Inflation Differentials in a Monetary Union:

the case of Malta[1]

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Executive Summary

The objective of this paper is to enhance the understanding of inflation dynamics in Malta and investigate the underlying sources of inflation differentials with the euro area.

A country that registers persistently higher inflation than its main trading partners will suffer from a deterioration in its external price competitiveness, with subsequent losses in output and employment. This is even more relevant in the context of a monetary union, where asymmetric shocks cannot be corrected by changes in monetary or exchange rate policies but rather through structural policies and relative adjustments in prices and wages. Although some degree of price dispersion is a common feature of currency unions, inflation differentials in the euro area have been very persistent, with some countries systematically registering higher or lower inflation compared to the union's average, exacerbating the internal imbalances within the monetary union.

The paper is organised in three sections.

The **first part** identifies five stylized facts about the determinants of the inflationary process in Malta:

1. Since 1999, inflation in Malta has fluctuated around a constant mean of 2.5%. On average, inflation in Malta has been around 0.5 percentage points higher than that registered in the euro area.
2. Higher inflation in Malta is not limited only to the headline HICP index but is also present in other HICP sub-indices that exclude the most volatile components (such as energy and unprocessed food) or administrative prices.
3. Inflation persistence in Malta is moderate and broadly similar to estimates for the euro area.
4. Differences in household consumption baskets can exacerbate inflation differentials. In Malta's case, the hotels and restaurants category and, to a lesser extent, food, have a higher weight in the HICP basket; on the contrary, the weight of energy in Malta's consumption basket is the lowest in the euro area. These categories have been important drivers of inflationary pressures in recent years.
5. The underlying drivers of inflation differentials are different in Malta's pre- and post-EU membership period. Decomposition from the expenditure side suggests that services have been the main driver of inflation differentials until 2004, while the contribution of energy and foods prices has become more significant in recent years. Supply-side decomposition shows that growth in wages was the main driver of the differentials, as measured by the GDP deflator, in the pre-EU period, while growth in gross operating surplus has driven the differentials after 2005.

The **second part** of the report reviews the main theories put forward in the literature to explain inflation differentials in a monetary union. The main theories can be broadly grouped in three categories: (i) price

level convergence; (ii) cross-country differences in the business cycles and the role of asymmetric demand shocks and (iii) structural features of the economy.

Evidence suggests that the Balassa-Samuelson effect may have played only a limited role in explaining inflation differentials in Malta, with both income and price levels indicators increasing only marginally vis-à-vis the euro area over the last decade. The second category is also not supported by the data: between 1999 until the start of the recession of 2008-09, average GDP growth in Malta has only been slightly above that of the euro area but considerably below the growth rates experienced by other countries that were subject to demand shocks in the form of asset bubbles or with similar levels of economic development. In addition, Malta's business cycle has become increasingly synchronized with that of the euro area, especially after 2004.

Structural features of the economy may imply different inflation dynamics even in the face of symmetric shocks. This can arise, for instance, due to different degrees of oil dependency, differences in exchange rate pass-through patterns or country-specific characteristics, such as those pertaining to product and labour markets. This is likely to be an important factor for Malta where differences in market structures, in part influenced by the characteristics of Malta's small island economy, are more likely to play an important role. Testament to this is the experience with higher international energy and food prices between 2007 and 2009, when the magnitudes and timing of the pass-through to domestic prices were different from those observed in the euro area.

The **final part** of the report focuses on domestic price setting behaviour through the lens of a two-country dynamic stochastic general equilibrium (DSGE) model of a monetary union. In this context, we adopt the model used by Rabanal (2009) and extend it in two directions – by including price mark-up (cost-push) shocks and wage stickiness – thereby making it more relevant to Malta's characteristics.

The estimation suggests that price and wage setting behaviour in Malta is less sticky than in the euro area. The average duration of prices in Malta is estimated at around 1.5 to 2.5 quarters, compared to between 2 and 4 quarters in the euro area. Turning to the labour market, the average duration of wage contracts in Malta is estimated at around 3.5 quarters compared to slightly more than 6 quarters in the euro area. The range of these estimates is broadly in line with the findings of the Inflation Persistence Network and the Wage Dynamics Network. In addition, price indexation in Malta is broadly similar to that observed in the euro area but wage indexation is higher. The latter finding is in line with our prior information given the partial wage indexation mechanism present in Malta.

Within the context of the New Keynesian Phillips Curve (NKPC), these results imply that inflation expectations play an important role in the price setting decisions in both economies and that Maltese firms are more sensitive to costs than their European counterparts.

Structural shock decomposition suggests that cost-push shocks are by far the most important shock explaining inflation differentials between the two economies. The importance of cost-push shocks and the sensitivity of domestic inflation to cost pressures suggest that developments along the supply-chain could be key to a better understanding of the relatively higher inflation in Malta. These elements can also lead to differences in the pass-through – possibly both in terms of timing and magnitude – of foreign commodity prices to inflation between the two economies.

Finally, it should be emphasized that inflation differentials should not be analysed in isolation but rather assessed from a holistic perspective in which they are possibly a symptom of wider macroeconomic rigidities. For instance, in recent years, wage developments in Malta have been similar to those in the euro area but productivity growth has been lagging behind. Addressing these supply-side rigidities, for example through policies designed to increase competition in some market segments or providing incentives to promote higher investment in ICT technologies in the distribution sector, are likely to spur productivity growth and enhance the economy's potential growth rate. In the process, this should exert downward pressure on prices.

1. Introduction and motivation

Since 1999, Malta has experienced persistently higher inflation than the euro area in all but three years (see Figure 1).[2] Since the start of Economic and Monetary Union (EMU) in 1999, consumer price inflation in Malta, as measured by the Harmonized Index of Consumer Prices (HICP) averaged 2.5% per annum, 0.5 percentage points higher than in the euro area.

Figure 1
HICP INFLATION IN MALTA AND THE EURO AREA
(annual growth rates; differentials in percentage points)

