respect to capital. The technology shock z_t follows the autoregressive process

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

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

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

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

$$\ln(r_t/r) = \omega_\mu \ln(\mu_t/\mu) + \omega_\pi \ln(\pi_t/\pi) + \omega_y \ln(y_t/y) + \ln(\upsilon_t), \tag{9}$$

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 and money growth in response to deviations of gross inflation and detrended output 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 υ_t follows the autoregressive process

$$\ln(\upsilon_t) = \rho_\upsilon \ln(\upsilon_{t-1}) + \varepsilon_{\upsilon t}, \tag{10}$$

where $0 < \rho_\upsilon < 1$ and $\varepsilon_{\upsilon t} \sim N(0, \sigma_\upsilon^2)$.

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 three 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 three 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 $t = 0, 1, 2....$

Since the model is nonlinear, there is no exact closed-form solution. 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 $\mathbf{s_t} = \mathbf{A}\mathbf{s_{t-1}} + \mathbf{B}\varepsilon_\mathbf{t}$ 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. $\varepsilon_\mathbf{t}$ 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 Hamilton (1994) or Canova (2007), the likelihood function of a state space model can be expressed in terms of one-step-ahead forecast errors of the observables, conditional on the initial observations, and of their recursive variance, both of which are obtained using the Kalman filter. Because likelihoods can have several peaks we use multiple starting values as well as different numerical search algorithms[1] to circumvent stalling at a local peak.

3 Data

To estimate the structural parameters of the model we use French, German and Spanish quarterly (seasonally adjusted) data for consumption, investment, money balances, inflation and the interest rate. While French and German time series data run from 1980:Q1 to 2008:Q3, we decided to follow Burrriel 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. Being aware of the potential problem of spuriousness, as discussed in DeJong and Dave (2007), we detrend the time series for (logs of) consumption, investment and M3 applying the Hodrick-Prescott (H-P) filter.

Despite its relative simplicity, the model contains a large number of parameters

[1] Therefore, we implement Christopher Sims' hybrid optimization algorithm „csminwel", which combines the derivative-based BFGS method with a simplex algorithm. The „csminwel" program can be found on http://sims.princeton.edu/yftp/optimize/.

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 are stable over time. Inoue and Rossi (2011) propose the following recursive procedure. First, test the joint null hypothesis that all parameters are stable, using any 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. It has to be emphasized that the individual tests do not rely on the assumption that the other parameters are constant over time. Therefore, the individual tests allow all the other parameters to be time-varying. In the words of Inoue and Rossi (2011, p. 2): „If parameters that are assumed to be constant are in reality time-varying, [traditional procedures] may incorrectly attribute the time variation to the wrong source.“ 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. This new econometric procedure identifies the set of constant parameters. For 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.

5 Results

5.1 Full Sample Estimates

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 procedure similar to those applied in Cho and Moreno (2006) or Ireland (2007). As outlined in Ireland (2007) this methodology simulates the estimated model for each country in order 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 three 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 $|L|$.

	France		Germany		Spain	
Parameter	Estimate	Std Error	Estimate	Std Error	Estimate	Std Error
β	0.9905	0.0112	0.9921	0.0014	0.9932	0.0277
γ	0.0152	0.0091	0.0738	0.0116	0.0366	0.0334
ϕ_P	10.2132	2.7778	14.0161	0.4214	27.0936	6.9245
ϕ_K	26.5408	4.1028	30.2300	0.4423	20.5672	3.4103
ω_μ	0.2009	0.0411	0.4362	0.0136	0.3163	0.0832
ω_π	0.9391	0.1491	1.6001	0.0037	0.8161	0.0901
ω_y	-0.1011	0.0842	-0.0025	0.0084	-0.0711	0.0495
e	4.1884	0.0202	2.9638	0.0002	4.3559	0.0056
z	4214.3794	0.0001	4184.4742	0.0001	1866.9879	0.0001
ρ_a	0.9678	0.0357	0.9002	0.0056	0.9731	0.0221
ρ_e	0.8778	0.0552	0.9001	0.0022	0.9360	0.0373
ρ_x	0.9615	0.0381	0.9001	0.0011	0.9294	0.1063
ρ_z	0.9125	0.0318	0.9005	0.0074	0.9210	0.0518
ρ_v	0.4826	0.0096	0.2994	0.0083	0.3818	0.0121
σ_a	0.0124	0.0012	0.0155	0.0011	0.0189	0.0020
σ_e	0.0096	0.0007	0.0145	0.0014	0.0102	0.0003
σ_x	0.0236	0.0201	0.0821	0.0082	0.0182	0.0094
σ_z	0.0090	0.0012	0.0135	0.0010	0.0140	0.0014
σ_v	0.0041	0.0007	0.0071	0.0005	0.0069	0.0008
$\|L\|$	2195.2950		2037.3376		1553.1251	

Table 1: Maximum Likelihood Estimates: Full Samples

In order 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 $i, j \in \{\text{France, Germany, Spain}\}, i \neq j$. W follows a $\chi^2(1)$ distribution under the null 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). A full set of the test statistics is available from the authors upon request.

