Same Spain, Less Pain?[*]

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We explore how the Spanish economy would have performed in the aftermath of the 2008 financial crisis if it had retained an independent monetary policy rather than joining the euro. A novel aspect of our approach is that we set up and estimate a structural model that takes account of the break in the conduct of monetary policy that occurred when Spain joined the euro, including anticipation effects. On average, Spanish economic growth would have been around 0.8 percentage points higher and consumption growth 0.5 percentage points higher between 2008 and 2013 if Spain had retained an independent monetary policy. But because euro entry led to a large boom prior to the crisis, the level of economic activity would have been similar by late 2016, regardless of Spain's monetary arrangements.

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1 Introduction

In the aftermath of the 2008 financial crisis the Spanish economy experienced a deep and prolonged recession. Between 2008 and 2013 the level of GDP contracted by 9.3 per cent and at the time of writing remains well below its pre-crisis peak. The unemployment rate increased from an average rate of 9.7 per cent in the five years prior to the crisis to 26.2 per cent at its peak in mid-2013.

The performance of the Spanish economy in this episode is a puzzle. Many European economies experienced deep recessions. But unlike some of its counterparts, Spanish macroeconomic policy settings prior to the crisis appeared sound. In the decade prior to the crisis the central government ran small budget deficits (and on occasion surpluses), its public debt-to-GDP ratio was modest, employment was expanding rapidly and the sovereign yield spread was low.

Admittedly, with the benefit of hindsight some aspects of the Spanish economy look to have been unsustainable.[1] Spain experienced a residential property boom that featured a large run-up in house prices, rapid expansion of the residential construction sector and, in some segments of the market, imprudent lending practices. Spain also ran large current account deficits. Some form of correction may have been necessary to resolve these imbalances. Yet, even allowing for this, Spain's economic downturn was unusually severe. The United States also experienced a large house price crash and saw a number of large financial institutions become insolvent. But by the end of 2013 per capita real GDP in the United States was above its pre-crisis level and its labour market was on the road to recovery.

One explanation for the poor performance of the Spanish economy is that, as a member of the euro currency union, it lacked an independent monetary policy (Krugman (2011), Wolf (2011), De Grauwe (2015)). Euro membership may have depressed the Spanish economy in several ways. The European Central Bank (ECB) targets

[1] Ortega and Penalosa (2012) provide a comprehensive analysis of the Spanish economy in the leadup to the 2008 financial crisis.

economic conditions in the eurozone as a whole. Its monetary policy settings may have been tighter than optimal for Spain, whose economic conditions were particularly weak. Euro membership also meant that relative-price adjustment between Spain and its trading partners had to occur largely through changes in domestic wages and prices, which may be slower and more costly than a nominal exchange rate depreciation. And, had Spain retained an independent monetary policy, the shift in investor preferences away from Spanish assets that occurred between 2010 and 2013 may have translated into a weaker exchange rate rather than a rise in sovereign interest rates and firms' borrowing costs (Krugman (2014)).

Our first contribution is to take these hypotheses to the data and quantitatively evaluate how the Spanish economy would have fared during the Great Recession and sovereign debt crisis if it had retained an independent monetary policy. To do this, we set up and estimate a two-country small open economy model of Spain and the euro area over the period 1988 - 2016. We apply solution and estimation methods that account for Spain's entry into the euro in 1999, and the anticipation of future euro entry in the years prior. This model provides us with the economic shocks that explain the behaviour of the Spanish economy over our sample. We evaluate the performance of the Spanish economy outside the euro through counterfactual exercises in which we feed into the model the estimated shocks that hit the Spanish economy but assume that Spain retained the monetary policy arrangements it had prior to 1999.[2] Comparing these counterfactual exercises to actual data tells us the extent to which euro membership influenced Spain's economic outcomes.

We find some support for the idea that euro membership contributed to the poor performance of the Spanish economy in the years following 2008. If it had retained an independent monetary policy, Spanish economic growth would have been around 0.8 percentage points higher and consumption growth around 0.5 percentage points

[2] Aside from euro entry, there were additional changes to Spain's monetary policy arrangements in the 1990s associated with the introduction of an inflation target. We also account for these changes in our estimation and counterfactual simulations.

higher in average annualised terms between 2008 and 2013. Core inflation would have also been closer to target. In part, this improved economic performance reflects a substantial depreciation of the nominal exchange rate, of around 20 per cent.

These results come with two caveats. First, although Spain would have experienced faster economic growth since 2008, this would not have translated into a higher *level* of economic activity and consumption. This reflects the fact that euro entry led to a boom in economic activity that Spain would not have experienced if it had retained an independent monetary policy.

Second, our results are only a first step towards addressing the broader question of whether euro membership is desirable for Spain. A complete answer must also take account of the benefits of euro membership, including lower trade costs (Rose (2000), Frankel (2010) among many others) and the long-term productivity gains from realising economies of scale in a larger market (Balassa (2012), Baldwin (1989)). Instead, we tackle the narrower question of the consequences of the loss of monetary policy autonomy and its implications for the Spanish economy during the Great Recession and its aftermath.

Our paper also contributes to the literature exploring Spanish economic outcomes since its adoption of the euro. A number of these papers focuses on the years prior 2008. For example, Rabanal (2009) explores the sources of persistent differences in trend inflation between Spain and eurozone, while Jimeno and Santos (2014), FEDEA (2010), Estrada et al. (2009) and Suarez (2010) have also sought to uncover the factors contributing to macroeconomic imbalances in Spain in the 2000s.

Like this earlier literature, Veld et al. (2014) and Veld et al. (2015) describe the factors behind the buildup of imbalances in Spain prior to 2008. These papers, however, also explore the reasons for the subsequent slump in economic activity. Both papers conclude that tightening collateral constraints and falling house prices were important contributors to the Spanish economy's weak recovery from the crisis. We extend this literature by quantifying the extent to which the loss of monetary autonomy affected

Spanish economic outcomes in the lead-up to, and aftermath of, the Great Recession and sovereign debt crisis.

Our paper also makes a methodological contribution to the literature estimating DSGE models of euro area economies. The transition from a system of individual monetary policies to a currency union represents a change in economic structure that standard solution methods can not account for. Reflecting this, euro-area DSGE models are typically estimated over short samples, over which the assumption of a single monetary regime is plausible (e.g. Andres et al. (2010), Rabanal (2009), Veld et al. (2014), Veld et al. (2015)). Others estimate over a longer sample and ignore the change in monetary policy regime associated with the transition to, and introduction of, the euro (e.g. Smets and Wouters (2005), Burriel et al. (2010)). Both approaches have drawbacks. The use of short samples may result in imprecise inference and overstate the importance of idiosyncratic aspects of recent economic episodes. Models estimated over longer samples that do not account for the shift in monetary policy regime are necessarily misspecified.

We show how to apply solution and estimation methods that account for changes in the conduct of monetary policy associated with euro entry. These methods also incorporate anticipation effects in the years prior to euro entry and endogenously account for the gradual shifts in inflation and interest rates observed in the data. The methods are straightforward to implement, produce credible results and could become a standard feature of estimated DSGE models of euro area economies.

The rest of the paper is structured as follows. Section 2 lays out the model. Section 3 describes the estimation. In Section 4 we use the estimated model to explore the performance of the Spanish economy outside the euro zone. Section 5 concludes.

2 Model

We work with a New Keynesian small open economy model along the lines of Gali and Monacelli (2005). The model features two economies: a large economy (the euro-area) and a small economy (Spain). Economic developments in the large economy affect the small economy, but the reverse is not true.

The set-up of the large economy is standard; it features a household that chooses consumption and hours of work to maximize expected lifetime utility, firms that face pricing rigidities and a monetary authority that adjusts nominal interest rates to stabilize inflation and aggregate output.

The modelling of the small economy is richer since it is the focus of our analysis. In addition to consumption and hours worked, housing also enters the utility function of households in the small economy. Households have access to several savings instruments, including housing, productive capital and bonds denominated in either domestic or foreign currency. A government sector issues public debt and raises lump-sum taxes to finance an exogenous flow of government expenditures.

On the production side of the small economy, there are five sectors. An intermediate goods sector faces working capital constraints and combines capital and labor into domestically-produced goods. A domestic final goods retailer aggregates intermediate goods into a final domestic good. An exporting sector purchases a portion of the domestic final goods and differentiates them for sale to the large economy. An importing sector buys goods produced abroad and differentiates them for sale to domestic consumers and firms. And a final goods retailer purchases domestic and imported goods and aggregates them for sale to domestic consumers.

The interest rates faced by the government and households can differ from the policy rate set by the central bank. Spreads between government borrowing rates and the policy rate depend, in part, on the public debt-to-GDP ratio, with an elasticity that depends on the monetary regime. An increase in the government spreads, in turn, increases the interest rates faced by households and firms. Government and household spreads are also subject to transitory idiosyncratic risk premia shocks, whose persistence and size is allowed to vary according to Spain's monetary policy arrangements. The model also accounts for the possibility that adopting the euro led to a permanent reduction in risk premia in Spain, lowering borrowing and lending rates across the economy (Estrada et al. 2009).

Prior to euro entry, Spanish monetary authorities follow a reaction function that responds to developments in inflation, output and the nominal exchange rate. After entering the euro, the Spanish policy rate is equal to the euro-area policy interest rate plus an exogenous risk premium.

In the remainder of this section we lay out the basic features of the model. Readers looking for more detail may consult Appendix A for the log-linearized equations and our online appendix for the full derivation.

2.1 The Large Economy

Households

The large economy features a representative household that maximizes its expected lifetime utility given by:

$$\sum_{t=0}^{\infty} \beta^t \left[\left(\xi_t^* \log(C_t^* - h^* C_{t-1}^*) - A_L^* \frac{{N_t^*}^{1+\phi}}{1+\phi} \right) \right] \tag{1}$$

where C_t^* denotes consumption of the large economy's final good, N_t^* represents the household's labor supply and h^* parameterizes the degree of the household's habit formation. The term ξ_t^* is a consumption preference shock that evolves as an autoregressive process in logs:

$$\log(\xi_t^*) = \rho_{\xi^*} \log\left(\xi_{t-1}^*\right) + u_{\xi^*,t} \tag{2}$$

where $u_{\xi^*,t} \sim N(0, \sigma_{\xi^*}^2)$.

Utility maximization is subject to the budget constraint:

$$P_t^* C_t^* + \frac{D_{t+1}^*}{R_t^*} \leq D_t^* + W_t^* N_t^* + T_t^* \tag{3}$$

where P_t^* is the price of the final good, W_t^* is the nominal wage, and T_t^* denotes lump-sum taxes/transfers. Households have access to a risk-free one-period nominal bond, D_t^*, that pays a return of one unit of the large economy's currency. $R_t^{*,-1}$ is the price of the bond, where R_t^* is the nominal interest rate in the large economy.

Firms

On the production side, each firm produces an intermediate good, indexed by $i \in [0, 1]$, using a technology linear in labor given by:

$$Y_t^*(i) = Z_t N_t^*(i) \tag{4}$$

where Z_t is labour augmenting productivity. Its growth rate, $z_t = \log(Z_t/Z_{t-1})$, follows a unit root with drift:

$$z_t = \mu + u_{z,t} \tag{5}$$

where $u_{z,t} \sim N(0, \sigma_z^2)$. Real marginal costs are equal across firms and given by:

$$MC_{R,t}^* = \frac{W_t^*}{P_t^* Z_t} \tag{6}$$

A competitive final good producer combines intermediate goods using the aggregator $Y_t^* = \left[\int_0^1 Y_t^*(i)^{1-\frac{1}{\epsilon_t^*}} dj\right]^{\frac{\epsilon_t^*}{\epsilon_t^*-1}}$. Final good producer's profit maximization implies a demand function of the form:

$$Y_t^*(i) = \left[\frac{P_t^*(i)}{P_t^*}\right]^{-\epsilon_t^*} Y_t^* \tag{7}$$

where ϵ_t^* is the elasticity of substitution between intermediate goods which follows the process:

$$\log(\epsilon_t^*) = (1 - \rho_{\epsilon^*}) \log(\epsilon^*) + \rho_{\epsilon^*} \log\left(\epsilon_{t-1}^*\right) + u_{\epsilon^*,t} \tag{8}$$

where $u_{\epsilon^*,t} \sim N(0, \sigma_{\epsilon^*}^2)$.

Price-setting

As standard in this literature, we assume Calvo pricing: each firm may reset its price with probability $1 - \theta^*$ each period, independently of the time of the last price readjustment. The firm's pricing problem is:

$$\max_{P_t^*(i)} \sum_{k=0}^{\infty} (\beta\theta^*)^k E_t \left\{ \frac{\Lambda_{t+k}^* P_t^*}{\Lambda_t^*} \left[\frac{P_t^*(i)\overline{\Pi}^{*k}}{P_{t+k}^*} Y_{t+k}^*(i) - MC_{R,t+k}^* Y_{t+k}^*(i) \right] \right\} \tag{9}$$

where $\overline{\Pi}^*$ is the steady-state level of inflation in the large economy and Λ_{t+k}^* measures the marginal utility value to the representative household of an additional unit of real profits at $t + k$.

Monetary Policy and Market Clearing

The large economy's monetary policy authority follows a reaction function that responds to the deviation of inflation from target as well as the level and growth rate of output:

$$\frac{R_t^*}{R^*} = \left[\frac{R_{t-1}^*}{R^*} \right]^{\rho_R^*} \left[\left(\frac{\Pi_t^*}{\overline{\Pi}^*} \right)^{\varphi_\pi^*} \left(\frac{Y_t^*}{Y_{t-1}^* \mu} \right)^{\varphi_g^*} \left(\frac{Y_t^*}{Z_t} \right)^{\varphi_y^*} \right]^{1-\rho_R^*} e^{u_{R,t}^*} \tag{10}$$

where R^* is the steady-state nominal interest rate and $u_{R^*,t} \sim N(0, \sigma_{R^*}^2)$ is a monetary policy shock.

Finally, goods market clearing requires that:

$$Y_t^* = C_t^* \tag{11}$$

2.2 The Small Economy

Households

The small economy is populated by a representative household that maximizes expected lifetime utility given by:

$$\sum_{t=0}^{\infty} \beta^t \left[\left(\xi_t \log(C_t - hC_{t-1}) - A_L \frac{N_t^{1+\phi}}{1+\phi} + A_S \log(K_{S,t}) \right) \right] \tag{12}$$

subject to the budget constraint:

$$P_tC_t+P_tI_{B,t}+P_tI_{S,t}+(1+\zeta)\frac{D_{G,t+1}}{R_{H,t}}+(1+\zeta)\frac{\mathcal{E}_tD_{F,t+1}}{R^H_{F,t}} \leq \frac{R_{B,t}K_{B,t}}{1+\zeta}+D_{G,t}+\mathcal{E}_tD_{F,t}+W_tN_t+P_tT_t \quad (13)$$

where ξ_t, P_t, C_t, W_t, T_t and N_t are the small economy counterparts of the starred variables for the large economy. $K_{S,t}$ and $K_{B,t}$ denote the stocks of housing and business capital. $I_{S,t}$ and $I_{B,t}$ are residential and business investment. And A_L and A_S are normalizing constants.

At time t, the household purchases $(1+\zeta)D_{G,t+1}$ units of domestic debt and $(1+\zeta)\mathcal{E}_tD_{F,t+1}$ units of foreign debt at price $1/R_{H,t}$ and $1/R^H_{F,t}$. $\mathcal{E}_t$ represents the nominal exchange rate, defined as the number of units of domestic currency needed to purchase one unit of foreign currency. At time $t+1$, the household receives $D_{G,t+1}$ and $\mathcal{E}_{t+1}D_{F,t+1}$ units of local currency.[3]

The term $1+\zeta$ is a steady-state risk premium attached to borrowing and lending in the small economy. We include this term as a reduced form device to account for the possibility that, prior to euro entry, concerns about macroeconomic and exchange-rate instability led investors to demand a higher steady state return for investments in Spain. Its effect is to create a wedge between the model's steady state rates of return, and their usual determinants such as the household discount rate, β and growth rate of productivity, μ. For example, the steady state of $R_{H,t}$ is:

$$R_H = \frac{(1+\zeta)\mu}{\beta} \quad (14)$$

Similar wedges appear in the steady states of the other rates of return in the small economy, including the rate of return on capital.[4] A positive value of ζ increases required rates of return in the small economy, lowering the steady state capital-to-labor

[3]We assume that the proceeds of the wedges, $\zeta D_{G,t+1}$ and $\zeta\mathcal{E}_{t+1}D_{F,t+1}$, are reimbursed in a lump-sum manner to the small economy's households.

[4]The presence of $1+\zeta$ in the return to capital in Equation 13 means that the risk premium on borrowing from abroad prior to Spains entry into the euro spills over into a higher required return on *domestic* borrowing and lending (Estrada et al. (2009)).

ratio, and reducing the level of economic activity.

In the empirical application, we set the parameter ζ equal to zero after Spain adopts the euro and estimate its value prior to that time. If the parameter ζ is non-zero then euro entry will affect the steady state of the economy's real variables, as well as inflation and nominal interest rates.

The capital stock of each type evolves according to the law of motion:

$$K_{j,t+1} = (1-\delta)K_{j,t} + \Upsilon_{j,t}\left(1 - F_{j,t}\left(\frac{I_{j,t}}{I_{j,t-1}}\right)\right)I_{j,t} \tag{15}$$

where $j \in \{B, S\}$. $\Upsilon_{j,t}$ is a shock to the efficiency of investment of type j that follows a first order autoregressive process in logs.

$$\log(\Upsilon_{j,t}) = \rho_{\Upsilon_j} \log(\Upsilon_{j,t-1}) + u_{\Upsilon_j,t} \tag{16}$$

For housing investment, a shock to $\Upsilon_{S,t}$ has similar effects to a shock to housing preferences in the household's utility function.