Source: Eurostat
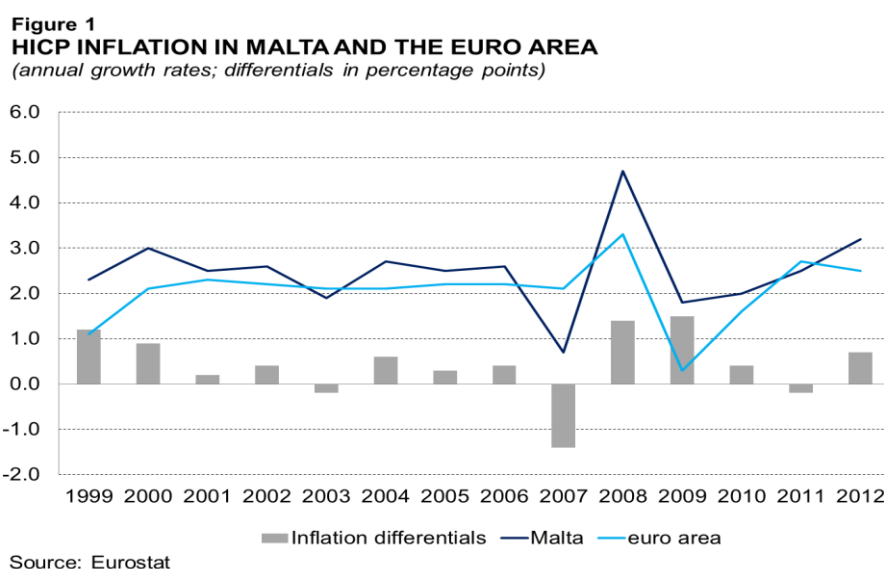
In a monetary union, high and persistent inflation above the union's average will eventually lead to the build-up of domestic imbalances and a deterioration in external competitiveness. While it is generally recognised that price dispersion is a common feature of currency unions, inflation differentials within the euro area have been very persistent, with some countries systematically registering higher or lower inflation compared to the euro area average, exacerbating the internal imbalances within the monetary union and evident in diverging unit labour costs and current account balances. In EMU, monetary policy is conducted by the European Central Bank (ECB) with the primary objective of maintaining price stability in the euro area as a whole and is therefore unable to address directly country-specific inflation developments. In this environment, the resulting erosion of external competitiveness will have to be regained through a process of 'internal devaluation', with prices and wages increasing by less than the union's average for a number of years.

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[2] Data used in this paper runs until end-2012.

Events since the financial crisis revealed substantial heterogeneity across euro area countries in their ability to adjust their prices to restore cost competitiveness (see Figure 2). For instance, out of the countries that required international assistance, Ireland and, to a lesser extent, Portugal, managed to reduce their positive inflation differentials vis-à-vis the euro area since 2008, whereas Greece and Cyprus still registered higher inflation compared to the rest of euro area. Since 2008, average inflation differentials between Malta and the euro area were more pronounced, driven primarily by the impact of commodity prices and, more recently, by accommodation prices.

Figure 2
INFLATION DIFFERENTIALS IN EURO AREA COUNTRIES
(percentage point difference from euro area average)
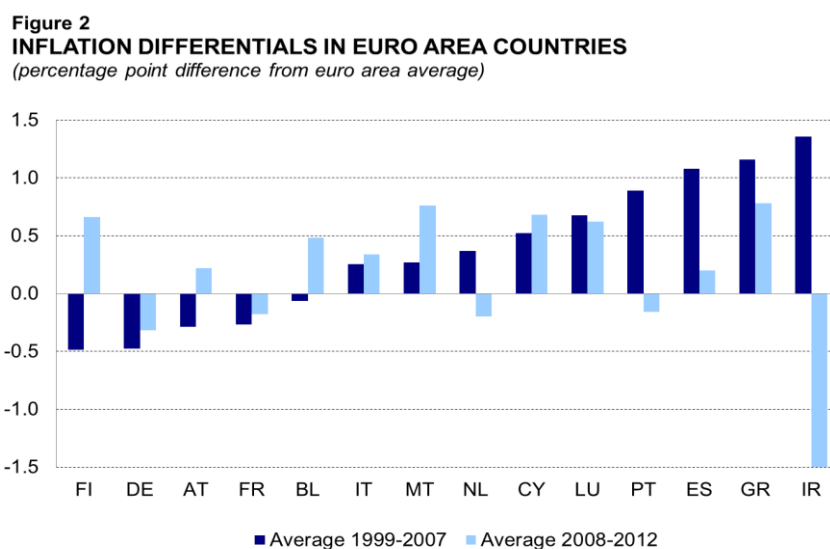
Source: Eurostat

The consequences of inflation differentials should not be understated. Higher prices erode households' purchasing power and increase the uncertainty for business operators. With a common euro area wide monetary policy, persistent higher inflation in Malta leads to lower real interest rates, which in turn can create internal imbalances and asset price bubbles. In Malta, price inflation partially feeds into wages through the Cost-of-Living Adjustment (COLA) mechanism, thereby undermining to some degree the export sector's cost competitiveness, especially in parts of the manufacturing industry and low-skilled employment intensive sectors, if not matched by productivity gains. Ultimately, a small and open economy like Malta can only generate wealth and increase its living standards in a sustainable manner through its ability to sell the goods and services that it produces in foreign markets. Since the country is a price taker in international markets, persistent above average increases in price inflation will eventually harm external competitiveness and cannot be sustained indefinitely.

The literature proposes three main theories to explain the underlying sources of inflation differentials. We find that, in general, those related to price level convergence and cross-country differences in the business cycles may have played only a limited role in explaining inflation differentials between Malta and the euro

area over the last decade. On the contrary, structural features of the economy, such as differences in market structures, are likely to have played a more important role.

In this paper, inflation differentials in Malta are also analysed through the lens of a two-country DSGE model of a monetary union. We adopt the model developed by Rabanal (2009) and extend it in two directions – by including a price mark-up (cost-push) shock and wage stickiness – thereby making it more relevant to Malta's characteristics.

The main conclusions from the DSGE analysis are the following. The estimation results suggest that price and wage setting behaviour in Malta is less sticky that in the euro area. Price indexation is broadly comparable but wage indexation in Malta is somewhat higher. Within the context of the NKPC, these results imply that inflation expectations play an important role in the price setting decisions in both economies and that Maltese firms are more sensitive to costs than their European counterparts. Cost-push shocks, which turn out to be correlated with international commodity prices, are predominant in explaining the fluctuations in inflation differentials. Differences in the relative importance of shocks explaining developments in HICP inflation are mainly due to the size and structure of the two economies, with cost-push shocks being predominant in explaining inflation in Malta while domestic factors, in the form of wages and productivity, play a more important role in the euro area.

The rest of this paper is organised as follows. Section 2 identifies five stylized facts about the inflationary process in Malta. Section 3 reviews the main theories proposed in the literature to explain inflation differentials in EMU. Section 4 provides a non-technical overview of the DSGE model. Technical details are available in a separate Appendix. Section 5 presents the estimation methodology. Section 6 discusses the results and considers several applications to evaluate the model. Section 6 wraps up the main conclusions, identifies the main policy recommendations and provides avenues for further research.

2. Stylized Facts

This section identifies five stylized facts about the inflationary process in Malta and the subsequent differentials against the euro area:

Stylized Fact #1: Since 1999, inflation in Malta has fluctuated around a constant mean of 2.5%. On average, inflation in Malta has been around 0.5 percentage points higher than that registered in the euro area.

In the late nineties, HICP inflation in Malta stood at around 4%, compared to less than 2% in the euro area, which was emerging from a decade long disinflationary process in the run-up to EMU. From 1999 to 2007, however, HICP inflation in both economies has fluctuated around a broadly constant mean, although somewhat higher and more volatile in Malta. The period from 2007 to 2009 was very volatile for both economies, owing to higher international energy and food prices, although the swings in Malta were more pronounced than those in the euro area. Between 1999 and 2012, HICP inflation in Malta averaged 2.5%, 0.5 percentage points higher than in the euro area, which, at 2.0%, has been broadly in line with the ECB's definition of price stability.