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

The money demand equation that follows from (3) implies an interest elasticity for real money holdings of $-\gamma$. Hence, we estimate significant, albeit small values of this elasticity with the correct sign for France, Germany and Spain. 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 (1) and prices ϕ_P defined in (8) are significant. The latter is significantly higher in Spain compared to France and Germany at the 5% and 10% level, respectively.

To gauge the plausibility of the price adjustment parameters, we use the approach of Keen and Wang (2007) to translate the estimates of ϕ_P into an average duration of quoted prices. For France and Germany we get an average duration of individual prices between 6 and 7 months, respectively. The findings are supported for France by the results of Baudry et al. (2004) using French CPI micro-data. Spain shows a higher degree of price stickiness implying an average of 8 to 9 months between price adjustments. This is in line with international micro evidence as reported in de Walque, Smets and Wouters (2006).

Turning to the monetary policy reaction function, our estimates of ω_π and ω_μ are non-zero for all three countries, allowing at least for two possible interpretations of monetary policy (see section 2.4). Relative to France and Spain ω_π is significantly higher in Germany. This might reflect the well-documented higher pre-occupation with inflation in this country. Concerning the positive estimates of ω_μ our results are consistent with the findings of Andrés, Lopéz-Salido and Vallés (2006) for the euro area. It is important to note that for each of the three countries the estimates of ω_μ and ω_π sum up to a value greater than unity. This ensures that the monetary policy rule is consistent with a unique rational expectations equilibrium (see Clarida, Gali and Gertler (2000)). For all countries the estimates of ω_y are negative. However, they are insignificant, which makes it difficult to interpret this 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 – albeit significantly – persistent. In the case of France and Germany, the estimated standard deviations of the innovations are dominated by the ones of the investment shock. This result is in line with the findings of Justiniano, Primiceri and Tambalotti (2010) for the U.S.. 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 The ESS Results

For each country tables 2 – 4 report the parameter estimates and standard deviations in both sub-samples, while tables 5 – 7 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 $\mathcal{S}$. In order to interpret the results we follow Inoue and Rossi (2011) and 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 5 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, implying a fall in the average duration of quoted prices from 6 to 4 month from the first to the second subsample. Further, the table shows significant changes in the monetary policy parameters ω_y and ω_π, both increasing in absolute values. Concerning the shock parameters ESS 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[2] we locate a break in 1994:Q2. As reported in table 6, 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

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

find monetary policy to be constant over time. This result suggests that there is 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:Q4 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 υ_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.

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 $(e, z, \rho_z, \rho_\upsilon, \sigma_a, \sigma_e, \sigma_x, \sigma_z$ and $\sigma_\upsilon)$. While ω_μ decreases, ω_π is significantly higher after the break (see table 4). Furthermore, we observe a sharp decline in capital and price adjustment costs. In particular, the average duration of quoted prices falls from 12 to 4 month in the 1998:Q2 to 2008:Q3 period. Regarding the persistence of the technology shock and the money policy shock, table 4 shows a decrease in both, while the latter declines sharply after the break. With the exception of the money demand shock, we also find a decrease in the volatilities of the shocks a_t, x_t, z_t and υ_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 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 and Germany 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 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 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 Statistics Office

  Money balances (M3): Deutsche Bundesbank

  Consumer price index: OECD

  Interest rate (Fibor): OECD

Population: Federal Statistics Office

- Spain:

  Real personal consumption: EUROSTAT

  Gross fixed capital formation: EUROSTAT

  Money balances (M3): Banco de España

  Consumer price index: OECD

  Interest rate (three-months money market rate): OECD

  Population: EUROSTAT

References

Andrews, Donald W. K. and Ray C. Fair, "Inference in Nonlinear Econometric Models with Structural Change.," *Review of Economic Studies*, October 1988, *55* (184), 615–639.

Andrews, Donald W.K., "Tests for Parameter Instability and Structural Change with Unknown Change Point.," *Econometrica*, July 1993, *61* (4), 821–856.

Andrés, Javier, J. David Lopéz-Salido, and Javier Vallés, "Money in an Estimated Business Cycle Model of the Euro Area.," *Economic Journal*, April 2006, *116* (511), 457–477.