The parameter δ is the depreciation rate, and the adjustment cost function $F_{j,t}$, which satisfies the Christiano et al. (2005) assumptions, is given by:

$$F_{j,t}\left(\frac{I_{j,t}}{I_{j,t-1}}\right) = \frac{\varphi_{K,j}}{2}\left(\frac{I_{j,t}}{I_{j,t-1}} - \mu\right)^2 \tag{17}$$

where $\varphi_{K,j}$ controls the size of investment adjustment costs for capital of type j and μ is the growth rate of productivity in steady state.

Firms

There are five types of firms in the domestic economy: domestic intermediate producers, domestic final good producers, importers, exporters, and domestic final goods retailers. We describe each sector in turn.

Domestic Goods Producers

Intermediate producing firms have access to a Cobb-Douglas technology which combines labor and business capital:

$$Y_{H,t}(i) = (Z_t N_t(i))^{\alpha} \left(K_{B,t}(i)\right)^{1-\alpha} \tag{18}$$

where Z_t is a labour augmenting productivity, common to the large and small economies.[5]

Firms are subject to working capital constraints and finance their wage bill in advance.[6] The interest rate on working capital loans is the household interest rate, $R_{H,t}$.

Firms face Calvo price-stickiness, with the parameter θ denoting the degree of price rigidity. The firm's pricing problem is given by:

$$\max_{P_t(i)} \sum_{k=0}^{\infty} (\beta\theta)^k E_t \left\{ \frac{\Lambda_{t+k} P_t}{\Lambda_t} \left[\frac{P_{H,t}(i) Y_{t+k}(i) \Pi^k}{P_{t+k}} - \frac{MC_{t+k}}{P_{t+k}} Y_{t+k}(i) \right] \right\} \tag{19}$$

where MC_t denotes nominal marginal cost, which is equal across firms and given by $MC_t = \alpha^{-\alpha}(1-\alpha)^{-(1-\alpha)} \left(\frac{R_{H,t} W_t}{P_t Z_t}\right)^{\alpha} \left(R_{B,t}\right)^{1-\alpha}$.

Domestic Final Goods Retailers

The domestically-produced final good, $Y_{H,t}$ is assembled by a perfectly competitive domestic final good retailer that combines domestically-produced intermediate goods using the technology:

$$Y_{H,t} = \left[\int_0^1 Y_{H,t}(i)^{\frac{\epsilon_t - 1}{\epsilon}} di \right]^{\frac{\epsilon_t}{\epsilon_t - 1}} \tag{20}$$

[5]A common unit root in labour augmenting productivity in the large and small economies is necessary to ensure the existence of a balanced growth path. Previous work has found that differential productivity processes are important in explaining the behaviour of traded and non-traded sectors in small open economies (Rabanal (2009) and Kulish and Rees (2017)). Unlike these papers, however, we do not model the traded and non-traded sectors separately.

[6]The inclusion of a working capital channel creates an alternative mechanism to technology and markup shocks that can move output and inflation in opposite directions.

where ϵ_t denotes the elasticity of substitution across varieties that follows the process:

$$\log(\epsilon_t) = (1-\rho_\epsilon)\log(\epsilon) + \rho_\epsilon \log(\epsilon_{t-1}) + u_{\epsilon,t} \tag{21}$$

where $u_{\epsilon,t} \sim N(0, \sigma_\epsilon^2)$.

Importers

Importers bring in homogeneous products from abroad at price $\mathcal{E}_t P_t^*$ and differentiate them by branding them. The differentiated imports are combined into the imported consumption good using the CES technology:

$$Y_{F,t} = \left[\int_0^1 Y_{F,t}(i)^{\frac{\epsilon_{F,t}-1}{\epsilon_{F,t}}} di\right]^{\frac{\epsilon_{F,t}}{\epsilon_{F,t}-1}} \tag{22}$$

with the corresponding price index $P_{F,t} = \left[\int_0^1 P_{F,t}(i)^{1-\epsilon_{F,t}} di\right]^{\frac{1}{1-\epsilon_{F,t}}}$ and the elasticity of substitution $\epsilon_{F,t}$. The latter follows the process:

$$\log\left(\epsilon_{F,t}\right) = (1-\rho_{\epsilon_F})\log(\epsilon_F) + \rho_{\epsilon_F} \log\left(\epsilon_{F,t-1}\right) + u_{\epsilon_F,t} \tag{23}$$

where $u_{\epsilon_F,t} \sim N(0, \sigma_{\epsilon_F}^2)$.

Consequently, each importer faces the demand curve:

$$Y_{F,t}(i) = \left(\frac{P_{F,t}(i)}{P_{F,t}}\right)^{-\epsilon_{F,t}} Y_{F,t} \tag{24}$$

Importers face standard Calvo pricing frictions. The probability of resetting the price for importers equals $1-\theta_F$. The problem is:

$$\max_{P_{F,t}(i)} \sum_{k=0}^{\infty} (\beta\theta_F)^k E_t \left\{ \frac{\Lambda_{t+1} P_t}{\Lambda_t} \left[\frac{P_{F,t}(i) Y_{F,t}(i) \Pi^k}{P_{t+k}} - \frac{\mathcal{E}_{t+k} P_{t+k}^* Y_{F,t+k}(i)}{P_{t+k}} \right] \right\} \tag{25}$$

subject to the demand constraint above.

Exporters

Exporters buy a bundle of domestically produced goods at price $P_{H,t}$ and differentiate it through branding for sale in the foreign economy. A retailer bundles these goods before selling them overseas according to the technology:

$$X_t = \left[\int_0^1 X_t(i)^{\frac{\epsilon_{X,t}-1}{\epsilon_{X,t}}} (i) \right]^{\frac{\epsilon_{X,t}}{\epsilon_{X,t}-1}} \tag{26}$$

with corresponding price index in foreign currency equal to $P^*_{X,t} = \left[\int_0^1 P^*_{X,t}(i)^{1-\epsilon_{X,t}} di \right]^{\frac{1}{1-\epsilon_{X,t}}}$ and elasticity of substitution between varieties of $\epsilon_{X,t}$. The latter follows the process:

$$\log\left(\epsilon_{X,t}\right) = (1-\rho_{\epsilon_X}) \log(\epsilon_X) + \rho_{\epsilon_X} \log\left(\epsilon_{X,t-1}\right) + u_{\epsilon_X,t} \tag{27}$$

where $u_{\epsilon_X,t} \sim N(0, \sigma^2_{\epsilon_X})$.

The export retailer faces the following demand function:

$$X_t = \nu \left(\frac{P^*_{X,t}}{P^*_t} \right)^{-\eta_F} Y^*_t \tag{28}$$

where $P^*_{X,t}$ is the foreign-currency price of the bundle of exported goods, ν is a normalizing constant and η_F is the elasticity of demand for the small economy's goods in the large economy.

The demand for each exporter's goods are given by:

$$X_t(i) = \left(\frac{P^*_{X,t}(i)}{P^*_{X,t}} \right)^{-\epsilon_{X,t}} X_t \tag{29}$$

The firm's problem under sticky prices is:

$$\max_{P^*_{X,t}(i)} \sum_{k=0}^{\infty} (\beta\theta_S)^k E_t \left\{ \frac{\Lambda_{t+1} P_t}{\Lambda_t} \left[\frac{P^*_{X,t}(i) \Pi^k X_{t+k}(i) \mathcal{E}_{t+k}}{P_{t+k}} - \frac{P_{H,t+k} X_{t+k}(i)}{P_{t+k}} \right] \right\} \tag{30}$$

subject to the demand constraint given above.

Final Goods Retailers

Final goods retailers produce final goods using domestically-produced and imported consumption goods using the technology:

$$DFD_t = \left[(1-\nu)^{\frac{1}{\eta}}\left(Y^D_{H,t}\right)^{\frac{\eta-1}{\eta}} + \nu^{\frac{1}{\eta}}\left(Y_{F,t}\right)^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}} \tag{31}$$

where $Y^D_{H,t}$ denotes the home-produced goods consumed in the small economy -not exported- and $Y_{F,t}$ is the foreign good. The parameter η is the elasticity of substituion between domestic and imported goods. The price index corresponding to this bundle is:

$$P_t = \left[(1-\nu)\left(P_{H,t}\right)^{1-\eta} + \nu\left(P_{F,t}\right)^{1-\eta}\right]^{\frac{1}{1-\eta}} \tag{32}$$

The final good retailer's demands for each good are given by:

$$Y^D_{H,t} = (1-\nu)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} DFD_t; \qquad Y_{F,t} = \nu\left(\frac{P_{F,t}}{P_t}\right)^{-\eta} DFD_t \tag{33}$$

Government

The government issues debt and raises lump-sum taxes to finance an exogenous flow of government expenditure, G_t. The ratio of government expenditure to GDP evolves according to:

$$\log\left(\frac{G_t}{Y_t}\right) = (1-\rho_g)g + \rho_g \log\left(\frac{G_{t-1}}{Y_{t-1}}\right) + u_{G,t} \tag{34}$$

The government's budget constraint is given by:

$$\frac{B_{G,t+1}}{R_{G,t}} + T_t = G_t + \frac{B_{G,t}}{\Pi_t} \tag{35}$$

where $B_{G,t} \equiv D_{G,t}/P_t$ and $R_{G,t}$ is the interest rate at which the government borrows. Lump-sum taxes follow a rule to stabilise government debt as a share of GDP:

$$\frac{T_t}{Y_t} = \tau \times \left(\frac{B_{G,t+1}/Y_t}{b_G}\right)^{\varphi_{T,b}} e^{\epsilon_{\tau,t}} \tag{36}$$

where τ is the steady state ratio of taxes over GDP, b_G is the steady state ratio of government debt as a share of GDP and $\epsilon_{\tau,t}$ is an exogenous process that follows an AR(1) process in logs:

$$\log\left(\epsilon_{\tau,t}\right) = \rho_\tau \log\left(\epsilon_{\tau,t-1}\right) + u_{\tau,t} \tag{37}$$

where $u_{\tau,t} \sim N(0, \sigma_\tau^2)$. Because we assume that taxes are lump sum, the main impact of shocks to $\epsilon_{\tau,t}$ comes through its effect on the level of public debt.

Interest Rate Spreads

The interest rates paid by households and firms are related to, but can diverge from, the policy interest rate set by the central bank, R_t.

The interest rate spread on government borrowing, denoted by $\Omega_{G,t}$, depends on the deviation of the public debt-to-GDP ratio from its steady state value and an exogenous sovereign risk premium, $\xi_{G,t}$:[7]

$$\Omega_{G,t} = \frac{R_{G,t}}{R_t} = E_t\left\{\left(\frac{B_{G,t+1}/Y_t}{b_G}\right)^{\psi_{G,k}} e^{\xi_{G,t}}\right\} \tag{38}$$

The term $\psi_{G,k}$, $k \in \{O, I\}$, controls the responsiveness of the government spread to the level of public debt. The value of this parameter can vary depending on whether the economy is outside (O) or inside (I) a currency union. The idiosyncratic component of the spread, $\xi_{G,t}$, follows the process:

$$\log(\xi_{G,t}) = \rho_{\xi_{G,k}} \log(\xi_{G,t-1}) + u_{\xi_G,t} \tag{39}$$

where $u_{\xi_G,t} \sim N\left(0, \sigma^2_{G,k}\right)$ and $k \in \{O, I\}$. We allow both the persistence and variance of $\xi_{G,t}$ (and the model's other risk premia shocks) to vary according to whether Spain has an independent monetary policy or is in the euro area.

The spread between the interest rates faced by households and firms and the policy

[7] Unlike ζ which is a permanent risk premium that affects the model's steady state, $\xi_{G,t}$, $\xi_{H,t}$ and $\xi_{F,t}$ have a transitory effect on borrowing costs.

rate, $\Omega_{H,t}$ is given by:

$$\Omega_{H,t} = \frac{R_{H,t}}{R_t} = \left[\Omega_{G,t}\right]^{\psi_H} e^{\xi_{H,t}} \tag{40}$$

This term has two components. The first, $\left[\Omega_{G,t}\right]^{\psi_H}$, is a spillover from the government bond spread to the household spread. The second, $\xi_{H,t}$, is an idiosyncratic household risk premium that follows the process:

$$\log\left(\xi_{H,t}\right) = \rho_{\xi_{H,k}} \log\left(\xi_{H,t-1}\right) + u_{\xi_H,t} \tag{41}$$

where $u_{\xi_H,t} \sim N\left(0, \sigma^2_{H,k}\right)$ and $k \in \{O, I\}$.

The household interest rate spread, $\Omega_{H,t}$ also influences the interest rate faced by households when borrowing from abroad:

$$R^H_{F,t} = R^*_t \Omega_{H,t} \Omega_{F,t} \tag{42}$$

where $\Omega_{F,t}$ is the wholesale spread between the interest rate on borrowing from abroad and the foreign policy rate, given by:

$$\Omega_{F,t} = \frac{R_{F,t}}{R^*_t} = (1+\zeta)\left[\frac{B_{F,t+1}/Y_t}{b_F}\right]^{\psi_F} e^{\xi_{F,t}} \tag{43}$$

where $B_{F,t+1} = D_{F,t+1}/P_t$ is the real value of net Spanish overseas asset holdings (that is, Spanish holdings of overseas assets less Spanish assets owned by foreigners). This term depends on the small economy's steady state risk premium, ζ, the level of Spanish net overseas assets, $\left[\frac{B_{F,t+1}/Y_t}{b_F}\right]^{\psi_F}$, and an idiosyncratic risk premium shock, $\xi_{F,t}$.[8] The latter follows the process:

$$\log\left(\xi_{F,t}\right) = \rho_{\xi_{F,k}} \log\left(\xi_{F,t-1}\right) + u_{\xi_F,t} \tag{44}$$

where $u_{\xi_F,t} \sim N\left(0, \sigma^2_{F,k}\right)$ and $k \in \{O, I\}$.

[8] The response to Spanish borrowing from abroad ensures that the economy's net foreign asset position is stationary.

Market Clearing and the Current Account

Market clearing for the domestically-produced final good retailer requires that all production is sold either at home or abroad:

$$Y_{H,t} = Y_{H,t}^{D} + X_t \tag{45}$$

Market clearing for the final good retailer requires that all production is either consumed by households, invested or demanded by the government:

$$DFD_t = C_t + I_{B,t} + I_{S,t} + G_t \tag{46}$$

The current account equation relates the accumulation of net foreign assets, $D_{F,t}$, to the trade balance:

$$\frac{\mathcal{E}_t D_{F,t+1}}{R_{F,t}^{H}} = \mathcal{E}_t D_{F,t} + \mathcal{E}_t P_{X,t}^{*} X_t - \mathcal{E}_t P_t^{*} Y_{F,t} \tag{47}$$

Monetary Policy Before and After Euro Entry

Before adopting the euro, the Spanish monetary authorities follow a reaction function that responds to the Spanish CPI inflation rate, the level and growth rate of Spanish output, and the change in the nominal exchange rate:

$$\frac{R_t}{R} = \left[\frac{R_{t-1}}{R}\right]^{\rho_{R,j}} \left[\left(\frac{\Pi_t}{\overline{\Pi}_j}\right)^{\varphi_{\pi,j}} \left(\frac{Y_t}{Y_{t-1}\mu}\right)^{\varphi_{g,j}} \left(\frac{Y_t}{Z_t}\right)^{\varphi_{y,j}} \left(\frac{\mathcal{E}_t}{\mathcal{E}_{t-1}}\right)^{\varphi_{\mathcal{E},j}}\right]^{1-\rho_{R,j}} e^{u_{R,t}} \tag{48}$$

for $j \in \{i, m\}$ where $\overline{\Pi}_j$ is the Spanish inflation target, R is the steady-state Spanish nominal interest rate and $u_{R,t}$ is a monetary policy shock.

As we discuss in the next section, we allow for two Spanish monetary policy regimes prior to joining the euro, an initial regime (i) and an intermediate regime (m). We do this to account for a change in the conduct of policy when Spain adopted an explicit inflation target in the mid-1990s. We allow the shift in the policy rule to alter the response of interest rates to inflation, output and the exchange rate, as well to change the inflation target.

After joining the euro, Spain no longer has an independent monetary policy. To implement this in the model, we replace the Spanish monetary policy reaction function with the restriction that the nominal exchange rate must be constant:

$$\frac{\mathcal{E}_t}{\mathcal{E}_{t-1}} = 1 \tag{49}$$

To understand the operation of monetary policy within the currency union note that, regardless of Spain's monetary policy arrangements, uncovered interest rate parity (UIP) must hold:

$$R_t = (1+\zeta)R_t^* E_t\left\{\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t}\right\}\left[\frac{B_{F,t+1}/Y_t}{b_F}\right]^{\psi_F} e^{\xi_{F,t}} \tag{50}$$

Before Spain joins the euro, monetary policy in Spain and abroad controls R_t and R_t^*. Conditional on these policy rates and the risk-premium term, the UIP condition then determines the expected change in the Spanish exchange rate. After euro entry the expected change in the exchange rate is zero, and R_t is no longer under the control of the Spanish monetary authorities. Therefore, the UIP condition condition determines the Spanish policy interest rate, which reflect three forces. The first is the policy rate in the euro area, R_t^*. The second is the small systematic response to Spanish borrowing from abroad to ensure stationarity. The third is a time-varying country risk premium that foreign investors demand when lending to Spanish borrowers, $\xi_{F,t}$. Euro entry may not eliminate the time-varying foreign risk premium.[9] But whereas prior to euro entry the risk premium showed up largely as an exogenous movement in the nominal exchange rate, after euro entry it affects the Spanish economy primarily as a common shock to the interest rates faced by Spanish households, firms and the government.