Stylized Fact #2: Higher inflation in Malta is not limited only to the headline HICP index but is also present in other HICP sub-indices that exclude the most volatile components (such as energy and unprocessed food) or administrative prices.

Higher inflation in Malta is not limited only to the headline HICP index but is also present in other HICP sub-indices that exclude the most volatile components (such as energy and unprocessed food) or administered prices (see Table 1). Between 1999 and 2012, measures of underlying inflation that exclude energy and unprocessed food averaged around 0.4 to 0.5 p.p. higher than in the euro area and have been more volatile. For example, overall inflation excluding energy and unprocessed food in Malta fluctuated between a maximum of 5.0% and a minimum of -0.5% during this period, whereas in the euro area, the range was between 2.7% and 0.7%, respectively. Even with the exclusion of administered prices, inflation in Malta has been on average 0.2 p.p. higher. These findings warrant a deeper understanding of the structural forces behind Malta's inflation dynamics and the price setting behaviour of domestic firms.

Table 1
KEY SUMMARY STATISTICS 1999 - 2012
percent

	Average	Maximum	Minimum	Volatility[a]
Malta				
HICP inflation	2.5	5.7	-1.1	0.5
HICP inflation excluding energy	2.2	4.8	-0.6	0.5
HICP inflation excluding energy and unprocessed food	2.1	5.0	-0.5	0.5
HICP inflation excluding administered prices[b]	2.3	5.1	-0.8	0.5
Euro area				
HICP inflation	2.1	4.0	-0.6	0.4
HICP inflation excluding energy	1.7	3.1	0.6	0.3
HICP inflation excluding energy and unprocessed food	1.7	2.7	0.7	0.3
HICP inflation excluding administered prices[b]	2.1	4.2	-0.9	0.4

(a) Measured as the standard deviation of the series divided by the mean.
(b) Series start in 2002

Stylized Fact #3: Inflation persistence in Malta is moderate and broadly similar to estimates for the euro area.

Estimates of inflation persistence in Malta point towards moderate degrees of inflation persistence.[3] Demarco (2004) estimates inflation persistence using a first-order autoregressive model on each of the ten main sub-components of the Retail Price Index (RPI). More recent estimates using HICP information point to a similar conclusion, with a persistence parameter of the overall HICP inflation around 0.3.[4] In both studies, unprocessed food and energy components exhibit low persistence while the degree of persistence is higher for services and industrial goods. In addition, estimates from the literature suggest that inflation persistence in Malta is broadly similar to the euro area countries and in general, lower than the estimates for the 10 New Member States that joined the EU in 2004.[5]

Stylized Fact #4: Differences in household consumption baskets can exacerbate inflation differentials. In Malta's case, the hotels and restaurants category and, to a lesser extent, food, have a higher weight in the HICP basket; on the contrary, the weight of energy in Malta's consumption basket is the lowest in the Euro area.

One possible source of inflation differentials can be households' different consumption expenditure patterns. A comparison of the evolution of the HICP consumption basket of Malta and the euro area between 1999 and 2012 leads to four main observations. First, despite the downward trend observed in Malta's hotels and restaurants category, this component, with a weight of 15.7% in 2012, is still significantly larger than in the euro area, which stood at 9.2%, reflecting Malta's reliance on the tourism industry. Second, the weight of the housing, water, electricity and gas component in Malta's expenditure basket, which stood at 8.5% in 2012, still remains almost half of that observed in the euro area. This is also reflected in the weight of the energy component in Malta, which at 7.3% in 2012, is one of the lowest among the euro area countries. Third, the weight of the food category in Malta, at 20.2%, is around 1 p.p. higher than in the euro area, although the gap in this category has been gradually narrowing down in recent years. Finally, one observes an increase in households' expenditure on recreational and information technology-related items at the expense of more traditional categories, such as furnishing and clothing. This trend reflects society's changing consumption

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3 Altissimo et al (2006) defined inflation persistence as "the tendency of inflation to converge slowly towards its long run value following a shock".Different degrees of inflation persistence compared to the euro area could also be a source of inflation differentials.
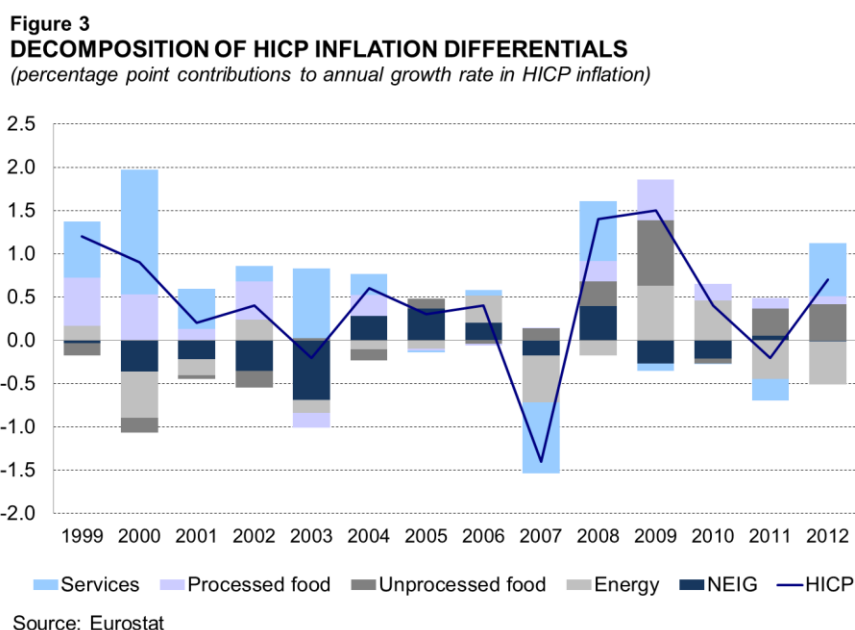4 See Central Bank of Malta (2013)
5 See, for example, Vladova and Pachedjiev (2008) who estimate univariate models for the euro area countries and Franta et al (2010) who apply a model with time-varying mean for the new Member States and selected euro area countries.

patterns, especially the importance of online shopping observed in recent years, and is, in general, in line with spending habits in the euro area.

With the first three categories – hotels and restaurants, energy and food – being important drivers of inflationary pressures in recent years, differences in weights in both regions' consumption baskets could have contributed to exacerbate or dampen inflation differentials in the face of common shocks to both economies.

Stylized Fact #5: The underlying drivers of inflation differentials are different in the pre- and post-EU period. Decomposition from the expenditure side suggests that services have been the main driver of inflation differentials in the pre-EU period, while the contribution of energy and foods inflation has become more significant in recent years. Supply-side decomposition shows that growth in wages has been the main driver of the differentials in the GDP deflator between the two economies in the pre-EU period, while growth in gross operating surplus has driven the differentials between 2005 and 2012.

Figure 3 decomposes the inflation differentials between Malta and the euro area into 5 main expenditure components of the HICP consumption basket: processed food, unprocessed food, energy, non-energy industrial goods and services. Between 1999 and 2004, the services category and, to a lesser extent, processed food have been the main contributors of inflation differentials, while the other components have contributed in the opposite direction.