Angeloni, Ignazio and Michael Ehrmann, "The Euro and the Transmission of Monetary Policy," in Lawrence R. Klein, ed., *Long-Run Growth and Short-Run Stabilization: Essays in Memory of Albert Ando*, Elgar, 2006, pp. 161–206.

Baudry, Laurent, Hervé le Bihan, Patrick Sevestre, and Sylvie Tarrieu, "Price rigidity. Evidence from the French CPI micro-data," *ECB Working Paper Series*, August 2004, (384).

Beck, Günter W. and Axel A. Weber, "Inflation Rate Dispersion and Convergence in Monetary and Economic Unions: Lessons for the ECB," *CFS Working Paper Series*, November 2005, (2005/31).

Blanchard, Oliver Jean and Charles M. Kahn, "The Solution of Linear Difference Models under Rational Expectations.," *Econometrica*, July 1980, *48* (5), 1305–1311.

Browne, Frank, Gabriel Fagan, and Jerome Henry, "Money Demand in EU Countries: A Survey," Macroeconomics 0503004, EconWPA March 2005.

Burriel, Pablo, Jesús Fernández-Villaverde, and Juan Rubio-Ramírez, "MEDEA: a DSGE model for the Spanish economy," *SERIEs - Journal of the Spanish Economic Association*, March 2010, *1* (1), 175–243.

Cameron, A. Colin and Pravin K. Trivedi, *Microeconometrics: Methods and Applications*, Cambridge University Press, 2005.

Canova, Fabio, *Methods for Applied Macroeconomic Research*, Princeton University Press, 2007.

Cho, Seonghoon and Antonio Moreno, "A Small-Sample Study of the New-Keynesian Macro Model.," *Journal of Money, Credit & Banking*, September 2006, *38* (6), 1461–1481.

Christensen, Ian and Ali Dib, "The Financial Accelerator in an Estimated New Keynesian Model," *Review of Economic Dynamics*, January 2008, *11* (1), 155–178.

Clarida, Richard, Jordi Galí, and Mark Gertler, "Monetary Policy Rules and Macroeconomic Stability: Evidence and Some Theory.," *Quarterly Journal of Economics*, February 2000, *115* (1), 147–180.

Cukierman, Alex and Francesco Lippi, "Labour Markets and Monetary Union: A Strategic Analysis.," *Economic Journal*, July 2001, *111* (473), 541–565.

de Walque, Gregory, Frank Smets, and Raf Wouters, "Price Shocks in General Equilibrium: Alternative Specifications.," *CESifo Economic Studies*, March 2006, *52* (1), 153–176.

DeJong, David N. and Chetan Dave, *Structural Macroeconometrics*, Princeton University Press, 2007.

DiCecio, Riccardo and Edward Nelson, "An Estimated DSGE Model for the United Kingdom.," *Federal Reserve Bank of St. Louis Review*, July 2007, *89* (4), 215–231.

Efron, Bradley and Robert J. Tibshirani, *An Introduction to the Bootstrap*, Chapman & Hall/CRC Monographs on Statistics & Applied Probability, 1993.

European Commission, *EMU@10: Successes and challenges after 10 years of Economic and Monetary Union.*, Office for Official Publ. of the Europ. Communities, 2008.

Fagan, Gabriel, Jérôme Henry, and Ricardo Mestre, "An Area-Wide Model for the Euro Area.," *Economic Modelling*, January 2005, *22* (1), 39–59.

Fernández-Villaverde, Jesús, "The Econometrics of DSGE Models," *SERIEs - Journal of the Spanish Economic Association*, March 2010, *1* (1), 3–49.

Fratzscher, Marcel and Livio Stracca, "The political economy under monetary union: has the euro made a difference?.," *Economic Policy*, 2009, *24* (58), 307 – 348.

Greenwood, Jeremy, Zvi Hercowitz, and Gregory W. Huffman, "Investment, Capacity Utilization, and the Real Business Cycle.," *American Economic Review*, June 1988, *78* (3), 402–417.

Hamilton, James D., *Time series analysis*, Princeton University Press, 1994.

Hughes Hallett, Andrew and Christian Richter, "Has there been any structural convergence in the transmission of European monetary policies?," *International Economics and Economic Policy*, July 2009, *6* (2), 85–101.

Inoue, Atsushi and Barbara Rossi, "Identifying the Sources of Instabilities in Macroeconomic Fluctuations," *Review of Economics and Statistics*, 2011, *forthcoming.*

Ireland, Peter N., "A Small, Structural, Quarterly Model for Monetary Policy Evaluation," *Carnegie-Rochester Conference Series on Public Policy*, December 1997, *47*, 83–108.