[9] Although all central banks in the euro area set the same policy rate, interest rates in the interbank market - the first stage of the monetary transmission mechanism - can vary between countries. As variations in interbank rates affect interest rates at all further stages of the monetary transmission mechanism, we consider these to be equivalent to variation in the policy interest rate. Frutos et al. (2016) document departures from the ECB policy rate in the Spanish interbank market during the sovereign debt crisis.

2.3 Model Solution with Structural Change

We apply the solution methods proposed in Kulish and Cagliarini (2013) and Kulish and Pagan (2017) and the estimation method of Kulish et al. (2017). Because these methods have more general application than the context we are considering, we discuss how the methods apply to our case.

In estimation, we allow for two breaks in Spain's monetary policy framework. The most obvious break occurred when Spain joined the euro in 1999Q1. We denote the date of this structural break as T_b. Of course, the introduction of the euro was widely anticipated before 1999. To account for this, we allow agents to incorporate future euro entry into their expectations from some earlier date, $T_a < 1999Q1$. Unlike the date at which Spain joined the euro, which is a known parameter, we must estimate T_a.

The second break in the policy framework captures the adoption of inflation targeting in the mid-1990s. We model this break by allowing for, but not requiring, a change in the parameters of the Spanish monetary policy reaction function, including the inflation target. We denote the date of this break in regime as T_m. There is some uncertainty about this date. The Banco de Espana officially labelled itself an inflation targeting central bank in November 1994. However, because of concerns about the consequences of an increase in consumption taxes in 1995, it did not set a target for inflation until 1996. In light of this uncertainty, we also estimate T_m.

We now describe how we solve the model accounting for structural change in the Spanish monetary policy rule. For clarity, we show this for the case of a single anticipated change in the policy rule associated with entry into the euro. It is straightforward to extend the approach to allow for an additional break in the Spanish policy reaction function prior to euro entry.

From period $t = 1, 2, \ldots, T_a - 1$ Spanish monetary authorities operate an independent monetary policy and agents expect this regime to continue. The first order approximation to the equilibrium conditions around the initial steady state is a system of n

equations that we will write as:

$$\mathbf{A}x_t = \mathbf{C} + \mathbf{B}x_{t-1} + \mathbf{D}E_t x_{t+1} + \mathbf{F}w_t \tag{51}$$

where x_t is the state vector and w_t is the vector of structural shocks, which we take to be *iid* without loss of generality. If the rational expectations solution to Equation 51 exists and is unique it will be a VAR of the form:

$$x_t = \mathbf{J} + \mathbf{Q}x_{t-1} + \mathbf{G}w_t \tag{52}$$

where the matrices J, Q and G are constructed in the standard way by the method of undetermined coefficients. From period $t = T_b, T_b + 1, \ldots, T$ Spain is part of the euro area. The first order approximation to the equilibrium conditions around the final steady state is a system of n equations that we will write as:

$$\mathbf{A}^* x_t = \mathbf{C}^* + \mathbf{B}^* x_{t-1} + \mathbf{D}^* E_t x_{t+1} + \mathbf{F}^* w_t \tag{53}$$

where the superscript $*$ denotes the matrices corresponding to the model equations when Spain is part of the euro zone.[10] The reduced form solution from this point on is simply $x_t = \mathbf{J}^* + \mathbf{Q}^* x_{t-1} + \mathbf{G}^* w_t$.

In the period $t = T_a, T_a + 1, \ldots, T_b - 1$ Equation 51 continues to describe the structure of the model solution. However, in constructing expectations one now has to account for the fact that Spanish residents expect to join the euro zone in period T_b. Following Kulish and Pagan (2017), the solution may be written as a time-varying VAR of the form:

$$x_t = \mathbf{J}_t + \mathbf{Q}_t x_{t-1} + \mathbf{G}_t w_t \tag{54}$$

Equation 54 implies that expectations are $E_t x_{t+1} = \mathbf{J}_{t+1} + \mathbf{Q}_{t+1} x_t$. Substituting these

[10]Note that in Equation 53 we account for the fact that entry to the euro alters the steady state around which we log-linearize the equations.

expectations into Equation 51 implies that at period t:

$$\mathbf{A}x_t = \mathbf{C} + \mathbf{B}x_{t-1} + \mathbf{D}\left(\mathbf{J}_{t+1} + \mathbf{Q}_{t+1}x_t\right) + \mathbf{F}w_t \tag{55}$$

which implies by the method of undetermined coefficients the following recursions:

$$\begin{aligned}
\mathbf{J}_t &= \left[\mathbf{A}_t - \mathbf{D}_t\mathbf{Q}_{t+1}\right]^{-1}\left(\mathbf{C} + \mathbf{D}\mathbf{J}_{t+1}\right) \\
\mathbf{Q}_t &= \left[\mathbf{A}_t - \mathbf{D}_t\mathbf{Q}_{t+1}\right]^{-1}\mathbf{B} \\
\mathbf{G}_t &= \left[\mathbf{A}_t - \mathbf{D}_t\mathbf{Q}_{t+1}\right]^{-1}\mathbf{F}
\end{aligned}$$

The backward recursion of time-varying reduced form matrices, $\{\mathbf{Q}_t\}_{t=T_a}^{T_b-1}$ starts from the terminal condition $\mathbf{Q}_{T_b} = \mathbf{Q}^*$ and works its way back to T_a, yielding a system of time-varying reduced form matrices.[11] From the sequence for $\mathbf{Q}_t$, the sequence for $\mathbf{G}_t$ may be computed as well. One can then compute the sequence for $\mathbf{J}_t$ using the sequence for $\mathbf{Q}_t$ and the terminal condition $\mathbf{J}_{T_b} = \mathbf{J}^*$.

2.4 Transition to a Currency Union

In this section, we describe the consequences of a pre-announced transition to a currency union and discuss features that aid identification of the structural parameters associated with this transition.

To construct the exercise, we first set all of the model's parameter values, except for the country risk premium parameter, ζ, to the prior means listed in Table 1. We set ζ equal to 0.004. This value is somewhat arbitrary and is chosen to illustrate the mechanisms at work. It is, however, a plausible choice, as it lies well within the posterior distribution of this parameter in our empirical estimates in Table 1. We then simulate the model for 60 quarters, setting all stochastic shocks equal to zero. For the first 30 quarters, the small economy has an independent monetary policy. At

[11] Because agents know the structure of the economy from time T_b onwards, at each step in the recursion from $T_{b-1}, T_{b-2}, \ldots, T_a$ Q_{t+1} and J_{t+1} are measurable at time t.

the end of quarter 30 it enters a currency union with the large economy. Agents first incorporate the future change in monetary arrangements into their expectations at the start of quarter 15, four years before the small economy enters the currency union.

[Figure 1 about here.]

Figure 1 shows the result of the exercise. For the first 15 quarters all variables are at their initial steady state values. For the small economy, this corresponds to an annualised inflation rate of 3 per cent and a nominal policy rate of around 7 per cent. As the small economy's steady state inflation rate is higher than that of the large economy, its nominal exchange rate depreciates at a rate that exactly offsets the inflation differential, ensuring that the real exchange rate is constant.

Entering a currency union has consequences for both the nominal and real sides of the economy. For the nominal variables, entering a currency union entails a reduction in inflation and nominal interest rates. The fall in inflation is equal to the difference between the small economy's inflation target prior to entering the currency union and the inflation target of the currency union. Nominal interest rates decline by slightly more than inflation because of the elimination of the small economy's steady state risk premium after it enters the currency union.

For the real side of the economy, the most long-lasting effect of entering a currency union comes from the elimination of the steady state risk premium. This lowers the required rate of return on capital and raises the steady-state capital-to-labour ratio. This, in turn means that the steady state values of output, consumption and investment are permanently higher as a result of entering the currency union.

Another consequence of the reduction in the country risk premium is to reduce interest payments on the economy's stock of net foreign liabilities. Lower interest payments allow the economy to stabilise its net foreign liability position with a lower trade surplus (or larger deficit). As a result, the long-run increase in aggregate demand exceeds the long-run increase in aggregate supply from the larger capital stock, implying that the trade balance is permanently lower.

In addition to the changes in the steady state of the small economy, the anticipation of entering a currency union in the future induces a transition that has implications for the paths of the small economy's endogenous variables. The transition begins as soon as agents incorporate future currency union entry into their expectations and occurs even in the absence of stochastic shocks.

Because firms set prices in a forward-looking manner, the expectation of lower inflation in the future reduces inflation in the present. Rather than displaying a discrete break when the small economy enters the currency union, inflation starts to drift downwards as soon as agents learn of the future change in monetary policy arrangements. As the small economy's monetary authorities continue to follow their standard reaction function, the fall in inflation causes nominal interest rates to decrease. Lower inflation also reduces the pace of nominal exchange rate depreciation in the years leading up to currency union entry.

On the real side of the economy, the anticipation of currency union entry induces a boom in economic activity. Some of this boom reflects the anticipation of a lower country risk premium and real interest rate, allowing the small economy to finance increased consumption and investment levels after entry to the currency union. As for firms, because households are forward-looking the expectation of lower real cost of borrowing in the future increases consumption and investment in the present.

The existence of a transition across a range of observable variables allows our estimation procedure to identify the date at which Spanish households and firms first incorporated entry into the euro into their expectations. This date corresponds to the start of the transition. It also helps to identify some of the structural parameters, for example the Spanish inflation target prior to euro-entry, as these parameters influence the size and shape of the transition.

3 Estimation

We estimate our model using Bayesian methods, as is common in the DSGE literature. Our case, however, is non-standard because we allow for structural change and jointly estimate two sets of distinct parameters: the structural parameters of the model, ϑ, that have continuous support, and the unknown dates of the structural breaks, $\mathbf{T} = \{T_a, T_m\}$, that have discrete supports.

The joint posterior density of ϑ and $\mathbf{T}$ is:

$$p(\vartheta, \mathbf{T}|\mathcal{Y}) \propto \mathcal{L}(\mathcal{Y}|\vartheta, \mathbf{T})\, p(\vartheta, \mathbf{T}) \tag{56}$$

where $\mathcal{Y} \equiv \{y_t^{obs}\}_{t=1}^{T}$ is the data and y_t^{obs} is a $n^{obs} \times 1$ vector of observable variables. $\mathcal{L}(\mathcal{Y}|\vartheta, \mathbf{T})$ is the likelihood. The priors of the structural parameters are taken to be independent, so that $p(\vartheta, \mathbf{T}) = p(\vartheta)\, p(\mathbf{T})$. We use a flat prior for each element of $\mathbf{T}$ so $p(\mathbf{T}) \propto 1$, which is proper given its discrete support.

3.1 Priors and Data

Our estimation sample spans 1988Q1 to 2016Q2. The observable variables for the large economy are euro-area GDP growth, core inflation and the ECB policy rate.[12] We exclude Spain from the calculation of the euro-area GDP and inflation series. The observable variables for Spain are the growth rates of GDP, consumption, residential construction investment and non-residential investment, core inflation, government spending, and, for the period before 1999Q4 the change in the Peseta-Deutsche mark nominal exchange rate. We also include as observable variables the public debt-to-GDP ratio and three measures of interest rates; the mortgage rate, the spread between ten-year government borrowing rates in Spain and Germany and, until Spain entered the euro area in 1999Q1, the Spanish policy rate.[13] The Spanish residential

[12] For the period before 1999 we use the German GDP, inflation and interest rate data.

[13] The model's counterpart for the mortgage rate is the interest rate faced by households and firms borrowing domestically, $r_{H,t}$. For the mortgage rate, we use the interest rate on new housing loans.

investment series begins in 1995Q1. For the period before this we treat aggregate investment (that is, the sum of residential and non-residential investment) as an observable variable. Figure 2 plots the data series that we use in estimation. All data are seasonally adjusted. GDP and its components are expressed in per capita terms.

[Figure 2 about here.]

[Figure 3 about here.]

We calibrate a number of parameters that are likely to be poorly identified using the observable data series. We set the parameter governing the elasticity of labour supply, ϕ , to 1.0, which is a standard value in the literature and is the same calibration used in Rabanal (2009) and Andres et al. (2010). We set the labor share in domestic goods production, a, to 0.7, which is a standard value in the literature and similar to the one used in Burriel et al. (2010) and Veld et al. (2015). We set the parameter governing the share of imports in the Spanish consumption basket, ν, to 0.27 to match the average share of imports in GDP seen in the data, the foreign asset position in steady state b_F to 2.0 to match the average Spanish trade deficit, the steady-state public debt-to-GDP ratio b_G equal to 60 per cent, the normalizing parameter associated with housing in the utility function, A_S, to 0.18 and the quarterly investment depreciation rates to 0.01 to match various shares in the data. The latter calibrations ensure that the model matches observed residential and business investment share of GDP. We set the elasticity of substitution between Spanish and euro-area goods, η, to 0.8, which is roughly the midpoint of the estimates in the literature (e.g. Rabanal (2009) and Veld et al. (2015)). We set the same value for the large–economy counterpart of this elasticity, η_F. We also set the elasticity of the foreign rate spread to the foreign debt level, ψ_F, to 0.001. This is small enough to have little effect on the dynamics of the model while ensuring that foreign debt is stationary. We set the same value for the

As most Spanish homeowners hold adjustable rate mortgages, this measure also reflects the average interest rate on existing loans. Corporate borrowing rates are highly correlated with mortgage rates over our sample.

elasticity of the government rate spread to the ratio of government debt over GDP, $\psi_{G,O}$, for the period before euro entry. We set $\psi_{G,I}$ to 0.004 for the period after euro entry following the empirical evidence on elasticity of demand for sovereign debt for OECD economies before and after the financial crisis (Ardagna et al. (2006) and Grande et al. (2013)). To put these parameters in context, the initial value of $\psi_{G,O}$ implies that a 60 percentage point increase in the government debt-to-GDP ratio (roughly equivalent to that experienced by Spain between 2008 and 2014) raises the interest rate on public debt by 1.0 percentage points. The post-euro value of $\psi_{G,I}$ implies that a 60 percentage point increase in public debt raises the interest rate on public debt by 3.8 percentage points. Finally, following Corsetti et al. (2014), we set the response of the domestic spread to the government spread, ψ_H, to 0.5.

We estimate the remaining parameters using Bayesian methods. Most of our priors are standard in the literature. We center the prior on quarterly trend productivity growth, μ, at 0.35. This is roughly equal to the average growth rate of per capita GDP in Spain and the euro zone over our sample period. We center the euro area inflation target at 0.50 per cent in quarterly terms, consistent with the European Central Bank's (ECB) stated inflation target. For the initial Spanish inflation target we use a higher mean of 1.25 per cent in quarterly terms. For the intermediate Spanish inflation target, we use a mean of 0.75 per cent in quarterly terms. We use looser priors for the Spanish inflation targets than for the ECB's inflation target, reflecting our uncertainty about the value of these parameters. We pick a wide uniform prior for the steady state risk premium parameter, ζ, centered around 0.

The domain of the priors over T_a and T_m spans the period 1991Q1 to 1998Q4. The start date coincides with the opening of the negotiations for the Maastricht Treaty, which led to the creation of the euro. The end date represents the quarter immediately prior to the formation of the euro in 1999Q1. This is a plausible range for when agents could have incorporated future euro entry into their expectations, T_a. It also contains the date in which Banco de Espana officially labelled itself an inflation targeter in late 1994. We use the methods described in Kulish and Pagan (2017) to construct $\mathcal{L}(\mathcal{Y}|\vartheta, \mathbf{T})$.

3.2 Estimation Results

The left panel of Figure 4 shows the probability density function of the posterior distribution of the break in Spanish agents' beliefs about their economy's future monetary policy arrangements. Each bar shows the probability that Spaniards first incorporated the expectation of future euro entry at that date. The mode of the distribution occurs in 1997Q4, although there is around a 30 per cent probability that beliefs adjusted earlier. The relatively late adjustment in beliefs is consistent with the fact that euro membership was conditional on compliance with a series of requirements laid down in the Maastricht Treaty to ensure a high degree of nominal convergence among member countries and that, until the mid-1990s, Spain was one of the candidates for euro entry that was furthest from meeting these requirements (Estrada et al. 2009). In evaluating the performance of the Spanish economy outside the euro area we use information from the full posterior parameter distribution, including the distribution of T_a. This means that our results also account for the possibility that anticipation of euro entry affected the behaviour of Spanish economic variables prior to 1997Q4.

The right panel of Figure 4 shows the estimated date of the break in the Spanish monetary policy rule. Over 50 per cent of the probability mass lies in 1996Q3. This accords with the time for which the Banco de Espana first set a numerical target for inflation (Malo de Molina (2003)). This result reinforces the plausibility of the model and the estimation methodology. The estimation was free to pick any date between 1991Q1 to 1998Q4. That it chose the actual date at which Spain adopted an inflation target reflects the ability of the estimation method to capture accurately the effects of a shift in policy settings.

[Figure 4 about here.]

Table 1 show the results for the structural parameters that we estimate.

We estimate an inflation target for the ECB of just above 0.5 per cent in quarterly terms, consistent with their stated inflation target. For Spain, we estimate an initial inflation target of 1.4 per cent in quarterly terms. This is broadly in line with average inflation outcomes in Spain for the period 1988-1996, that is before the Spanish economy began its transition to euro entry and introduced inflation-targeting. After adopting inflation targeting, the estimated Spanish inflation target drops to 0.8 per cent. This is close to the Bank of Spain's publicly stated inflation target of 3.5 - 4 per cent when it adopted inflation targeting in 1996 (Bernanke et al. (1999)).[14]

Turning to the Spanish monetary reaction function, we estimate that Spanish monetary authorities displayed a relatively strong reaction to inflation, both before and after the mid-1990s break in monetary policy rule. The initial rule shows little responsiveness to the exchange rate and to the level and growth of output, with $\varphi_{y,i}$, $\varphi_{g,i}$ and $\varphi_{\Delta e,i}$ all insignificantly different from zero. After the break in the Spanish policy rule in 1996, the responsiveness to changes in the exchange rate increases.