Figure 3
DECOMPOSITION OF HICP INFLATION DIFFERENTIALS
(percentage point contributions to annual growth rate in HICP inflation)

Source: Eurostat

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Inflation differentials have been more volatile and pronounced between 2007 and 2009. The sharp drop in 2007 was mainly due to hospitality prices and energy. The latter reflect the decision by the authorities to postpone the adjustment of utility prices to higher global oil prices. The subsequent revision in utility prices in the latter part of 2008 led to positive inflation differentials in a period when energy prices in the euro area started to decelerate. The positive inflation differentials in 2008 were also driven by the pickup in hospitality prices, driven by a buoyant tourism sector following the arrival of low-cost airlines. Fluctuations in this sector were amplified since hotels & restaurants comprise a relatively large share in Malta's HICP basket. Food price inflation remained stubbornly high in the latter half of 2008 and 2009 despite the downward correction in international food prices. Food and energy remained the main contributors to inflation differentials in 2010. In 2012, the differentials were driven by accommodation and food prices, whereas the contribution of energy prices was negative in both 2011 and 2012.

From a supply-side perspective, price inflation as measured by the annual growth rate of the GDP deflator, can be decomposed in three components: growth in wages, profits (gross operating surplus) and net taxes. The nominal value of GDP is the sum of compensation of employees, gross operating surplus and net taxes:

$$PY = wL + GOS + NT$$

where P denotes the GDP price deflator, Y is the GDP volume, w is the nominal compensation per worker, L is the number of workers, GOS is the gross operating surplus and NT represents net taxes. Dividing both sides by Y, we arrive at the following identity for the GDP deflator:

$$P = \frac{wL}{Y} + \frac{GOS}{Y} + \frac{NT}{Y}$$

The first two columns in Figure 4 decompose the contribution of these three components to inflation differentials for the periods 2001-2004 and 2005-2012, respectively. The last column computes the average for the two sub-periods.

Figure 4
SUPPLY SIDE DECOMPOSITION OF INFLATION DIFFERENTIALS
(percentage point contributions)
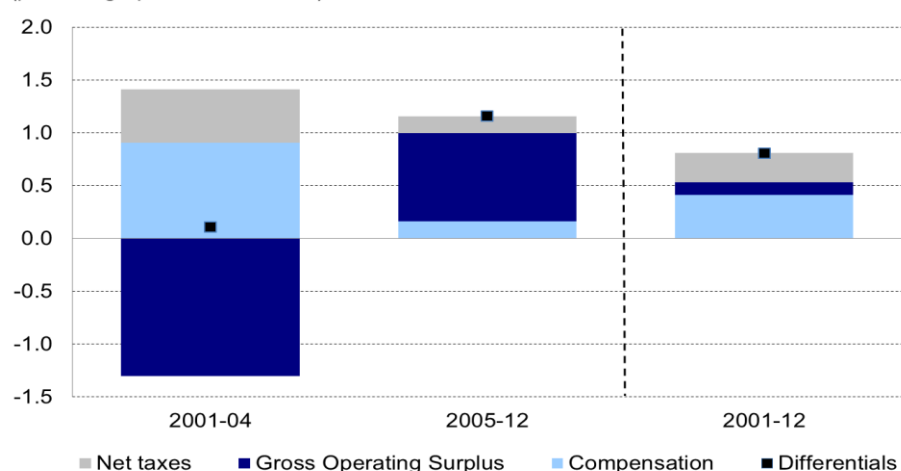
Source: Eurostat, own calculations

Growth in wages has been the main driver of the differentials in the GDP deflator between the two economies in the pre-EU period, in part driven by two collective agreements in the public sector. Net taxes also contributed positively during this period mainly due to the increase in VAT rate in 2004. The contribution from gross operating surplus was, however, negative following a period of restructuring in the manufacturing sector.

On the contrary, the differentials after EU membership have been driven mainly by gross operating surplus, reflecting the sectoral diversification of the Maltese economy towards higher value-added industries. The contribution of wages and net taxes has been slightly positive, at around 0.2 p.p. each. The lower contribution of wages reflects a period of wage moderation, with nominal wage growth increasing on average by 2.6% between 2005 and 2012, compared to 4.2% in the period 1995-2004.

3. Theories That Explain Inflation Differentials in EMU

The underlying sources of inflation differentials in EMU have been extensively studied and documented over the past decade. In general, the factors explaining the dynamics of inflation differentials can be broadly grouped in three categories: (i) price level convergence, (ii) cross-country differences in the business cycles and the role of asymmetric demand shocks and (iii) structural features of the economy, such as heterogeneous product and labour markets.

The methodologies applied in the literature are various, ranging from descriptive statistics (ECB, 2003) and regression analysis (Hononan and Lane, 2003) to factor models (Beck et al, 2006), small multi-country reduced form models (Angeloni and Ehrmann, 2004) and fully-fledged micro founded dynamic stochastic general equilibrium models (Rabanal, 2009; Andres, Ortega and Valles, 2003).

Inflation differentials can be the result of equilibrium changes in relative prices due to price level convergence as a result of economic catching-up process. In this case, higher inflation is not necessarily a 'bad' thing. One theory that has attracted particular attention is the Balassa-Samuelson effect, which focuses on the effect of sectoral differences in productivity growth on the aggregate price level. High productivity growth in the tradable sector, which is exposed to foreign competition, leads to high wage awards in that sector but with no corresponding increases in unit labour costs. In the presence of high sectoral labour mobility, however, higher wages tend to spill-over to the non-tradable sector. In the process, this exerts upward pressure on prices in that sector since this is typically characterised by lower average labour productivity growth. In general, the Balassa-Samuelson effect is often associated with the process of convergence in income levels across countries.

Table 2: Convergence Indicators, Malta and Selected EU Countries

GDP per capita in PPS
EA=100

	2002	2007	2012
Malta	74	72	80
Czech Rep.	66	76	73
Cyprus	79	87	84
Slovenia	74	82	76

Price Level Convergence
EA=100

	2002	2007	2012
Malta	69	69	71
Czech Rep.	54	61	69
Cyprus	85	87	85
Slovenia	72	76	79

Source: Eurostat

Evidence suggests that the Balassa-Samuelson effect may have played only a limited role in explaining inflation differentials in Malta. While estimates of tradable and non-tradable productivity growth in Malta are not available due to the absence of appropriate sectoral price indices, Table 2 shows the evolution of

GDP per capita in Purchasing Power Standard (PPS) and comparative price level indices against the euro area of Malta and three other countries with a similar level of economic development over the past decade. Before the onset of the financial crisis in 2008, income levels in Malta vis-à-vis the euro area have not improved. This is in clear contrast to the experience of Cyprus, the Czech Republic and Slovenia, which have all experienced steady increases in their income levels before the crisis. On the contrary, developments since the 2008 have partly reversed these trends, as relative GDP per capita in Malta has improved steadily, as the domestic recession was less severe than in the euro area and the recovery was more pronounced. A similar picture emerges if one looks at indicators of price level convergence.