_ , "Sticky-price models of the business cycle: Specification and stability.," *Journal of Monetary Economics*, February 2001, *47* (1), 3–18.

_ , "Endogenous Money or Sticky Prices?," *Journal of Monetary Economics*, November 2003, *50* (8), 1623–1648.

_ , "Changes in the Federal Reserve's Inflation Target: Causes and Consequences.," *Journal of Money, Credit & Banking*, December 2007, *39* (8), 1851–1882.

Jarocinski, Marek, "Responses to Monetary policy Shocks in the East and the West of Europe - A Comparison.," *ECB Working Paper Series*, November 2008, (970).

Jerger, Jürgen, "Socially Optimal Monetary Policy Institutions.," *European Journal of Political Economy*, November 2002, *18* (4), 761–781.

Justiniano, Alejandro, Giorgio E. Primiceri, and Andrea Tambalotti, "Investment Shocks and Business Cycles.," *Journal of Monetary Economics*, March 2010, *57* (2), 132–145.

Keen, Benjamin and Yongsheng Wang, "What is a Realistic Value for Price Adjustment Costs in New Keynesian Models?," *Applied Economics Letters*, September 2007, *14* (11), 789–793.

Lee, Jim, "Evaluating Monetary Policy of the Euro Area with Cross-Country Heterogeneity: Evidence from a New Keynesian Model.," *Economic Systems*, 2009, *33* (4), 325 – 343.

McCallum, Bennett T. and Edward Nelson, "An Optimizing IS-LM Specification for Monetary Policy and Business Cycle Analysis.," *Journal of Money, Credit & Banking*, August 1999, *31* (3), 296–316.

Milani, Fabio, "Adaptive Learning and Macroeconomic Inertia in the Euro Area.," *Journal of Common Market Studies*, June 2009, *47* (3), 579–599.

Neiss, Katharine S. and Edward Nelson, "The Real-Interest-Rate Gap as an Inflation Indicator.," *Macroeconomic Dynamics*, April 2003, *7* (2), 239–262.

Obstfeld, Maurice, "Exchange Rates and Adjustment: Perspectives from the New Open- Economy Macroeconomics," *Monetary and Economic Studies*, December 2002, *20* (S1), 23–46.

Ongena, Steven and Alexander Popov, "Interbank Market Integration, Loan Rates, and Firm Leverage.," *ECB Working Paper Series*, October 2010, (1252).

Reis, Ricardo, "Optimal Monetary Policy Rules in an Estimated Sticky-Information Model.," *American Economic Journal: Macroeconomics*, July 2009, *1* (2), 1–28.

Rotemberg, Julio J., "Sticky Prices in the United States.," *Journal of Political Economy*, December 1982, *90* (6), 1187–1211.

Smets, Frank and Raf Wouters, "Comparing Shocks and Frictions in US and Euro Area Business Cycles: A Bayesian DSGE Approach," *Journal of Applied Econometrics*, 2005, *20* (2), 161–183.

Taylor, John B., "Discretion Versus Policy Rules in Practice.," *Carnegie-Rochester Conference Series on Public Policy*, December 1993, *39* (1), 195–214.

Tovar, Camilo E., "DSGE Models and Central Banks," *Economics: The Open-Access, Open-Assessment E-Journal*, 2009, *3*, 1–31.

van Aarle, Bas, Harry Garretsen, and Cornelie van Moorsel, "Internal and External Transmissions of Monetary and Fiscal Policies in the EMU.," *Economic Systems*, 2001, *25* (2), 127 – 148.

von Hagen, Jürgen, "Macroeconomic Consequences of the EMU.," *Empirica*, December 1999, *26* (4), 359–374.

	1980:Q1 - 1994:Q2		1994:Q3 - 2008:Q3	
Parameter	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

	1980:Q1 - 1994:Q1		1994:Q2 - 2008:Q3	
Parameter	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	2.9999	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

	1987:Q1 - 1997:Q4		1998:Q1 - 2008:Q3	
Parameter	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 4: Maximum Likelihood Estimates: Spain

Model Parameters	Individual p-value	ESS p-value
z	0	0
σ_a	0	0
ρ_υ	0	0
ϕ_P	0	0
ρ_x	0	0
e	0	0
ρ_e	0	0
σ_υ	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 5: 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 of at each step of Inoue and Rossi's 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 6: 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 of at each step of Inoue and Rossi's 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 7: 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 of at each step of Inoue and Rossi's ESS procedure.