The estimated responsiveness to inflation in the ECB monetary reaction function is consistent with other estimates in the literature (e.g. Smets and Wouters (2005) and Rabanal (2009)). The responses to the growth rate and level of output that we estimate are, however, slightly higher than in other papers.

We estimate the response of taxes to the debt level, $\varphi_{T,b}$, to be 0.8, which is smaller than the one calibrated by Corsetti et al. (2014). The relatively low value of this parameter is consistent with the fact that Spain's public-debt to GDP ratio has experienced large deviations from its mean value of 60 per cent over our sample.

We find a high degree of price stickiness in the euro area as a whole, as well as in domestic and import prices in Spain. This is a common result in DSGE models of Europe (e.g. Smets and Wouters (2005)). Spanish export prices, however, appear to

[14]By 1998, the Bank of Spain had lowered its stated inflation target to 2 per cent, in anticipation of entering the euro area. This lower target is also within the posterior distribution of the intermediate inflation target.

Table 1: Estimated parameters (*continued next page*)

	Prior			Posterior			
Parameter	Dist	Mean	Std Dev	Mode	Mean	5 percent	95 percent
h^*	B	0.50	0.15	0.36	0.35	0.25	0.46
θ^*	B	0.75	0.05	0.90	0.90	0.86	0.93
$100(\pi^* - 1)$	N	0.50	0.10	0.55	0.54	0.46	0.63
ρ_R^*	B	0.60	0.20	0.87	0.87	0.83	0.89
φ_π^*	N	1.75	0.20	1.35	1.34	1.01	1.71
φ_g^*	N	0.20	0.10	0.37	0.38	0.25	0.51
φ_y^*	N	0.20	0.10	0.30	0.30	0.18	0.43
100μ	N	0.35	0.05	0.28	0.28	0.21	0.34
$100(\beta - 1)$	G	0.50	0.10	0.38	0.38	0.28	0.49
h	B	0.50	0.15	0.68	0.68	0.60	0.77
400ζ	U	0.00	2.89	0.64	0.71	−0.19	1.79
θ	B	0.75	0.05	0.93	0.92	0.89	0.95
θ_F	B	0.75	0.05	0.87	0.86	0.79	0.92
θ_X	B	0.75	0.05	0.73	0.73	0.64	0.82
$\phi_{K,B}$	N	5.00	2.00	9.01	9.03	6.77	11.43
$\phi_{K,S}$	N	5.00	2.00	9.43	9.42	7.31	11.54
$100(\pi_i - 1)$	N	1.25	0.20	1.36	1.34	1.01	1.66
$100(\pi_m - 1)$	N	0.75	0.20	0.81	0.83	0.51	1.15
$\rho_{R,i}$	B	0.60	0.20	0.83	0.82	0.76	0.87
$\varphi_{\pi,i}$	N	1.75	0.20	1.71	1.71	1.42	2.02
$\varphi_{g,i}$	N	0.20	0.10	−0.08	−0.08	−0.32	0.17
$\varphi_{y,i}$	N	0.20	0.10	−0.01	−0.02	−0.05	0.02
$\varphi_{\Delta e,i}$	N	0.00	0.20	0.06	0.05	−0.08	0.19
$\rho_{R,m}$	B	0.60	0.20	0.86	0.80	0.64	0.90
$\varphi_{\pi,m}$	N	1.75	0.20	1.78	1.81	1.48	2.13
$\varphi_{g,m}$	N	0.20	0.10	0.14	0.13	−0.16	0.43
$\varphi_{y,m}$	N	0.20	0.10	0.02	0.02	−0.07	0.12
$\varphi_{\Delta e,m}$	N	0.00	0.20	0.37	0.36	0.09	0.66
$10(\varphi_{T,b})$	IG	4.90	8.10	0.78	0.82	0.53	1.17

be relatively flexible.

The estimated persistence of household and government spreads shocks are roughly the same before and after Spain joined the euro area. However, foreign risk shocks become much smaller and less persistent. This is consistent with the idea that these shocks largely reflected investor uncertainty about Spain's monetary credibility, and a concern about the possibility of a currency devaluation. Once Spain joined the euro area, these concerns diminished. The posterior mode of the steady state risk premia, ζ, indicates that entering the euro lowered Spanish real interest rates by slightly over

Table 1: Estimated parameters (*continued*)

	Prior			Posterior			
Parameter	Dist	Mean	Std Dev	Mode	Mean	5 percent	95 percent
ρ^*_ξ	B	0.70	0.15	0.91	0.91	0.87	0.94
ρ^*_p	B	0.50	0.15	0.42	0.41	0.27	0.55
ρ_ξ	B	0.70	0.15	0.91	0.89	0.81	0.95
ρ_p	B	0.70	0.10	0.83	0.79	0.64	0.89
ρ_{p_M}	B	0.75	0.05	0.86	0.85	0.77	0.92
ρ_{p_X}	B	0.50	0.15	0.30	0.30	0.15	0.48
$\rho_{\xi_{G,O}}$	B	0.50	0.15	0.85	0.84	0.76	0.90
$\rho_{\xi_{H,O}}$	B	0.50	0.15	0.80	0.78	0.66	0.87
$\rho_{\xi_{F,O}}$	B	0.50	0.15	0.92	0.91	0.84	0.97
$\rho_{\xi_{G,I}}$	B	0.50	0.15	0.92	0.90	0.86	0.94
$\rho_{\xi_{H,I}}$	B	0.50	0.15	0.84	0.83	0.73	0.92
$\rho_{\xi_{F,I}}$	B	0.50	0.15	0.58	0.54	0.29	0.79
ρ_{Υ_B}	B	0.50	0.15	0.86	0.85	0.80	0.90
ρ_{Υ_S}	B	0.50	0.15	0.76	0.72	0.60	0.84
ρ_g	B	0.75	0.08	0.97	0.97	0.96	0.98
ρ_τ	B	0.50	0.15	0.47	0.48	0.36	0.61
$100 \times \sigma_z$	IG	0.50	1.00	0.84	0.90	0.70	1.15
$100 \times \sigma^*_\xi$	IG	2.00	1.00	2.18	2.23	1.83	2.70
$100 \times \sigma^*_p$	IG	0.50	1.00	0.16	0.16	0.13	0.20
$100 \times \sigma^*_r$	IG	0.15	1.00	0.08	0.08	0.07	0.09
$100 \times \sigma_\xi$	IG	2.00	1.00	2.50	2.67	2.04	3.50
$100 \times \sigma_p$	IG	0.50	1.00	0.09	0.09	0.06	0.13
$100 \times \sigma_{p_M}$	IG	0.50	1.00	0.17	0.18	0.11	0.27
$100 \times \sigma_{p_X}$	IG	0.50	1.00	2.32	2.36	1.93	2.81
$100 \times \sigma_{r,i}$	IG	0.15	1.00	0.21	0.22	0.17	0.28
$100 \times \sigma_{r,m}$	IG	0.15	1.00	0.10	0.11	0.07	0.17
$100 \times \sigma_{\xi_{G,O}}$	IG	0.15	1.00	0.11	0.11	0.09	0.14
$100 \times \sigma_{\xi_{H,O}}$	IG	0.15	1.00	0.12	0.13	0.10	0.15
$100 \times \sigma_{\xi_{F,O}}$	IG	0.50	1.00	0.26	0.32	0.15	0.53
$100 \times \sigma_{\xi_{G,I}}$	IG	0.15	1.00	0.09	0.09	0.08	0.11
$100 \times \sigma_{\xi_{H,I}}$	IG	0.15	1.00	0.06	0.06	0.06	0.08
$100 \times \sigma_{\xi_{F,I}}$	IG	0.50	1.00	0.04	0.04	0.03	0.05
$100 \times \sigma_{\Upsilon_B}$	IG	5.00	3.00	4.93	5.16	3.47	7.32
$100 \times \sigma_{\Upsilon_S}$	IG	5.00	5.00	9.17	9.48	6.00	13.16
$100 \times \sigma_g$	IG	0.50	1.00	1.03	1.03	0.92	1.16
$100 \times \sigma_\tau$	IG	2.00	1.00	3.11	3.18	2.84	3.85

60 basis points in annualised terms. There is some uncertainty about this value, however, with the 90 percent probability interval spanning an increase of 20 basis points to a decrease of 180 basis points.

For the other parameters, our results appear broadly consistent with other estimated DSGE models of the Spanish economy (Andres et al. (2010) and Burriel et al. (2010).) The estimation points to large adjustment costs in both business and housing investment. The standard deviations of the model's investment and intertemporal preference shocks are large compared to the markup and technology shocks. In contrast, the standard deviations of the monetary policy shocks in both Spain and the euro area are small.

4 How would Spain have performed outside the euro?

We evaluate the performance of the Spanish economy outside the eurozone through counterfactual exercises in which Spain experiences the same economic shocks but retains monetary autonomy. We study the case in which Spain introduces inflation targeting in the mid-1990s but does not adopt the euro.[15]

We construct the counterfactuals as follows. We take a draw from the posterior distribution of parameter values and use the Kalman smoother to extract the economic shocks the model uses to explain the observed data, conditional on those parameter values. We then feed these shocks back through an alternative model in which Spain does not adopt the euro and the monetary authority follows the post mid-1990s reaction function.[16] We repeat this process for a large number of draws from the posterior parameter distribution. This leaves us with a distribution of counterfactual outcomes.

Figures 5 and 6 compares actual outcomes for the observed Spanish data series against the counterfactual distribution.[17] Our results confirm that the transition to euro entry raised Spanish economic growth in the late 1990s and early 2000s.

[15]Given the world impetus towards low and stable inflation, it is hard to imagine Spain using its early 1990s inflation target and monetary policy rule into the 21st century.

[16]Specifically, we feed the shocks through the model holding all solution matrices at their mid-1990s values, rather than using the time-varying structure described in Section 2.3.

[17]Actual outcomes for business and housing investment growth are not available before 1995Q1. The nominal exchange rate is not observed after Spain joins the eurozone in 1999Q1.

Consistent with the parameter estimates in Table 1, nominal interest rates would have been higher for most of the past two decades had Spain not adopted the euro.

[Figure 5 about here.]

[Figure 6 about here.]

Our primary interest, however, is in the period from 2008 - 2013. For the most part, the Spanish economy would have experienced stronger economic outcomes if it remained outside the eurozone. In particular, the economic recovery in 2010 would have been sharper and the subsequent recession less deep. The stronger recovery would have been supported by a larger fall in nominal interest rates and a substantial nominal exchange rate depreciation.

But by most metrics Spain's economic performance would still have been poor. Spain would still have experienced a double-dip recession in 2011-2013. And the stronger recovery in 2010 would largely have reflected a less severe contraction in business and especially housing investment. Consumption growth, which is arguably a better measure of welfare, is very similar to its actual path in most of the counterfactual draws.

Table 2 quantifies the estimated differences in Spanish economic outcomes if it had remained outside the euro. The first five rows compare the average growth rates of per capita output, consumption, business investment, residential investment and public consumption between 2008 and 2013 in the data against moments of the counterfactual distribution. In the counterfactual, the mean outcome for Spanish GDP is a 0.9 per cent annual decline over the period, with a 90 per cent probability interval spanning -1.4 per cent to -0.3 per cent. This represents a modest increase from the actual rate of growth achieved by the Spanish economy, which shrank at an average rate of 1.7 per cent in annualised terms over this period. Other measures of economic activity also show similarly modest increases. Consumption, for example, would still have declined over 2008-2013, albeit by 0.5 percentage points less than it did in the data.

Table 2: Economic Outcomes: 2008Q1 - 2013Q4

Variable	Actual (%)	Counterfactual (%)		
		Mean	5 percent	95 percent
GDP Growth[1]	-1.7	−0.9	−1.4	−0.3
Consumption Growth[1]	-2.4	−1.9	−2.2	−1.7
Business Investment Growth[1]	-5.3	−2.0	−3.7	−0.3
Housing Investment Growth[1]	-13.8	−10.5	−12.0	−8.9
Public Consumption Growth[1]	0.2	1.0	0.5	1.6
Inflation[2]	-1.3	0.7	−0.7	2.7
Exchange Rate Depreciation[3]	–	18.1	2.7	36.0

Note: 1. Annualised quarterly percentage change. 2. Average annualised percentage point deviation from estimated inflation target. 3. Cumulative estimated nominal exchange rate depreciation.

The sixth row of Table 2 compares deviations in inflation from its target value in the data against the counterfactuals. In this case we compute average deviations from the inflation target. For the counterfactuals we use the estimated inflation target from each draw. For the data we take an annualised rate of 2 per cent to be the inflation target. In the majority of draws, the faster pace of economic activity in the counterfactual does not come at the cost of larger deviations of inflation from target. The final row of Table 2 shows the cumulated nominal exchange rate depreciation across the distribution of counterfactuals. The 90 per cent probability interval ranges a depreciation of 2.7 per cent to a depreciation of 36.0 per cent. The mean exchange rate depreciation in the counterfactual is 18.1 per cent. This illustrates an important mechanism through which maintaining an independent monetary policy could have aided the Spanish economy after 2008. Such large changes in relative prices would be difficult to achieve in such a short period of time given the estimated degree of price rigidity in Spain.

Our results suggest that euro entry raised Spanish economic growth rates in the 1990s and early 2000s, but depressed growth subsequently. To assess the net effect of euro entry, Figure 7 compares the *level* GDP and consumption in the data against the counterfactual distribution. The level of GDP in the data is above its counterfactual level until 2008. Subsequently, however, the gap closes and the actual level of GDP lies around the bottom of the counterfactual distribution from 2012 onwards. For consumption, the counterfactual distribution lies below the actual level of consumption for most of the period after Spain's euro entry.

[Figure 7 about here.]

4.1 Why are the Differences so Modest?

Although an independent monetary policy would have led to increased growth in output and demand over recent years, the differences are modest. One possible explanation is that the Spanish economy received a sequence of economic shocks that monetary policy is not well placed to offset. To examine whether this is the case we use the Kalman smoother to extract the economic shocks that the model uses to fit the observed data series. We then explore how observed outcomes differ when we remove individual shocks.[18]

Figure 8 shows the contributions of two important sets of shocks. The top panel compares actual GDP growth to a counterfactual in which we exclude the model's technology shock. The bottom panel shows the same exercise but excluding the Spanish consumption preference and risk premium shocks. These can be considered to be demand-type shocks, as they move prices and output in the same direction, and so it makes sense to examine their joint contribution.

The most relevant single shock in explaining the initial reduction in GDP growth in 2009 is the aggregate technology shock. Absent this shock, Spain's GDP contraction would have roughly halved; no other shock can explain as much of the slowdown in GDP growth in 2009 as the technology shock does.

This result helps to explain why the contraction in Spanish GDP in 2009 would have been similar even if Spain retained its own monetary policy (Figure 5). Monetary policy has limited effectiveness when faced with negative supply shocks. To illustrate

[18] Note that for these exercises we do not allow Spain to retain an independent monetary policy after 1999.

this point, Figure 9 compares impulse responses to a negative technology shock for an economy inside (in red) and outside a currency union (in black).[19] Regardless of the economy's monetary arrangements, the negative technology shock induces a large, and permanent, reduction in output. Monetary policy can influence the timing and path of the transition. But it cannot alter the fact that the negative technology shock has made the economy less productive.

[Figure 8 about here.]

[Figure 9 about here.]

We now turn to the sovereign debt crisis between 2010 and 2013. Figure 8 shows that in this period Spanish GDP growth would have been noticeably higher absent demand and risk-premium shocks. This is also consistent with our claim that the Spanish economy's recovery would have been stronger in 2010 and the subsequent recession not as deep, had it retained an independent monetary policy.

The reason for this is that the shocks that hit the Spanish economy between 2010 and 2013 are shocks that monetary policy is well equipped to offset. To illustrate this, Figure 10 plots impulse responses to a positive shock to the household risk premium, which causes an increase in the spread between household interest rates and the policy rate.

Outside of a currency union, an exogenous increase in household spreads is partially accommodated by an easing in domestic monetary policy. This limits the rise in household borrowing rates. The nominal exchange rate also depreciates, contributing to a rapid depreciation in the real exchange rate. The depreciation of the nominal exchange rate, and increased level of domestic economic activity, puts upward pressure on inflation, which remains close to target.[20]

Within a currency union, if the central bank targets average economic conditions across the entire currency union, and the domestic economy is small, the policy rate

[19] We constructed these IRFs setting all parameters at their posterior mean values from Table 1.

[20] This mechanism is also described in Krugman (2014).

rates may not respond to a contraction in domestic demand in the small economy. In the absence of a flexible nominal exchange rate, the depreciation of the real exchange rate is smaller than it is outside the currency union, and occurs more slowly. As a consequence, the decline in GDP is about twice as large, and there is a larger deviation of inflation from its target.

[Figure 10 about here.]

The results of this section suggest that, although having an independent monetary policy would have reduced the severity of demand and risk premium shocks on domestic economic activity and inflation, it would not have eliminated these effects entirely. This is the second reason for the limited difference in estimated economic outcomes for Spain had it retained an independent monetary policy. In Section 4.3 we investigate whether alternative policy settings could have further reduced the size of Spain's economic downturn.