Cross-country differences in business cycles may contribute to different inflation rates among countries sharing the single currency. Countries with a positive output gap, that is, with actual output being higher than their potential, tend to face upward pressure on prices, and vice versa. In this regard, Malta's business cycle has become increasingly synchronized with that of the euro area, especially after EU accession in 2004.[6]

Individual euro area countries may also be subject to idiosyncratic shocks. For instance, Ireland and Spain experienced strong demand shocks prior to the recent financial crisis driven by booming property prices. Between 1999 and 2007, average GDP growth in Malta stood at 2.6%, only 0.3 percentage points higher than the euro area average of 2.3%, but considerably below the growth rates experienced by other countries.[7] In general, this evidence suggests that, compared to other countries, differences in business cycles or idiosyncratic shocks have been less important in explaining inflation differentials in Malta during the period reviewed.

Structural features of the economy may lead to different inflation dynamics even in the face of symmetric shocks. For example, if euro area countries have different degrees of oil dependency or different exchange rate pass-through patterns, the impact of changes in oil prices and exchange rates on domestic prices will differ. The effect of exchange rate fluctuations on domestic prices is also affected by a country's geographical trade structure, especially against non-euro area trading partners. In this regard, more than half of Malta's imports come from euro area countries but only around a third of its exports are directed to them. Malta is also completely dependent on imported oil for the generation of electricity and on an energy intensive desalination process to augment the water supply from natural sources.

Finally, inflation differentials can arise from country-specific characteristics of the domestic product and labour markets. This is likely to be an important factor for Malta where differences in market structures, in part explained by the characteristics of Malta's small island economy, are more likely to play an important

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[6] The correlation coefficient of the output gap in Malta and the euro area, derived from a Cobb-Douglas Production Function from the European Commission, increased from 0.4 for the period 1997-2004 to 0.7 in 2005-2014.
[7] Average annual GDP growth rate between 1999 and 2007 stood at 3.9% in Cyprus, 4.5% in Slovenia and 4.3% in the Czech Republic (4.3%). GDP growth rates in Ireland and Spain, two countries that registered high increases in house prices before the crisis, averaged 6.4% and 3.7%, respectively. Data source: EC Spring Economic Forecasts 2013.

role. Consider, for example, the oil and commodity price boom of 2008, which exerted upward pressure on inflation in both Malta and the euro area. One observes this in the experience with higher international energy and food prices between 2007 and 2009, when the magnitudes and timing of the pass-through to domestic prices were different from those observed in the euro area and the respective prices in international markets (see Figures 5 and 6). For instance, unprocessed food inflation in the euro area peaked at 4.4% in July 2008, whereas in Malta it peaked 10 months later at 15.5%. The magnitude of energy price increases in Malta have also been more pronounced that those experienced by our trading partners despite the lower weight of energy in Malta's consumption basket. By the end of 2008, energy price inflation in Malta was still hovering around 20% at a time when the equivalent measure of inflation in the euro area had already declined in negative territory.

In addition, second round effects due to the interaction of wage and price dynamics can make inflation even more persistent, a process that is likely to be exacerbated by the partial wage indexation mechanism in Malta.

Figure 5
UNPROCESSED FOOD INFLATION AND INTERNATIONAL FOOD PRICES: 2006 - 2011
(annual growth rates)

Euro area (RHS) ——— Malta (RHS) ——— IMF Food price index (LHS)

Sources: Eurostat, IMF
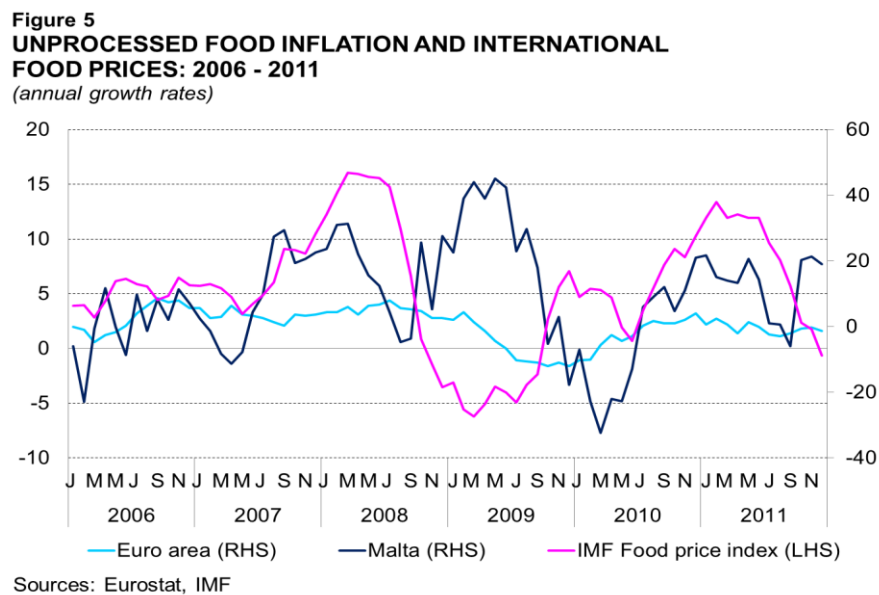
Figure 6
ENERGY INFLATION AND INTERNATIONAL ENERGY PRICES:
2006 - 2011
(annual growth rates)

Euro area (RHS) — Malta (RHS) — IMF Fuel (Energy) price index (LHS)
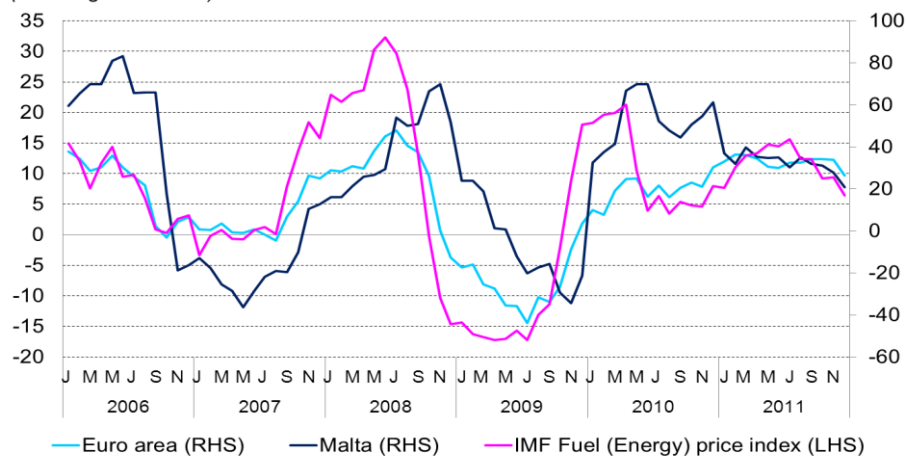
Sources: Eurostat, IMF

Overall, therefore, the evidence seems to suggest that out of the three factors identified in the literature to explain inflation differentials, it is likely that differences in market structures are likely to play an important role.