4.2 The Role of Fiscal Policy and Sovereign Risk

Public discussion of Spanish economic outcomes during the sovereign debt crisis of 2010 to 2013 typically attributes a large role to fiscal policy and sovereign risk. In this section we quantify the role of these forces and their interactions with Spain's monetary policy arrangements.

Our model contains three fiscal shocks: the government consumption shock ($u_{G,t}$), the public debt shock ($u_{\tau,t}$), and the sovereign risk shock ($u_{\xi_G,t}$). Our first exercise quantifies the contribution of these shocks to Spanish macroeconomic outcomes. To do this, we compute economic outcomes imposing Spain's actual economic structure but setting all of the fiscal shocks equal to zero. Figure 11 shows the results of this exercise.

Removing fiscal shocks raises Spanish GDP growth by around 1 percentage point on average between 2010 and 2014. Core inflation is also around $\frac{1}{2}$ percentage point higher on average over this period. The faster pace of economic activity reflects the direct effects of increased growth in public consumption as well as lower sovereign bond yields. The latter contributes to a roughly 1 percentage point reduction in household interest rates between 2011 and 2015. Absent fiscal shocks, Spain would still have experienced a double-dip recession. But its macroeconomic consequences would have been less severe.

[Figure 11 about here.]

The increase in sovereign bond yields in the latter part of our sample reflects three factors: (i) sovereign risk shocks, (ii) the endogenous effects of an increase in public debt; and (iii) the increase in the responsiveness of sovereign bond yields to public debt after Spain joined the euro. To gauge the contribution of the latter factor, we run a second counterfactual where we turn all of the model's shocks on but set the responsiveness of government spreads to public debt inside the euro zone to its value outside the euro zone.[21] Figure 12 shows the result of this exercise. The black line shows the actual Spanish government interest rate spread. The orange line shows the results of the previous exercise where we remove all fiscal shocks. The blue line shows the result of the exercise where we lower the interest elasticity of public debt. Lowering the elasticity raises the Spanish government bond spread prior to the Great Recession. But it lowers the spread substantially during the economic downturn of 2010-2013. By 2014, sovereign bond yields in the counterfactual are almost 2 percentage points below their actual levels.

[Figure 12 about here.]

As a final exercise, we explore how the effects of Spain's fiscal shocks would have differed if Spain had retained an independent monetary policy. To do so, we turn off all shocks other than the fiscal shocks. We then compare the effect of fiscal shocks if Spain remained outside the euro to the effect of these shocks given Spain's actual

[21] That is, we lower $\psi_{G,I}$ from 0.004 to 0.001.

monetary policy arrangements.[22]

Outside the euro Spanish sovereign bond yields would have been higher in the years prior to the Great Recession. This is because fiscal shocks were mostly expansionary over this period, warranting tighter monetary policy than delivered by the ECB. But from 2011 onwards, sovereign yields would have been lower. The contractionary effect of fiscal shocks on economic growth would have been considerably smaller during the sovereign debt crisis. In part, this reflects a 75bps reduction in the policy interest rate in response to contractionary fiscal shocks over this period. In sum, euro membership magnified the effect of contractionary fiscal shocks over recent years.

[Figure 13 about here.]

4.3 Was a Smaller Recession Possible?

The previous sections showed that part of the explanation for the modest increase in the average pace of economic activity in Spain in our counterfactual scenario lies in the nature of the shocks that affected the Spanish economy. But one might still wonder whether a smaller contraction in activity might have been possible under an alternative policy framework.

We have explored this possibility in two ways. First, we re-calculated the counterfactual exercise assuming that Spain adopted the ECB's monetary policy reaction function but remained outside the euro. Compared to the estimated Spanish policy rule, the ECB reaction function features a lower inflation target, a smaller response to inflation, a larger response to output growth and no direct response to exchange rate movements. The ECB policy rule produces a similar - albeit somewhat less volatile - path for output than that generated by the estimated Spanish reaction function. However, the differences remain modest - remaining outside the euro but adopting the ECB policy rule would not have generated large differences in Spain's macroeconomic performance.

[22]To make the interest rate graph interpretable, we set Spain's inflation target outside and inside the euro area to 2 per cent. This change does not affect the dynamics of the scenario.

Of course, there may be other policy rules that would have led to substantially improved outcomes. To explore this possibility, our second exercise compares estimated output gaps in the data (solid line) and the original counterfactual exercise in which Spain did not adopt the euro and retained its inflation targeting policy framework (dashed line). We calculate the output gap as the deviation of output from its flexible price level, calculated with all parameters set at their posterior mode values.[23] Figure 14 shows the results.

The model suggests that in the lead-up to the Great Recession Spanish economic activity was running far above its natural level. The recession was sufficiently large to push output almost 6 per cent below its flexible-price level. In the counterfactual, output does not rise as far above potential before the crisis, but still drops almost as far below potential as in the data.

[Figure 14 about here.]

What if Monetary Policy Does Not Respond to the Exchange Rate?

The estimated Spanish monetary policy rule features a strong response to exchange rate movements. This restricts one of the main mechanisms through which monetary policy can stabilise the level of economic activity in an open economy. To examine the effects of this on Spanish macroeconomic outcomes, we compare the estimated output gap in the data (solid line) to a counterfactual exercise in which Spain does not join the eurozone and uses a modified monetary policy rule that does not respond directly to changes in the exchange rate (dashed line).[24] Figure 15 shows the results. Under the alternative policy rule, output is considerably closer to potential throughout the estimation period. Moreover, this policy rule manages to close the output gap by the end of the estimation period.

This result accords with the standard argument that, under producer currency pricing, monetary authorities should not respond to exchange rate movements and instead

[23] In calculating the output gap we set all markup shocks equal to zero, although this choice does not meaningfully change the results.

[24] All other policy rule parameters are set to their intermediate regime values.

focus on stabilising the prices of domestically-produced goods (Corsetti et al. (2010) for a review). Price stickiness in the export and import sectors mean that producer currency pricing does not hold exactly. Nonetheless, our results suggest that for Spain not responding to exchange rate movements can help to stabilise output closer to potential. This approach to monetary policy, however, would represent a substantial departure from past practice for the Banco de Espana, even before euro entry.

The results of this section illustrate that alternative policy could have delivered better economic outcomes, in the sense of delivering a smaller output gap. But the most likely alternatives still point to only modest differences in macroeconomic outcomes had Spain maintained monetary autonomy.

[Figure 15 about here.]

5 Conclusion

In this paper we have quantified the consequences for Spain of the loss of monetary policy independence after adopting the euro. After adopting the euro, Spain lost the ability to tailor monetary policy settings to Spanish economic conditions. And adjustment of relative prices between Spain and the rest of the eurozone could no longer occur through changes in nominal exchange rates.

We find that Spain would have experienced a prolonged period of weak economic growth and low inflation in recent years, even if Spain had retained monetary autonomy. In common with other advanced economies, Spain would have still experienced a deep recession in 2009. And it would have endured a further downturn in 2011-13, although this episode would not have been as severe. Moreover, much of the increase in economic growth that would have occurred if Spain had retained an independent monetary policy would have come through increased investment; consumption outcomes would have been little changed.

Our analysis highlights two reasons for the modest increases in average rates of economic growth and inflation resulting from monetary policy independence. The first is the nature of the economic shocks affecting the Spanish economy. Particularly in the early part of the crisis, these were supply-side in nature. There is little that monetary policy can do in response to these types of shocks other than smooth the transition to a lower level of potential output. The second is the nature of the estimated Spanish policy rule, which we find would have failed to fully offset demand-side shocks, leading to a negative output gap between 2010 and 2016.

A further contribution of our work is to set up and estimate a structural model that explicitly accounts for the change in the conduct of monetary policy associated with joining the euro area. This feature could be built in to existing structural models of eurozone economies. It will also be useful for researchers analysing the economic consequences for other economies that are considering entering a currency union in the future.

The ongoing economic challenges facing the eurozone have led some to question whether the costs of euro membership outweigh the benefits. Our paper - by quantifying the effects of one aspect of euro membership - represents a first step to answering this question. The analysis of the benefits, and further costs, of euro membership we leave to further work.

A Log-linear System of Equations

A.1 Large Economy Log-linear Equations

$$
\begin{aligned}
(\mu - \beta h^*)(\mu - h^*)\lambda_t^* =& \mu h^* y_{t-1}^* + \mu\beta h^* E_t\{y_{t+1}^*\} - \left(\mu^2 + \beta h^{*2}\right) y_t^* - \mu h^* z_t \\
&+ (\mu - h^*)\left(\mu - \beta h^* \rho_\xi^*\right)\xi_t^*
\end{aligned} \tag{A.1}
$$

$$
0 = \lambda_t^* - E_t\left\{\lambda_{t+1}^*\right\} - \left(r_t^* - E_t\left\{\pi_{t+1}^*\right\}\right) \tag{A.2}
$$

$$
\pi_t^* = \beta E_t \pi_{t+1}^* + \kappa^* \left[\phi \; y_t^* - \lambda_t^*\right] + \epsilon_t^* \tag{A.3}
$$

$$
\begin{aligned}
r_t^* =& \rho_R^* r_{t-1}^* + (1 - \rho_R^*)\Big[\varphi_\pi^*(\pi_t^* - \pi^*) + \varphi_g^*(y_t^* - y_{t-1}^* + z_t) \\
&\varphi_y^* y_t^*\Big] + \varepsilon_{R,t}^*
\end{aligned} \tag{A.4}
$$

where $\kappa^* = (1 - \beta\theta^*)(1 - \theta^*)/\theta^*$.

A.2 Small Economy Log-linear Equations

Household First Order Conditions and Capital Law of Motion

$$
\begin{aligned}
(\mu - \beta h)(\mu - h)\lambda_t =& \mu h c_{t-1} + \mu\beta h E_t\{c_{t+1}\} - (\mu^2 + \beta h^2) c_t - \mu h z_t \\
&+ (\mu - h)(\mu - \beta h \rho_\xi)\xi_t
\end{aligned} \tag{A.5}
$$

$$
\phi \; n_t = \lambda_t + w_t \tag{A.6}
$$

$$
\lambda_t = \lambda_{j,t}^k - \phi_{k,j}\mu^2\left[(1 + \beta) i_{j,t} - i_{j,t-1} - \beta i_{j,t+1} + z_t\right] + \hat{\Upsilon}_{j,t} \tag{A.7}
$$

$$
\lambda_{B,t}^k = \left[\frac{\mu - \beta(1 - \delta_B)}{\mu}\right]\left[E_t\lambda_{t+1} + E_t r_{B,t+1}\right] + \frac{\beta(1 - \delta_B)}{\mu} E_t \lambda_{B,t+1}^k \tag{A.8}
$$

$$
\lambda_{S,t}^K = \frac{\beta(1 - \delta_S)}{\mu} E_t\{\lambda_{S,t+1}^K\} - \left[\frac{\mu - \beta(1 - \delta_S)}{\mu}\right] k_{S,t+1} \tag{A.9}
$$

$$
0 = \lambda_t - E_t\{\lambda_{t+1}\} - (r_{H,t} - E_t\{\pi_{t+1}\}) \tag{A.10}
$$

$$
0 = r_{H,t} - E_t\{\Delta e_{t+1}\} - r_{F,t}^H \tag{A.11}
$$

$$
k_{j,t+1} = \frac{1 - \delta_j}{\mu}\left(k_{j,t} - z_t\right) + \frac{\mu - 1 + \delta_j}{\mu}(i_{j,t} + \hat{\Upsilon}_{j,t}) \tag{A.12}
$$

Household Demand Functions

$$y^D_{H,t} = dfd_t - \eta\gamma_{H,t} \tag{A.13}$$

$$y_{F,t} = dfd_t - \eta_F\gamma_{F,t} \tag{A.14}$$

$$x_t = y^*_t + \eta_F(q_t - \gamma_{X,t}) \tag{A.15}$$

Relative Prices

$$q_t = q_{t-1} + \Delta e_t + \pi^*_t - \pi_t \tag{A.16}$$

$$\gamma_{F,t} = \gamma_{F,t-1} + \pi_{F,t} - \pi_t \tag{A.17}$$

$$\gamma_{X,t} = \gamma_{X,t-1} + \pi_{X,t} - \pi_t + \Delta e_t \tag{A.18}$$

$$\gamma_{H,t} = \gamma_{H,t-1} + \pi_{H,t} - \pi_t \tag{A.19}$$

Production Functions and Producers' First Order Conditions

$$y_{H,t} = \alpha n_t + (1-\alpha)z_t + (1-\alpha)k_{B,t} \tag{A.20}$$

$$\pi_t = (1-\nu)(\pi_{H,t} + \gamma_{H,t-1}) + \nu(\pi_{F,t} + \gamma_{F,t-1}) \tag{A.21}$$

$$\pi_{F,t} = \kappa_F(q_t - \gamma_{F,t}) + \beta E_t\{\pi_{F,t+1}\} + \epsilon_{M,,t} \tag{A.22}$$

$$\pi_{X,t} = \kappa_X(\gamma_{H,t} - \gamma_{X,t}) + \beta E_t\{\pi_{X,t+1}\} + \epsilon_{X,t} \tag{A.23}$$

$$\pi_{H,t} = \kappa mc_t + \beta E_t\{\pi_{H,t+1}\} + \epsilon_t \tag{A.24}$$

$$mc_t = \alpha(w_t + r_{H,t}) + (1-\alpha)r_{B,t} - \gamma_{H,t} \tag{A.25}$$

$$n_t = k_{B,t} + r_{B,t} - w_t - r_{H,t} - z_t \tag{A.26}$$

where $\kappa_F = (1-\beta\theta_F)(1-\theta_F)/\theta_F$, $\kappa_X = (1-\beta\theta_X)(1-\theta_X)/\theta_X$ and $\kappa = (1-\beta\theta)(1-\theta)/\theta$.

Government

$$g_t = \rho_g g_{t-1} + \varepsilon_{G,t} \tag{A.27}$$

$$\tau_t = \varphi_{T,b} b_{G,t+1} + \varepsilon_{\tau,t} \tag{A.28}$$

$$\frac{b_G}{R_H}(b_{G,t+1} - r_{G,t}) = g * g_t - \tau\tau_t + \frac{b_G}{\mu\Pi}(b_{G,t} - \pi_t - y_t - z_t + y_{t-1}) \tag{A.29}$$

Market Clearing and Current Account Conditions

$$y_{H,t} = \frac{Y^D_{H,t}}{Y_H} y^D_{H,t} + \frac{X}{Y_H} x_t \tag{A.30}$$

$$dfd_t = \frac{C}{DFD} c_t + \frac{I_B}{DFD} i_{B,t} + \frac{I_S}{DFD} i_{S,t} + \frac{G}{DFD}(g_t + y_{H,t}) \tag{A.31}$$

$$\frac{b_{F,t+1}}{r^H_{F,t}} = \frac{\Delta\mathcal{E} b_{F,t}}{\mu\Pi} + \frac{\Gamma_X X}{Y_H}(\gamma_{X,t} + x_t - y_{H,t}) - \frac{QY_F}{Y_H}(q_t + y_{F,t} - y_{H,t}) \tag{A.32}$$

Interest Rate Spreads

$$\omega_{G,t} = r_{G,t} - r_t \tag{A.33}$$

$$\omega_{H,t} = r_{H,t} - r_t \tag{A.34}$$

$$\omega_{F,t} = r_{F,t} - r^*_t \tag{A.35}$$

$$\omega_{G,t} = \psi_{G,k} b_{G,t+1} + \xi_{G,t} \tag{A.36}$$

$$\omega_{H,t} = \psi_{H,k} \omega_{G,t} + \xi_{H,t} \tag{A.37}$$

$$\omega_{F,t} = -\psi_F b_{F,t+1} + \xi_{F,t} \tag{A.38}$$

$$r^H_{F,t} = r^*_t + \omega_{F,t} + \omega_{H,t} \tag{A.39}$$

where k denotes the monetary regime; whether Spain is outside or inside the Euro area.

Monetary Policy

In the initial regime, the Spanish policy rule is:

$$r_t = \rho_{r,i} r_{t-1} + (1 - \rho_{r,i}) \Big[\varphi_{\pi,m} \pi_t + \varphi_{g,i} (y_{H,t} - y_{H,t-1} + z_t) + \varphi_{y,i} y_{H,t} + \varphi_{\Delta_e,i} \Delta e_t \Big] + \varepsilon_{r,t} \tag{A.40}$$

In the intermediate regime, the Spanish policy rule is:

$$r_t = \rho_{r,m} r_{t-1} + (1 - \rho_{r,m}) \Big[\varphi_{\pi,m} \pi_t + \varphi_{g,m} (y_{H,t} - y_{H,t-1} + z_t) + \varphi_{y,m} y_{H,t} + \varphi_{\Delta_e,m} \Delta e_t \Big] + \varepsilon_{r,t} \tag{A.41}$$

After the adoption of the euro, the Spanish policy rule is:

$$\Delta e_t = 0 \tag{A.42}$$

B Data Sources

Euro area GDP: From 1988Q1 to 1998Q4 the growth rate of German real GDP per capita. This is constructed by dividing German real GDP (source: Datastream code BDGDP...D) by the German population (source: FRED code POPTTLDEA148NRUG). From 1999Q1 to 2016Q2 the growth rate of euro-area GDP per capita, excluding Spain. We calculate the aggregate non-Spain euro GDP series (source: Eurostat) using the chain weighting formula and data on aggregate euro-area and Spanish GDP. We construct the population series by subtracting the Spanish population (source: INE) from the euro-area population (source: Eurostat.)

Euro area inflation: From 1988Q1 to 1998Q4, the growth rate of the German consumer price index ex-energy (source: Datastream.) From 1999Q1 to 2016Q2, euro-area HICP inflation excluding energy and food (source: Eurostat.) We use the chain weighting formula to remove the effects of Spanish inflation from this series.

Euro area interest rates: Between 1998Q1 and 1998Q4 the quarterly average of the Deutsche Bundesbank discount rate (Source: FRED.) From 1999Q1 to 2016Q2 the ECB overnight deposit rate (source: ECB.)

Spain GDP growth: The growth rate of Spanish real GDP per capita. We construct GDP per capita by dividing Spanish real GDP (Source: Banco de España) by the Spanish population from 1988Q1 to 2016Q2 (Source: INE)

Spain consumption growth: The growth rate of Spanish real final consumption expenditure per capita. (Source: INE).

Spain public consumption growth: The growth rate of Spanish real final public consumption expenditure per capita. (Source: INE).

Spain investment growth: The growth rate of Spanish Gross Fixed Capital Formation (GFCF) per capita (Source: INE). We include this variable as an observable variable in estimation between 1988Q1 and 1994Q4.

Spain business investment growth: The growth rate of real Spanish business investment per capita (Source: INE). This data is available only from 1995Q1 and we treat the series as missing from 1988Q1 to 1994Q4.

Spain housing investment: The growth rate of housing investment per capita. Housing investment is GFCF in dwellings (Source: INE). This data is available only from 1995Q1 and we treat the series as missing from 1988Q1 to 1994Q4.

Spain gross government debt: The ratio of gross nominal government debt to nominal GDP (Source: De Castro et al. (Forthcoming)).

Spain inflation: The growth rate of the Spanish consumer price index excluding taxes, food and energy prices. Between 1988Q1 and 1995Q4 the data source is OECD. Between 1996Q1 and 2016Q2 the source is Eurostat.

Spain policy rate: Between 1988Q1 and 1998Q4 the quarterly average of the daily interest rate on deposits in the interbank market. The variable is no longer observed after Spain joins the euro. (Source: Banco de Espana.)

Spain 10 year government bond rate: Difference between the Spanish 10 year government bond rate and the German 10 year government bond rate (Source: Banco de España and FRED respectively).

Spain mortgage rate: Mortgage rate on new borrowing by households (Source: Banco de España).

Spain exchange rate: Quarterly change in the log of the nominal Spanish Peseta / German Deutschemark exchange rate. The series is discontinued in 1999Q1 when Spain joins the euro. (Source: Banco de España.)

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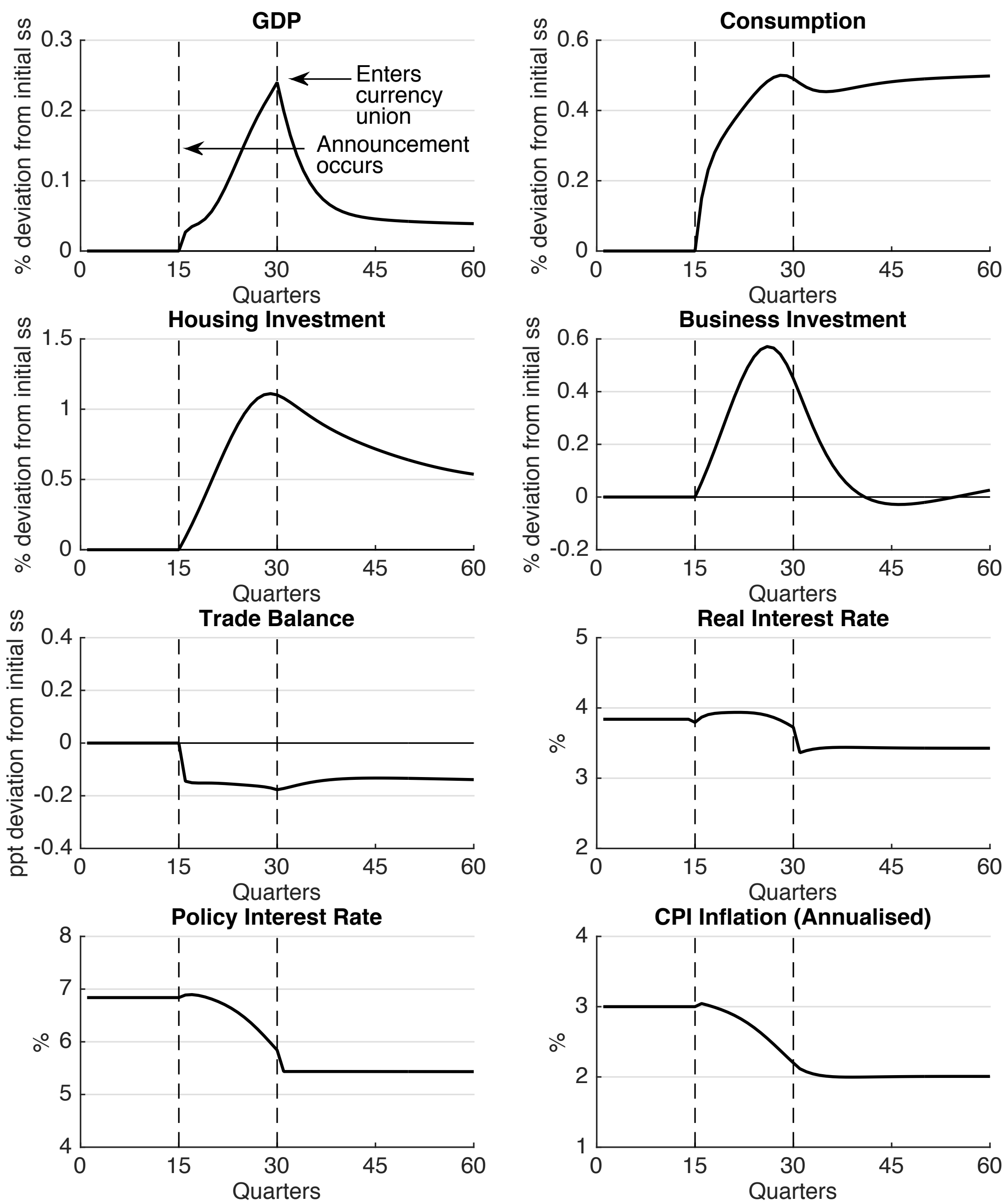

Figure 1: **Simulated transition to a currency union**. This figure plots a simulated transition to a currency union. The small economy enters the currency union in Quarter 31 and agents' first incorporate the change in monetary policy arrangements into their expectations in quarter 15.

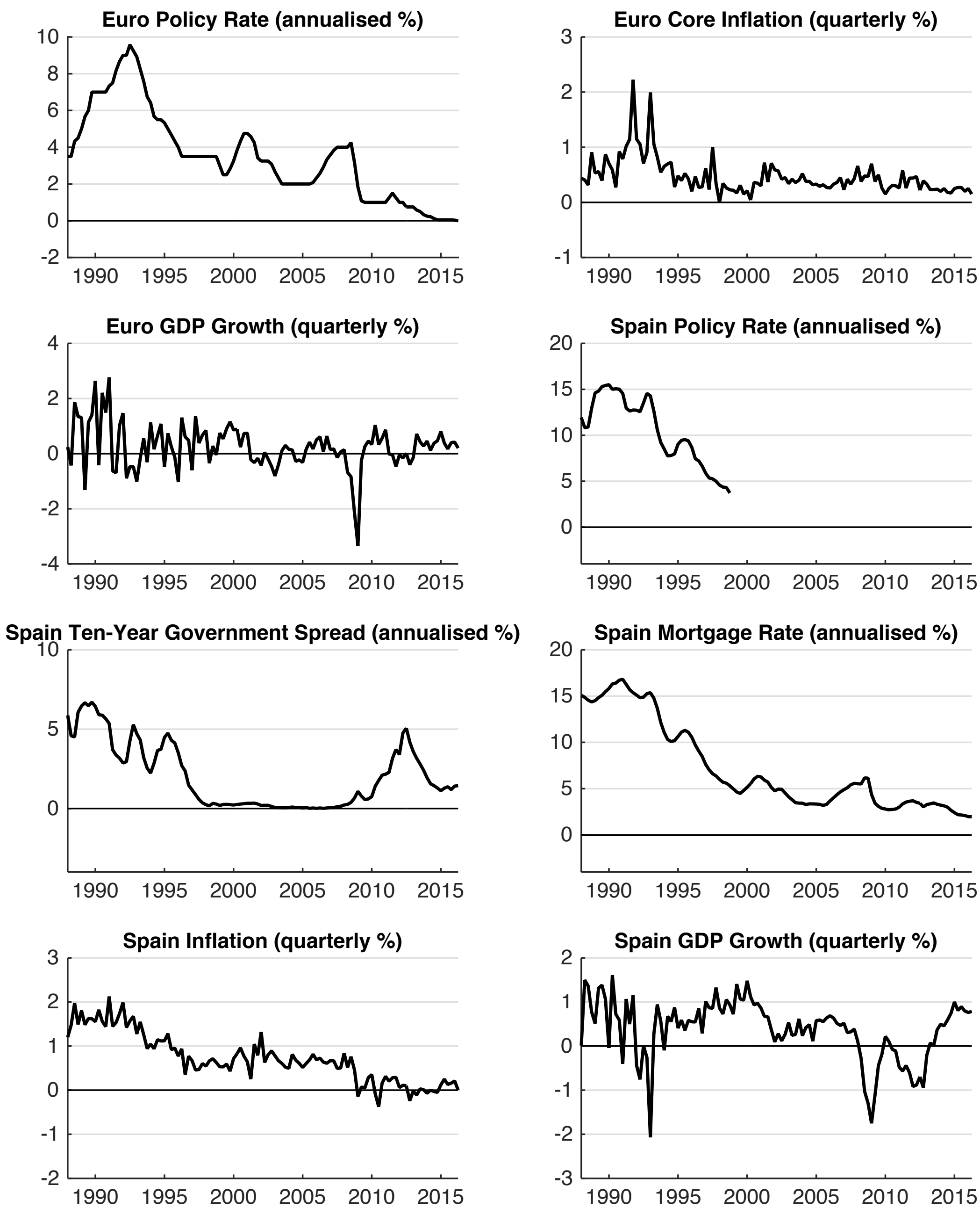

Figure 2: Data Used in Estimation (*continued on next page*).

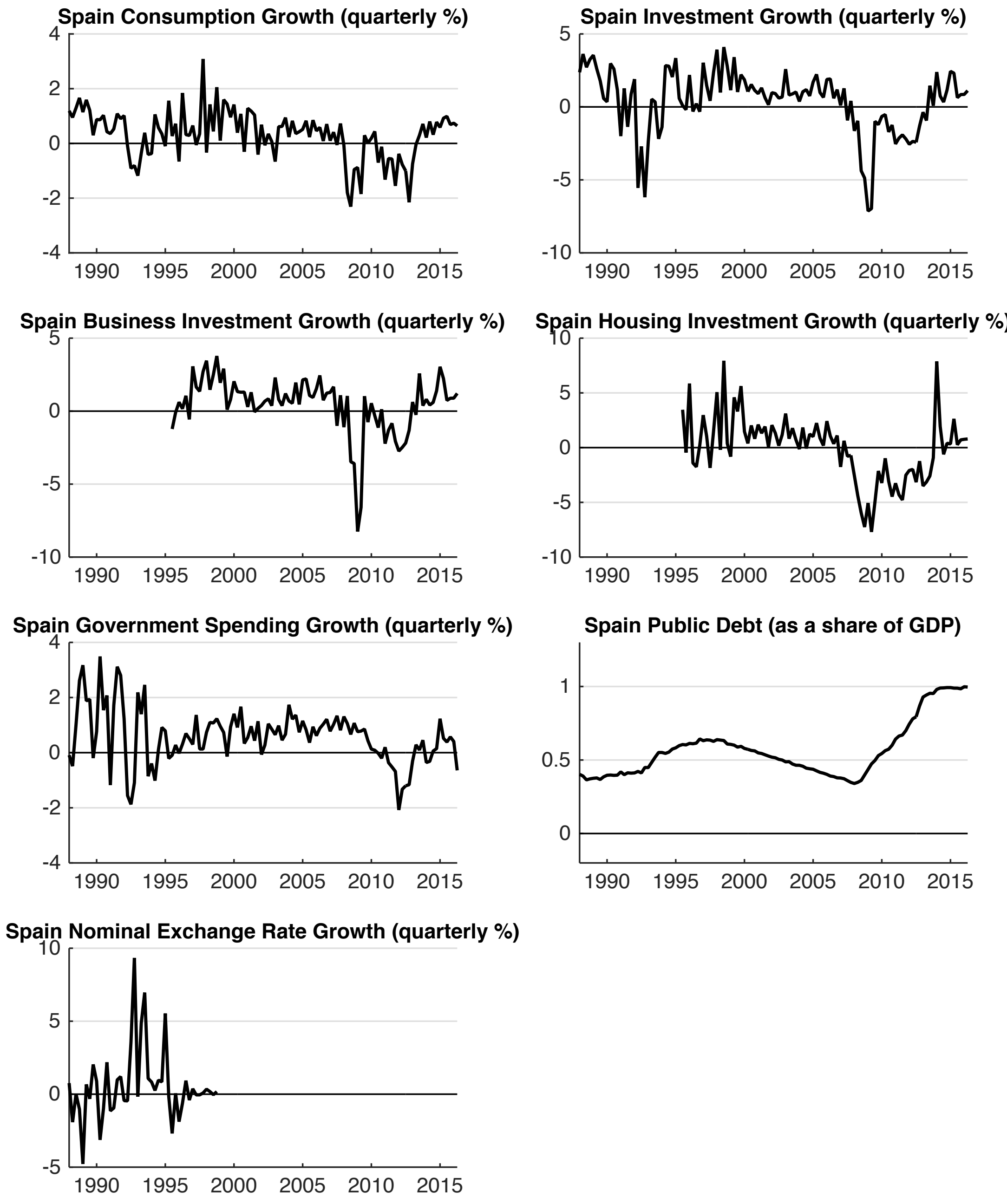

Figure 3: Data Used in Estimation (*continued*).

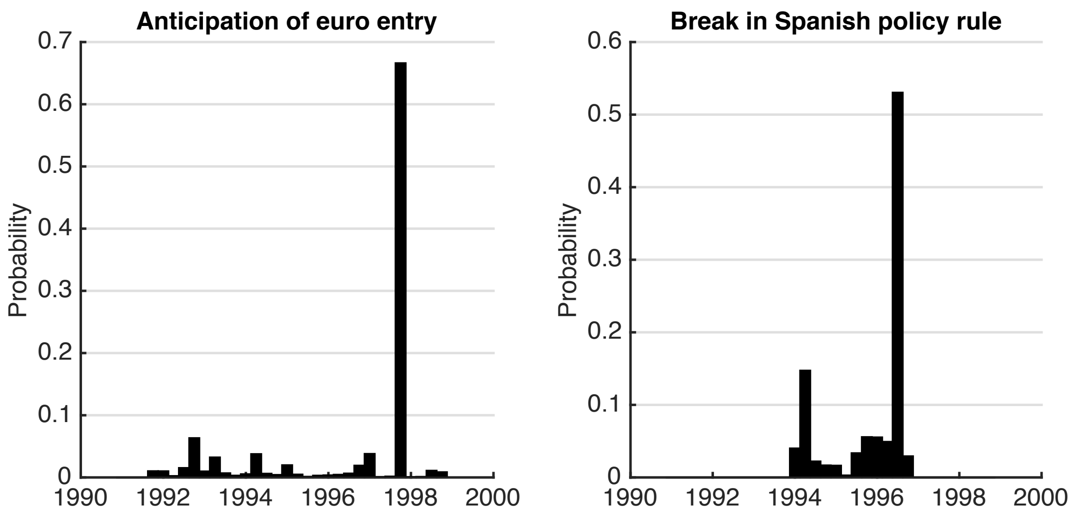

Figure 4: **Probability Density Function of Estimated Breaks**. This figure plots the probability density function of the distribution of breaks in Spanish agents' beliefs about Spain's euro entry (left panel) and of the break in the Spanish monetary policy rule (right panel). Each bar shows the probability of a break ocurring at that date.