4. The DSGE Model

We will now analyse the relative importance of the three main determinants of inflation differentials identified in the previous section from the lens of a medium-scale DSGE model. The model incorporates a number of New Keynesian nominal and real rigidities, such as price and wage stickiness, indexation in price and wage contracts and habit formation in consumption. Monetary policy is symmetric but its transmission to output and prices can be asymmetric due to the different degrees of rigidities. The model includes a number of shocks – demand shocks in the form of government expenditure, price and wage mark-up shocks, sectoral productivity shocks – the effect of which can also be asymmetric across the two economies.

In this paper, we adopt the model developed by Rabanal (2009), which consists of a two-country two-sector DSGE model of a monetary union. The model is estimated with Bayesian inference methods using data for Malta and the euro area. This approach, which can be considered as middle ground between classical estimation methods and calibration, is particularly useful when the sample is relatively short, as is the case of Malta, since it allows the modeller to incorporate additional information through the use of priors. A potential limitation of using a two-country model of a monetary union, which was also identified in the original paper by Rabanal (2009), is that external shocks to EMU, such as exchange rate fluctuations, are not explicitly modelled and, therefore, do not play a role in explaining inflation differentials.

Figure 7 presents a schematic representation of the DSGE model and its main features. A technical description of the model is available in Appendix D.

The original version of the model is extended in two directions which we consider important in explaining inflation dynamics in Malta. First, we allow for a richer labour market specification in which wages are rigid and do not adjust instantaneously, thereby creating a sluggish adjustment of the marginal costs of production. This extension is introduced to account for Malta's partial wage indexation mechanism (COLA), which is a feature of the Maltese labour market. Second, we allow for pricing-to-market, whereby producers are allowed to set different prices for the domestic and foreign markets. The latter modification facilitates the identification between productivity and cost-push shocks, which was not possible in Rabanal (2009) and can be interpreted to reflect differences in the degree of competition in the economies or in distribution costs.[8] Cost-push shocks were therefore introduced to account for the fact that commodity prices, like energy and food, played an important role in explaining inflation differentials in recent years.[9]

The monetary union is composed of two regions, Malta (MT) and the rest of the euro area (EA). The tradable sector accounts for a share γ in total production and produces goods sold domestically and abroad, while the non-tradable sector, with a share of $(1 - \gamma)$, produces goods for the domestic economy.

Households in each economy consume differentiated goods, produced either domestically or imported. They seek to maximize expected discounted utility subject to their intertemporal budget constraint, which states that income from labour, profits and their bond portfolio must cover consumption and transactions in financial markets. Following the recent literature, households' utility includes external habit formation, which leads to a more persistent and gradual response of consumption and output to economic shocks. The household optimization problem yields the usual Euler equation, where aggregate consumption depends on past and expected consumption and the real interest rate. The latter provides the main transmission channel through which monetary policy influences aggregate demand and prices in the model. The sensitivity of consumption to changes in the real interest rate is determined by two parameters, habit formation and the inverse elasticity of intertemporal substitution. Demand for sectoral goods (e.g. tradable and non-tradable goods) depends on price elasticities of substitution, the product's relative price against other price indices in the economy and overall demand.

Households provide labour services to firms in a monopolistically competitive manner, thereby setting their wages in each period to maximize their utility subject to their budget constraint. The labour market is

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[8] See, for instance, Gomes et al (2010) for a DSGE model which makes a distinction between tradables and non-tradables and has both productivity and mark-up shocks.
[9] Rabanal's original model was estimated for the period 1996-2006, thus excluding the high commodity prices experienced post-2007.

specific to each economy and there is no mobility of labour between the two economies. Wage rigidities are introduced a la Calvo, which implies that not all households are allowed to optimally adjust their wages in each period.[10] This means that when they re-optimize their wages, households take into consideration the possibility that wages will remain fixed for some time in the future. The probability that households adjust their wages is given by $(1-\theta_w)$. Those households that cannot re-optimize their wages will index their wages to past inflation, with the parameter φ_w determining the degree of wage indexation.

In the absence of the nominal exchange rate fluctuations between the two economies, changes in the real exchange rate are due to inflation differentials.

Turning to the production side, in each economy there is a continuum of imperfectly competitive firms that produce differentiated goods for domestic and export purposes. Domestic goods are further classified into non-tradable and tradable products. For simplicity, and following the common practice in small to medium scale DSGE models, we abstract from capital accumulation in the firms' production function. Firms' production function thus consists of only one productive factor, labour, together with sector specific productivity. Productivity is allowed to differ between the two economies and across sectors but in all cases, it is assumed to follow an AR (1) process. In addition, the model also includes a common European-wide productivity shock that affects both economies' tradable sector.

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[10] In DSGE models, wage rigidities are introduced by assuming some imperfections in the labour market. In particular, the key assumption is that households/workers have some monopoly power, which allows them to set wages for the differentiated labour services they supply. See Gali (2008) for a textbook treatment of a canonical DSGE model with sticky wages and prices.

Figure 7: Schematic representation of the model
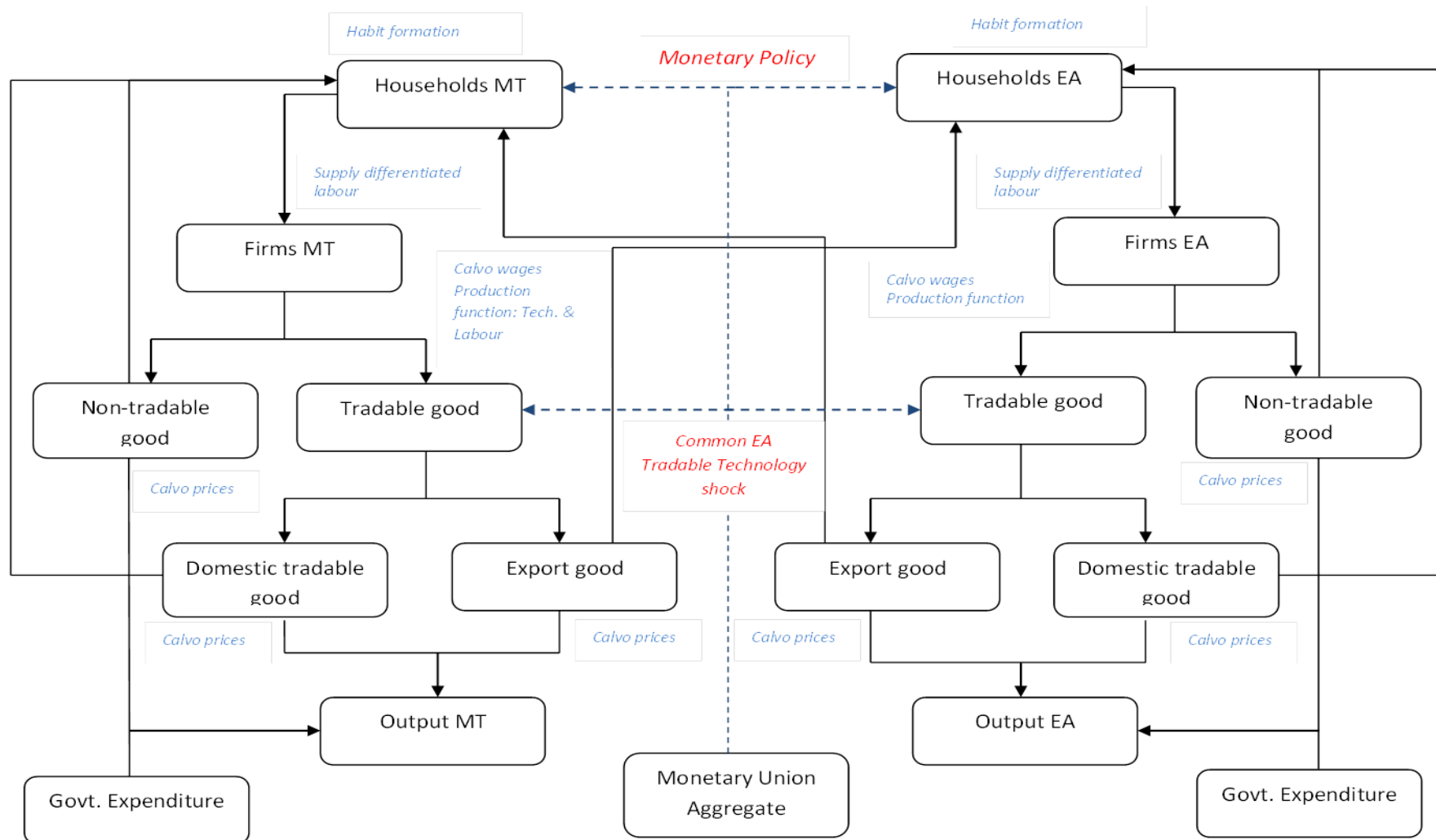
Price setting decisions are based according to the Calvo mechanism, where every period intermediate firms receive a signal that determines whether they can adjust their prices or not. This signal arrives to a producer with a probability $(1 - \theta)$, with θ being sector specific.[11] The model also includes price indexation to past inflation, φ, to introduce inertia and therefore provide a better fit to inflation dynamics. The resulting NKPC assumes the following form:

$$\pi_t = \omega\pi_{t-1} + (1 - \omega)E_t\pi_{t+1} + \gamma\widetilde{mc}_t$$

with $= \frac{\varphi}{1+\varphi\beta}$, $(1-\omega) = \frac{\beta}{1+\varphi\beta}$ and $\gamma = \frac{(1-\theta)(1-\beta\theta)}{\theta(1+\varphi\beta)}$. β refers to the rate of time preference. The last term determines the sensitivity of inflation to real marginal costs $\widetilde{mc}_t$ or, in other words, the slope of the Phillips Curve. In the model, real marginal costs depend positively on real wages and cost-push shocks (defined as AR (1) processes) and negatively on sectoral productivity and relative prices. The cost-push shock captures the effect of other variables that affect inflation, such as commodity prices, which are not explicitly included in the model. The model incorporates the Balassa-Samuelson effect since a productivity shock in the tradable sector will raise real wages in the economy, leading to higher inflation in the non-tradable sector in the absence of similar productivity gains in this sector. The relative price component implies that higher sectoral inflation will lead to a decline in demand for the particular sectoral output as consumers shift towards cheaper goods, thereby acting as a correcting mechanism.

Finally, demand shocks are incorporated in the model the form of government spending in both economies. These are assumed to be exogenous and are modelled as AR (1) processes. Monetary policy is common to both economies and is specified via a Taylor rule with interest rate smoothing.

5. Empirical Analysis and Bayesian Estimation

The model is estimated using Bayesian inference methods which in recent years have emerged as the most popular technique to estimate DSGE models.[12] Bayesian methods can be considered as middle ground between classical estimation methods, such as maximum likelihood, and calibration. An attractive feature of Bayesian methods is the incorporation of prior information available to the researcher (from micro studies, surveys or the literature), which can be especially useful when the sample is relatively small and the data uninformative about certain parameters. In addition, the use of priors restricts the parameters to stay within economically-sensible regions.

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[11] The productive sector consists of three sectors, $k = \{N, H, F\}$. N refers to the non-tradable sector, H to the domestic tradable sector and F to the export sector.
[12] See Almedia (2009) and An and Schorfheide (2007) for details of Bayesian inference methods.

The model is estimated using nine observable variables: GDP, overall HICP inflation, non-tradable HICP inflation and nominal wage growth for both Malta and the euro area, together with the 3-month Euribor rate. The Maltese series for non-tradable inflation was constructed using the services index excluding package holidays & accommodation and including the electricity & gas categories. Non-tradable inflation in the euro area is proxied by the services index. In contrast to Rabanal (2009), we abstract from using GDP series for the non-tradable sector since sectoral volume figures are not available for Malta.[13] The GDP series is HP-filtered while data on inflation, wage growth and nominal interest rates are demeaned so that they are interpreted as deviations from equilibrium.[14] The estimation is realized using quarterly data for the period 2000Q1 to 2011Q2 using DYNARE and all data are obtained from Eurostat. The full set of log-linearized equations and technical details of the estimated model are available in Appendices E to H.

The stochastic behaviour of the system is driven by twelve exogenous shocks. A first set – shocks to tradable and non-tradable productivity, demand, wage-markup and cost-push – is estimated to each economy separately. These shock variables are assumed to follow an independent first-order autoregressive stochastic process. The second set – shocks to monetary policy and the common technology – are assumed to follow IID independent processes.[15]

From the outset, we assume that the Maltese economy can be well approximated as being part of the monetary union since 2000 as the country adhered to a fixed exchange regime prior to ERM II membership in 2005, with the euro being assigned a weight of 70% in the country's currency basket.

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[13] This is due to the absence of appropriate price deflators, especially for services. In addition, the distinction between tradables and non-tradables is not clear cut in a small and open economy like Malta, where tourism and other services, like business services, are considered as tradables.

[14] Rabanal (2009) also estimates the model by introducing different trends in country- and sector-specific technology shocks. However, we refrain from this approach since we do not make a distinction between sector-specific differences in productivity. Moreover, Rabanal (2009) shows that the estimated model with model-consistent inflation and growth rates delivers a worse fit to the data than the demeaned version. This is due to the fact that Spain had both higher inflation and higher real GDP growth than the euro area over the estimated sample and the two facts cannot be explained with just one parameter, the productivity growth differential.

[15] This approach follows Smets and Wouters (2003), where identification is achieved by assuming that the structural shocks are uncorrelated and some of them follow a white noise process.