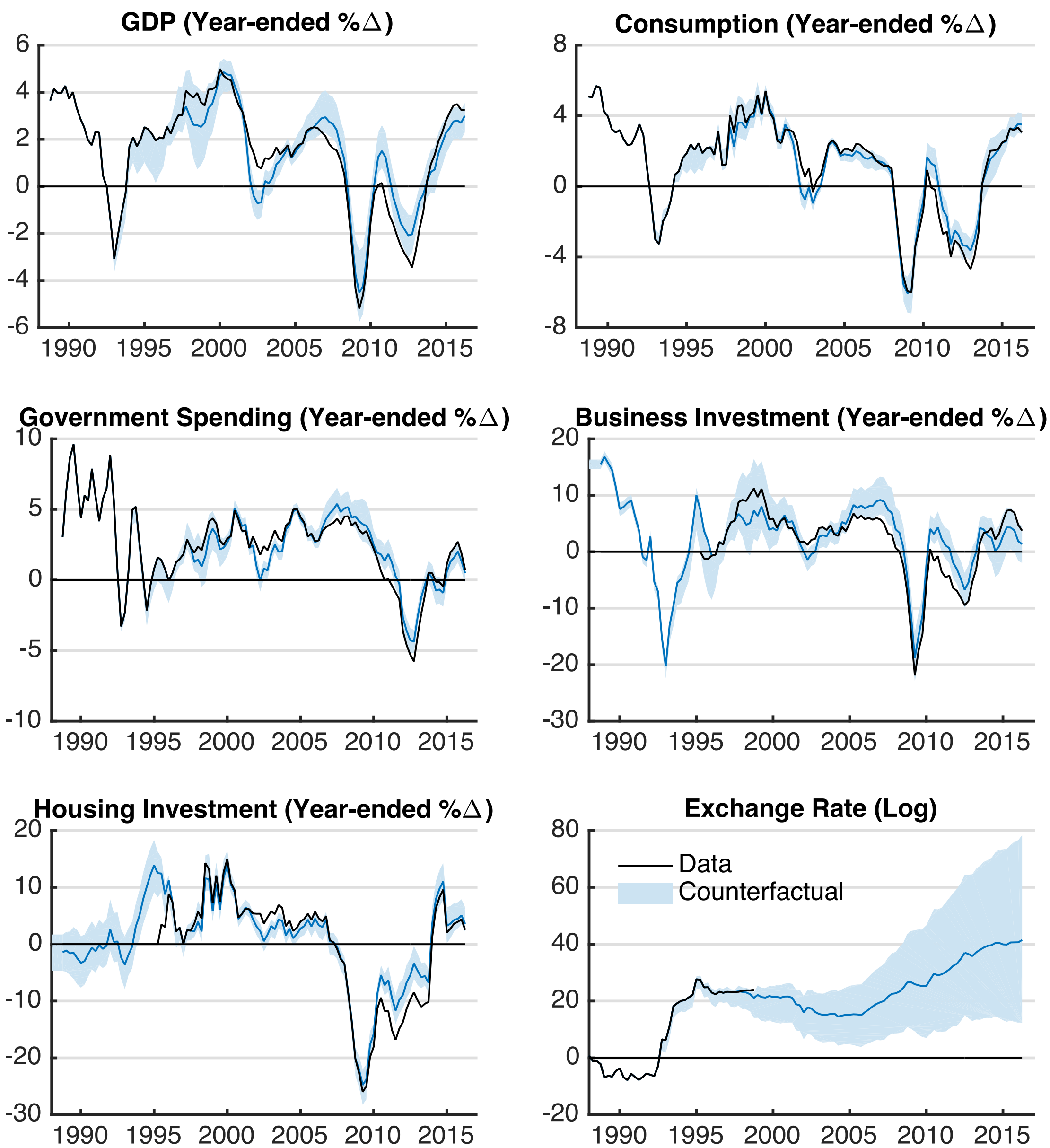

Figure 5: **Counterfactual Economic Outcomes**. This graph compares actual Spanish economic outcomes against counterfactuals in which Spain does not enter the eurozone. The black lines show actual data. The blue shaded area shows the distribution of counterfactual outcomes constructed using 1,000 draws from the posterior parameter distribution. (continued on next page)

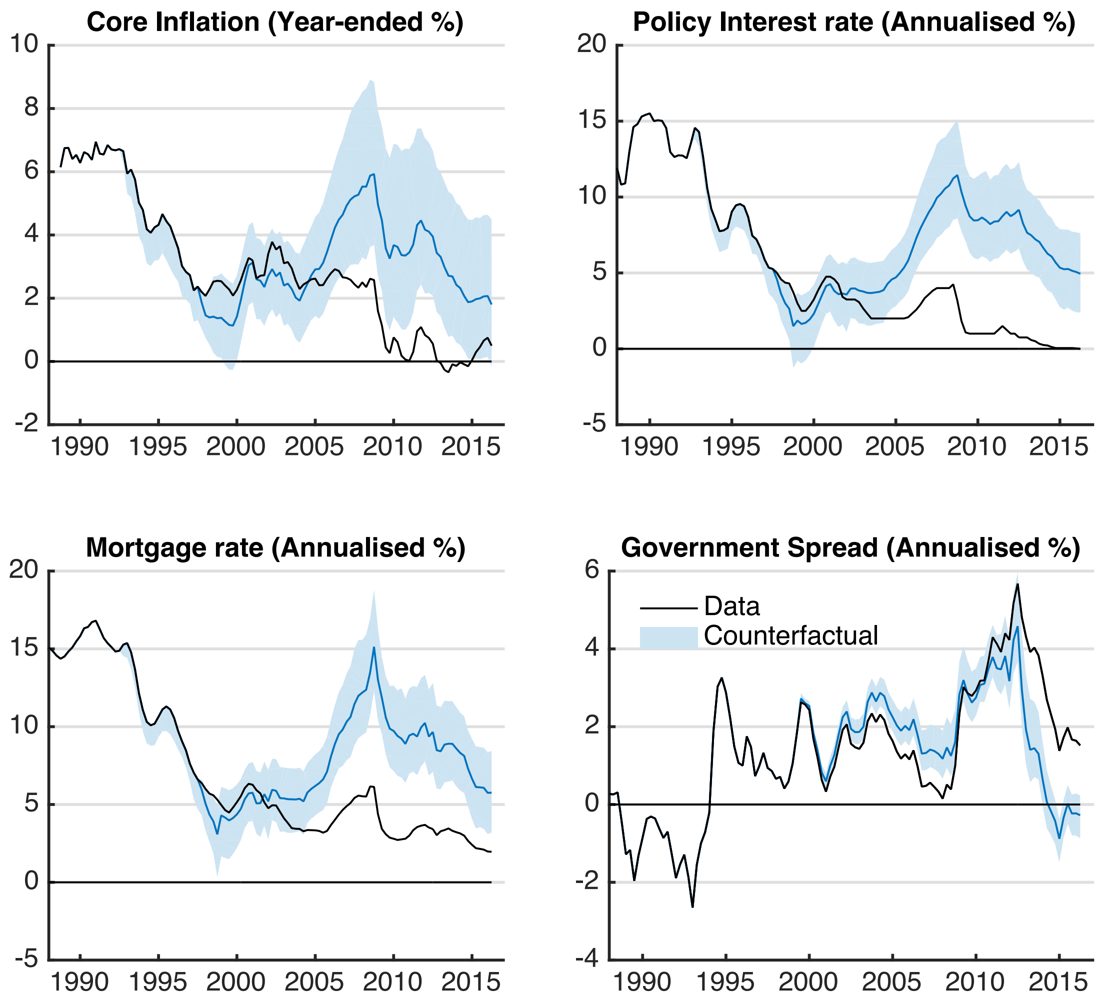

Figure 6: **Counterfactual Economic Outcomes** (*continued*). This graph compares actual Spanish economic outcomes against counterfactuals in which Spain does not enter the eurozone. The black lines show actual data. The blue shaded area shows the distribution of counterfactual outcomes constructed using 1,000 draws from the posterior parameter distribution.

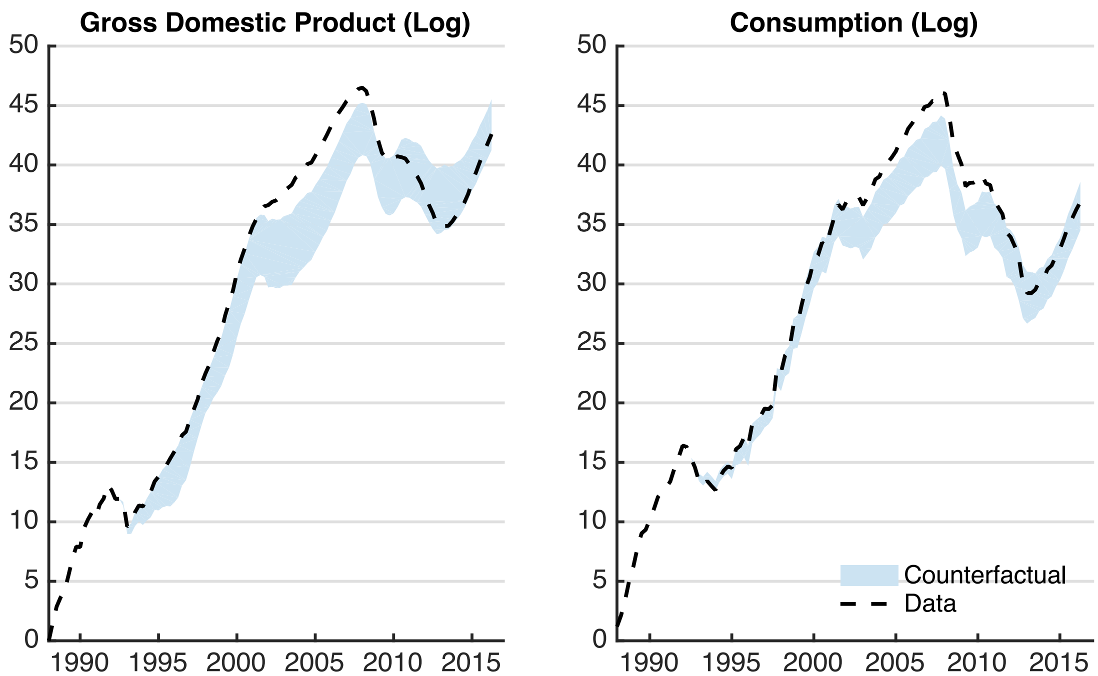

Figure 7: **Counterfactual Economic Outcomes**. This graph compares actual Spanish economic outcomes again counterfactuals in which Spain does not enter the eurozone. The black lines show actual data. The blue shaded area shows the distribution of counterfactual outcomes constructed using using 1,000 draws from the posterior parameter distribution.

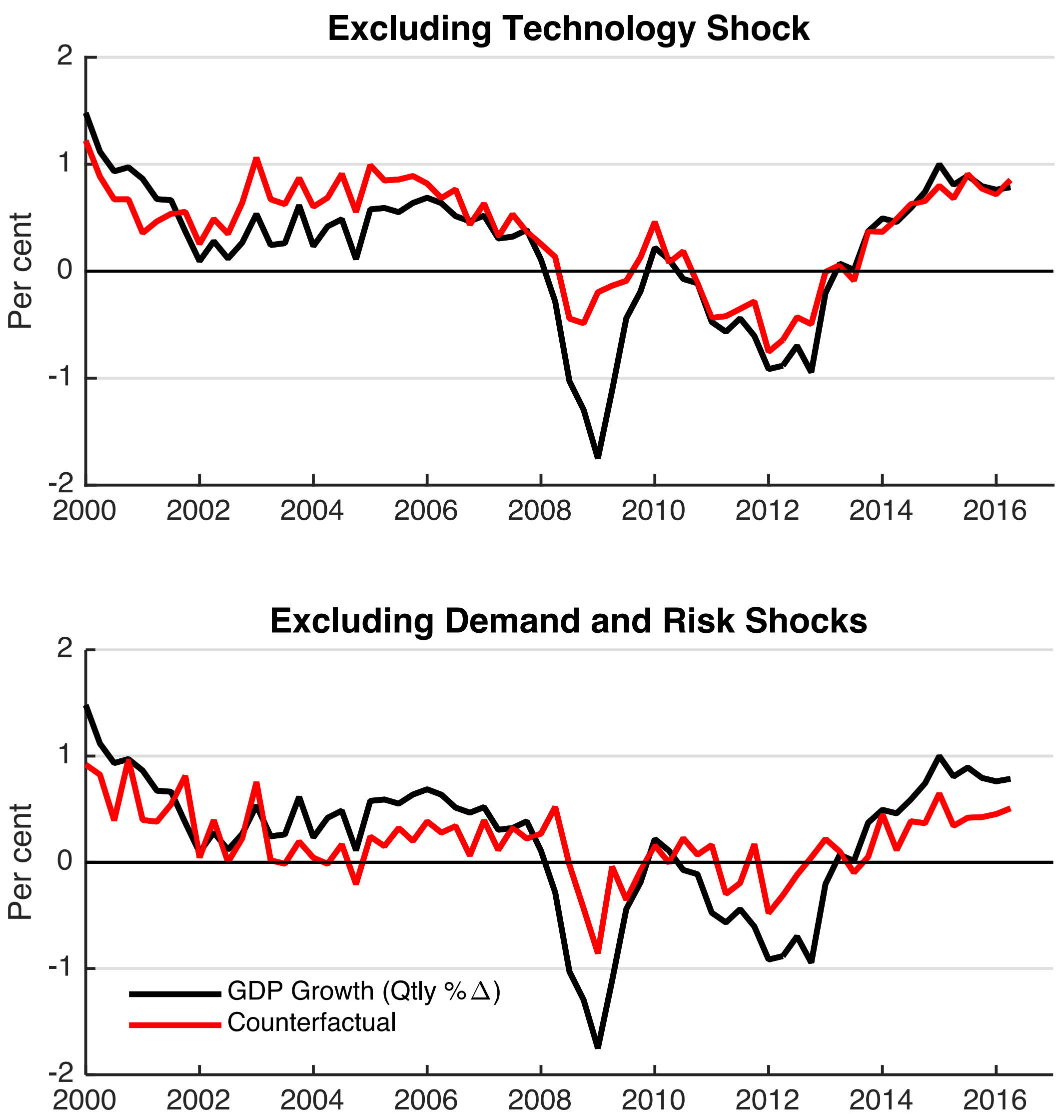

Figure 8: Counterfactual Economic Outcomes when Excluding Shocks. This graph compares actual Spanish GDP growth between 2000Q1 and 2016Q2 against counterfactual outcomes. The top panel shows the case in which we turn off the technology shock. The bottom panel shows the case in which we turn off the consumption preference, public demand and risk shocks. The black lines show actual data. The red lines show the counterfactual Spanish GDP growth.

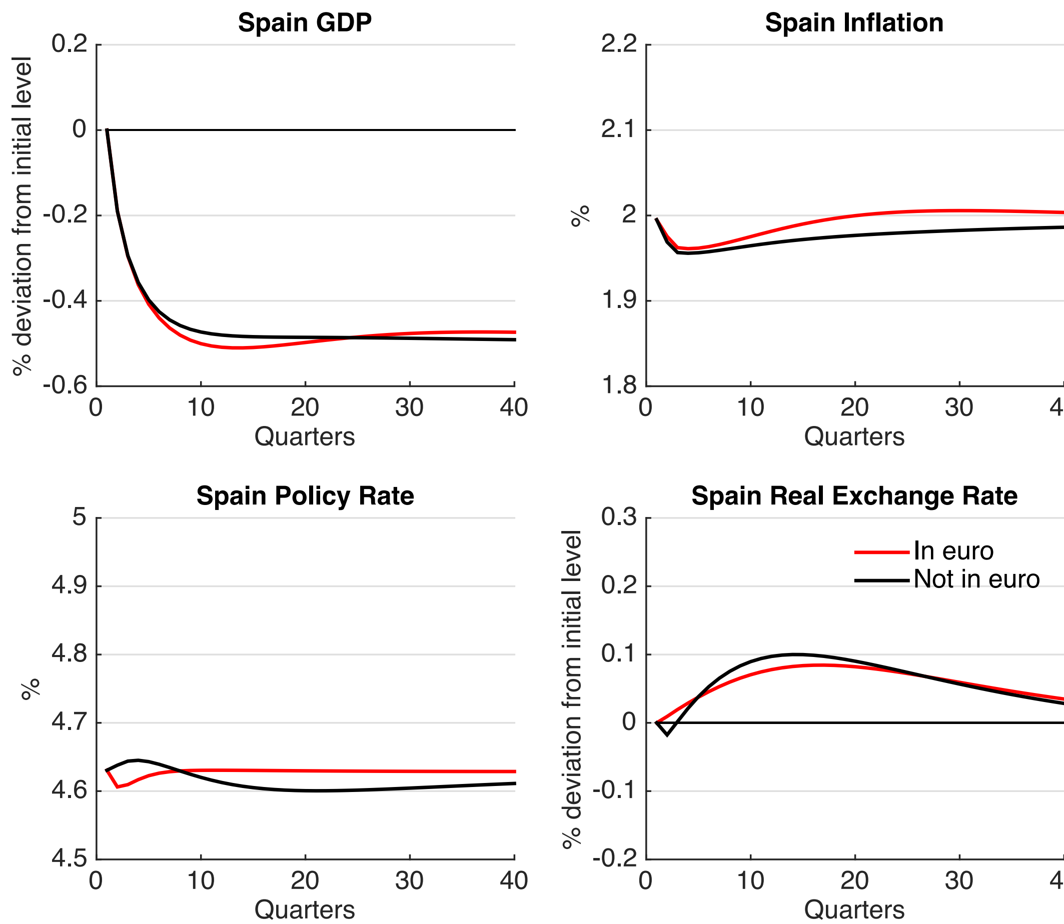

Figure 9: **Impulse response to a negative technology shock**. This figure plots the impulse responses to a one standard deviation technology shock in quarter 1.

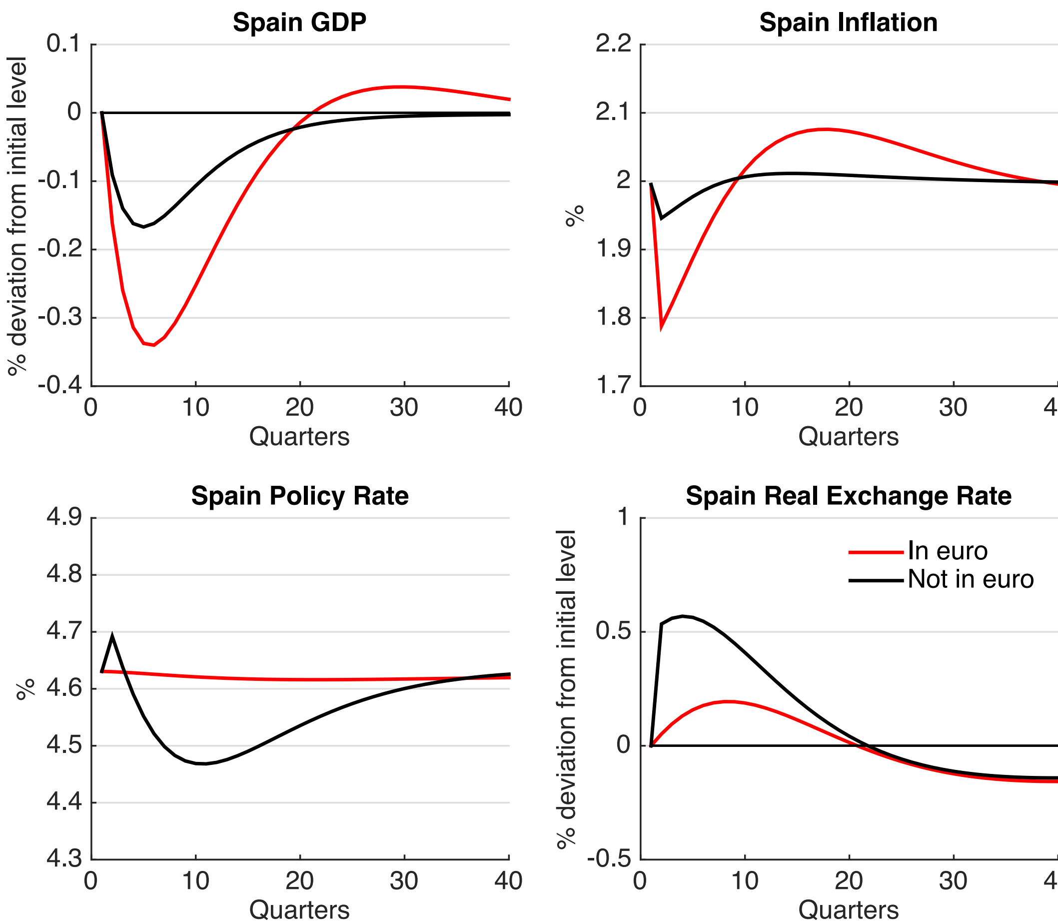

Figure 10: Impulse response to a positive household risk premia shock. This figure plots the impulse responses to a one standard deviation shock to household risk premia.

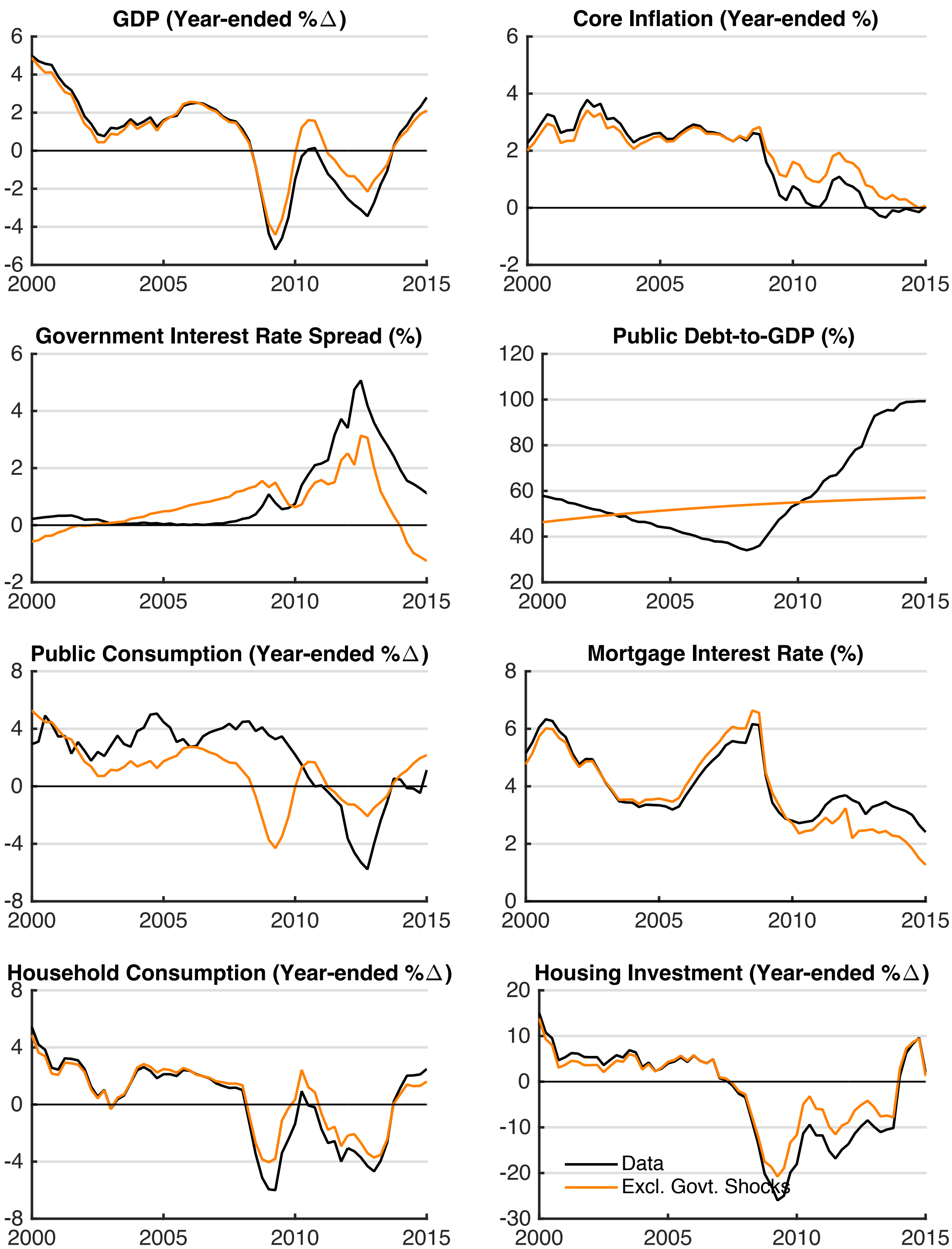

Figure 11: **Counterfactual Economic Outcomes.** This graph compares actual Spanish economic outcomes (black lines) against outcomes where the Spanish fiscal shocks are turned off (orange lines).

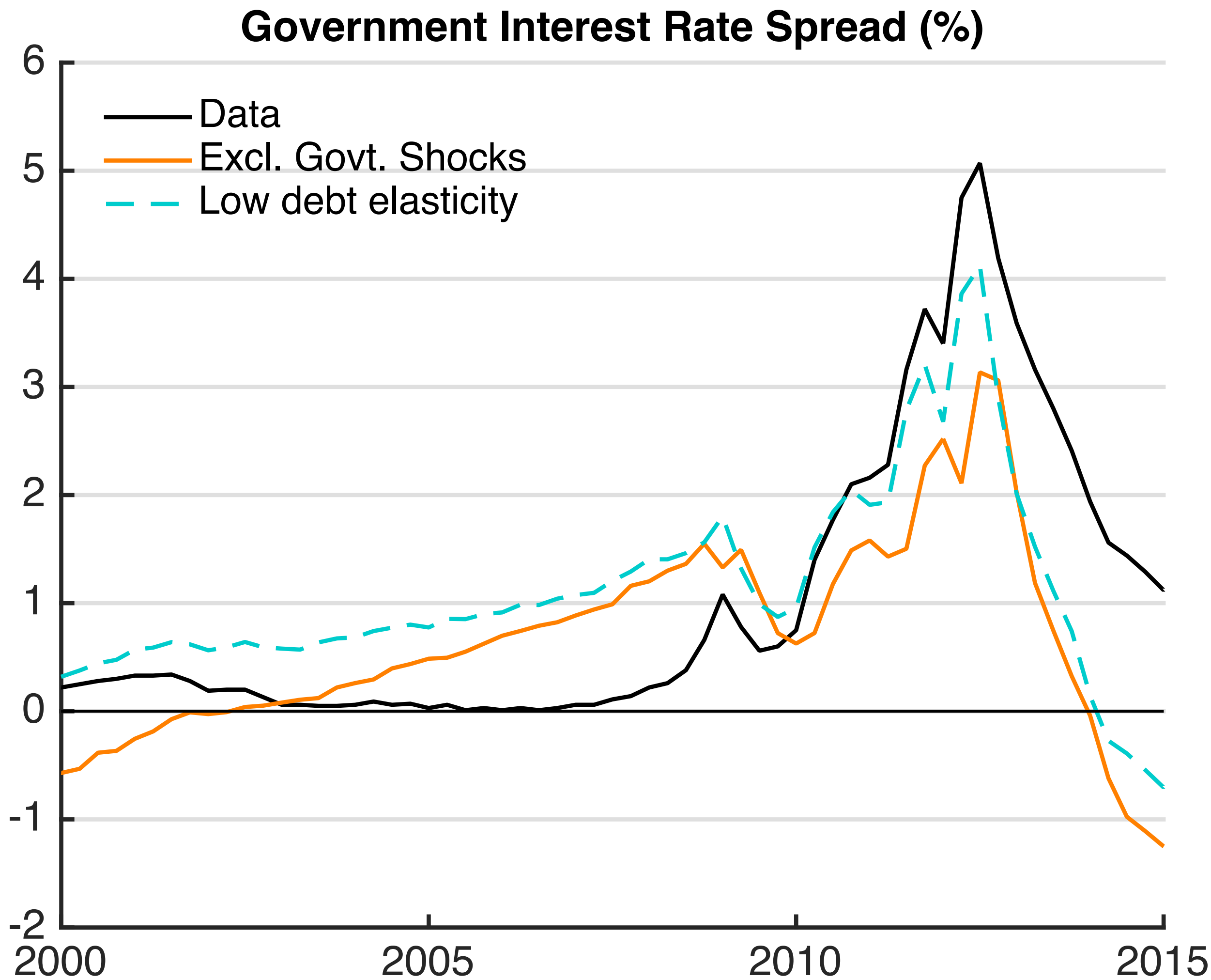

Figure 12: Counterfactual Economic Outcomes. This graph compares actual Spanish economic outcomes (black lines) against outcomes where the Spanish fiscal shocks are turned off (orange lines) and where the responsiveness of government bond yields to public debt is reduced to its pre-currency union value.

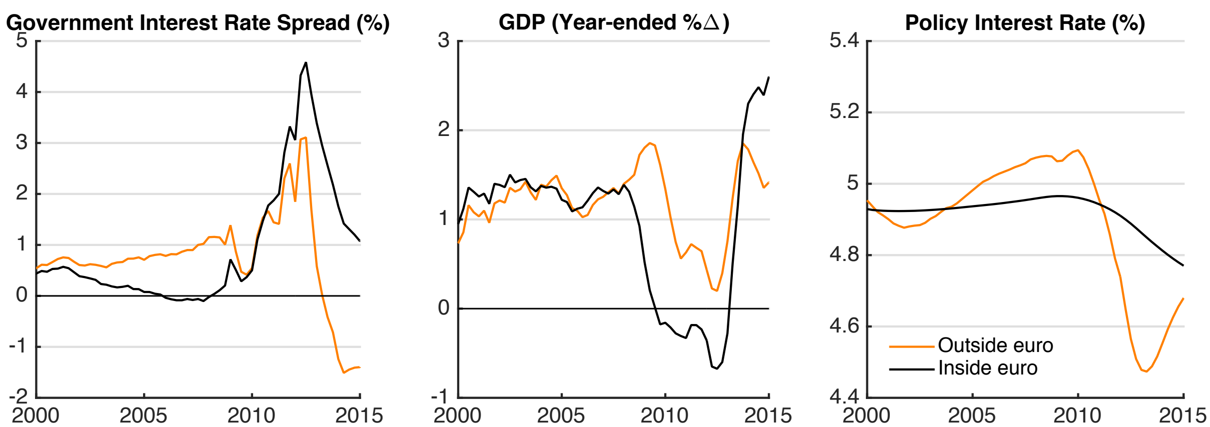

Figure 13: Counterfactual Economic Outcomes. This graph compares the economic consequences of estimated Spanish fiscal shocks if Spain were outside the euro (orange lines) and inside the euro (black lines).

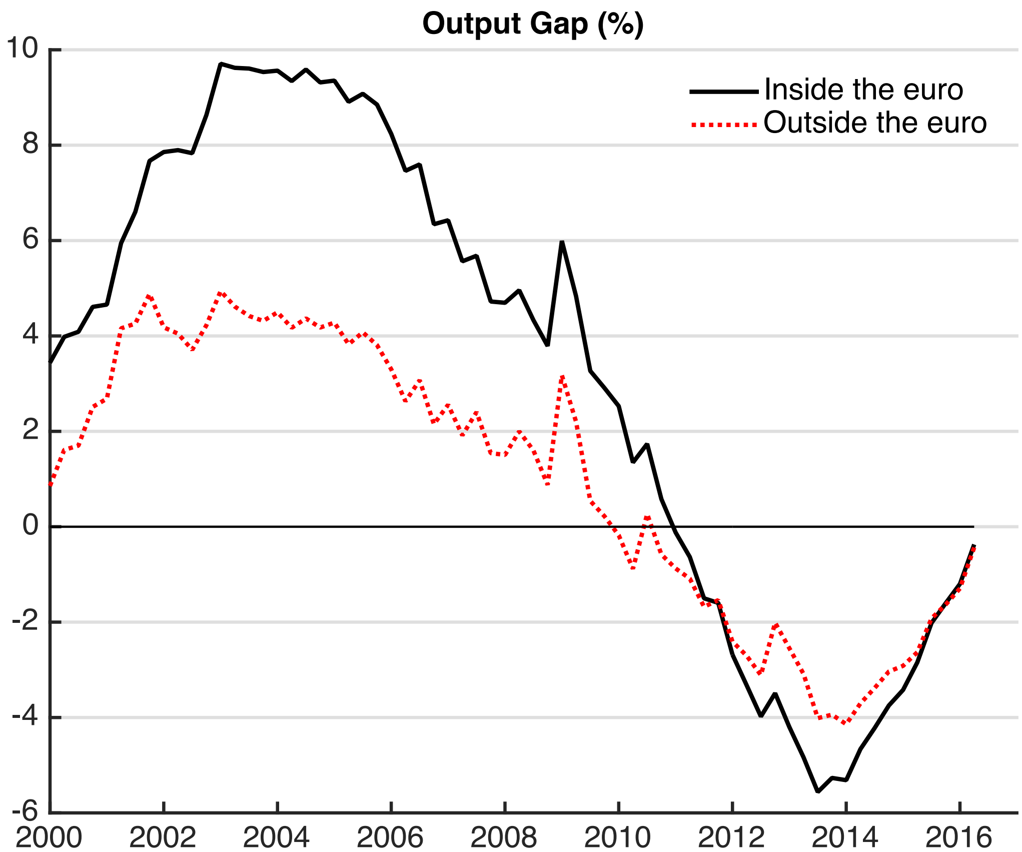

Figure 14: Output Gap. This graph shows estimated output gaps in the data (solid line) and a counterfactual in which Spain does not join the eurozone (dashed line).

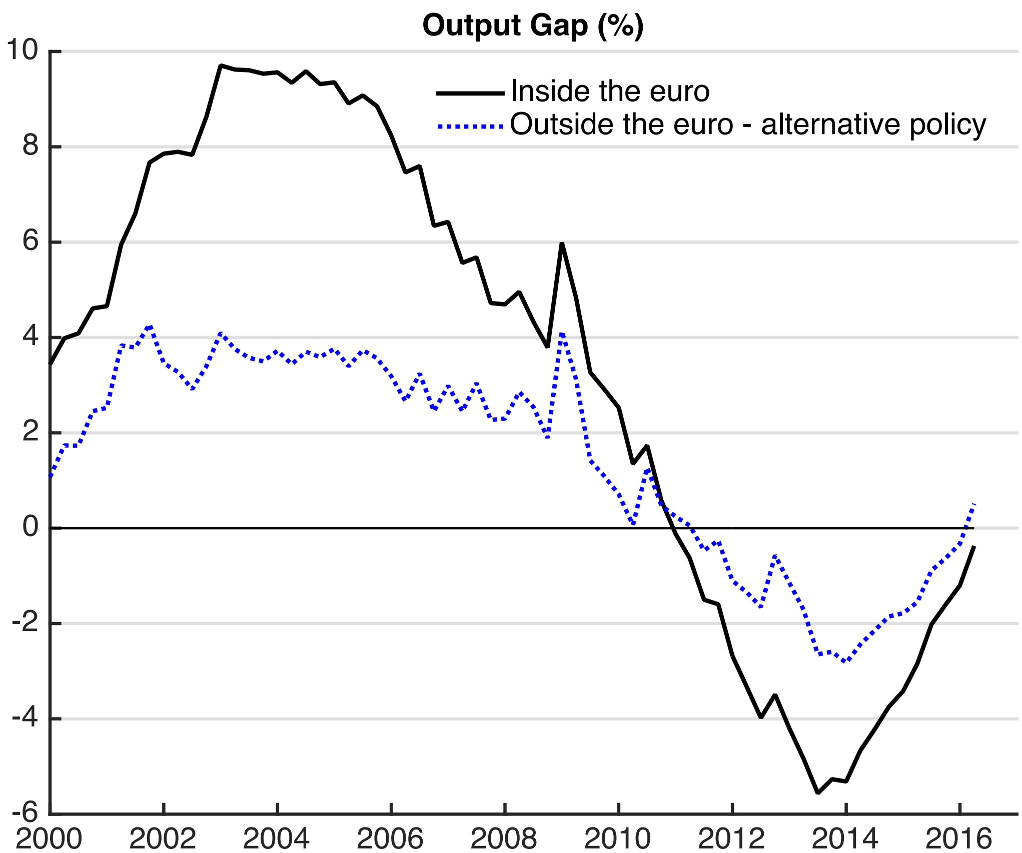

Figure 15: **Output Gap.** This graph shows estimated output gaps in the data (solid line) and a counterfactual in which Spain does not join the eurozone and uses a policy rule that does not react to the exchange rate (dashed line).