Table 3

Calibrated Parameters

Parameter	Description	Value
γ	Share of tradables in MT consumption	0.71
γ^*	Share of tradables in EA consumption	0.60
λ	Fraction of MT home goods in T*	0.50
λ^*	Fraction of EA home goods in T*	0.99
$\varepsilon, \varepsilon^*$	Elast. of substitution btw T and NT goods	0.50
ν, ν^*	Elast. of substitution between domestic and imported tradables	1.50
ω, ω^*	Wage elast. of demand for labour bundles	1.00
φ, φ^*	Frisch elasticity	2.00
h, h^*	External habit formation	0.60
G_Y	Share of Gov't spending in MT	0.20
G_Y^*	Share of Gov't spending in EA	0.21
β	Discount factor	0.99
ρ_R	Taylor Rule: interest rate smoothing	0.75
ρ_π	Taylor Rule: response to inflation	1.50
ρ_y	Taylor Rule: response to output	0.125

Given the short sample, we restricted the estimation to the Calvo and indexation price and wage parameters, the autoregressive processes and the standard deviation of the shocks. For the distributions of the priors we relied heavily on the original study of Rabanal (2009). In particular, we assume a Gamma distribution for non-negative parameters (like the standard deviations of the shock processes) and Beta distribution for parameters constrained between the 0 and 1 interval (like the shock persistence and the Calvo and indexation parameters). The standard errors of the priors reflect our subjective uncertainty on the values that different parameters should assume.

The rest of the parameters were calibrated a priori based on either their empirical counterparts in the data or using values from the literature (see Table 3). The discount factor and habit formation are set at 0.99 and 0.6, respectively, broadly in line with Smets and Wouters (2003). We assume that the degree of substitutability between domestic tradable and imported goods is higher than that between tradables and non-tradables, consistently with the existing literature. In particular, we set the elasticity of substitution between tradables and non-tradables at 0.5 while the elasticity between domestic and imported tradables at 1.5. Regarding labour market elasticities, we set the wage elasticity of demand for a specific labour bundle and the Frisch elasticity at 1 and 2, respectively. The share of tradable goods in the euro area is set at 0.6 (roughly

equivalent to the share of the Goods component in the HICP) and to 0.71 for Malta, reflecting the weight assigned following the construction of the non-tradable price index. The values for the shares of tradable goods and the share of domestically produced tradable goods were chosen to reproduce the respective size of the two economies and especially, the high degree of openness of the Maltese economy. The share of domestically produced tradable goods was set to 0.999 for the euro area, making it almost a closed economy within the context of a 2-country model and to 0.5 for Malta, making it a very open economy.[16] The share of government expenditure in GDP is calibrated from National Accounts statistics for the period 2000-2010. For the interest rate reaction function, we set the inflation coefficient at 1.5, the output gap coefficient at 0.125 and the interest rate smoothing parameter at 0.75.

Table 4 reports the distribution, the prior means and the standard deviation of the estimated parameters. Calvo parameters for tradable prices are assumed to have a prior mean of 0.667, implying that prices are changed every three quarters. For the non-tradable sector, we set a prior of 0.75 so that prices are re-optimized on average every four quarters. Both are common assumptions in the literature and broadly in line with micro evidence.[17] Calvo parameters for wages are centred at 0.833, which imply that wages are re-optimized every 6 quarters, in line with the findings of the Wage Dynamics Network.[18] Priors for price indexation parameters were centred at 0.5, while wage indexation were set at 0.75, reflecting existing wage indexation schemes in a number of European countries, including Malta. The standard deviation for the indexation parameters is set at 0.1, a common assumption in the DSGE literature, but we used tighter standard deviations for the stickiness parameters, thereby giving a greater weight to the results from micro evidence on price and wage re-setting processes. In addition, to reflect higher uncertainty about the number of times that prices are changed compared to wages, we set looser standard deviations for Calvo price parameters than for Calvo wage parameters. In the sensitivity analysis section, we assess the robustness of the results by changing both the prior means and the standard deviation of the stickiness parameters.

We had no strong a priori conviction about the autoregressive processes and we chose prior means of 0.75 and standard deviations of 0.1, which is in the range typically assumed in the literature.

We broadly followed Rabanal (2009) by assuming a gamma distribution for the innovation processes. We centred the prior means for the monetary and demand shocks at 1.0 and 1.5, respectively, higher than those used in the above mentioned study, since our estimation period includes the Great Recession of 2008/09 and its impact on monetary policy. Wage mark-up shocks were set lower than the cost-push shocks, reflecting the period of wage moderation observed over the past decade and the high energy and food prices in recent

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[16] The relative size of both economies is computed endogenously. Given the calibration, the relative size of Malta in the euro area is calculated at 0.1%.

[17] The results of the Inflation Persistence Network are summarized in Altissimo et al (2006).

[18] The results of the Wage Dynamics Network are summarized in ECB (2009).

years. Finally, prior means for the productivity shocks were set at relatively low values to reflect the fact that both economies registered sluggish productivity growth over the sample period.

Table 4

Prior mean and standard deviation

Parameter	Description	Distribution	Mean	Std. Dev.
$\theta_H, \theta_{F^*}, \theta_{H^*}, \theta_F$	Calvo price parameters (T)	Beta	0.67	0.05
θ_N, θ_{N^*}	Calvo price parameters (NT)	Beta	0.75	0.05
θ_W, θ_{W^*}	Calvo wage parameters	Beta	0.83	0.02
$\varphi_N, \varphi_H, \varphi_F, \varphi_{N^*}, \varphi_{H^*}, \varphi_{F^*}$	Price indexation parameters	Beta	0.50	0.10
φ_W, φ_{W^*}	Wage indexation parameters	Beta	0.75	0.10
$\rho_{GT}, \rho_{ZN}, \rho_{ZT}$	Shocks persistence parameters	Beta	0.75	0.10
ρ_P, ρ_W	AR terms in price and wage shocks	Beta	0.75	0.10
σ_r	Std. of monetary policy shock	Gamma	1.00	0.10
$\sigma_{ZT}, \sigma_{ZT^*}, \sigma_{ZN}, \sigma_{ZN^*}$	Std. of productivity	Gamma	0.15	0.10
$\sigma_{GT}, \sigma_{GT^*}, \sigma_W, \sigma_{W^*}$	Std. of government spending and wage mark-up shocks	Gamma	1.50	0.20
σ_P, σ_{P^*}	Std. of cost-push shocks	Gamma	2.50	0.50

6. Results & Evaluation

The model was estimated using the DYNARE toolbox for Matlab. We ran 2 chains of 150,000 draws of the Metropolis Hastings algorithm and discard the first one third of the draws. The acceptance rate for the two chains was broadly around 0.28, which is in line with Griffoli (2007). The Technical Appendix reports prior and posterior marginal densities and convergence diagnostics.

In general, posterior estimates of the structural shocks are larger in Malta than in the euro area (see Appendix A). This is consistent with the empirical evidence that small open economies are more vulnerable to shocks than larger, more closed economies. In particular, the posterior estimates of demand shocks are significantly higher than the prior means, reflecting the cyclical upswing before the crisis and the subsequent contraction in 2009.

Of particular importance for the purposes of this study is the size of the cost-push shock, which is larger in Malta. In part, this can be explained by the small size of the domestic economy and its dependence on international trade, with imports averaging around 85% of GDP. However, the fact that cost-push shocks are correlated with international commodity prices (see below) and that both economies are net importers of

commodities may suggest that this result is also driven by country-specific characteristics in the importation and distribution chains.

Table 5 reproduces the price and wage parameter estimates. Two main conclusions emerge.

First, price and wage setting behaviour in Malta is less sticky than that observed in the euro area. In Malta, the average duration of prices is estimated between 1.5 and 2.5 quarters, whereas in the euro area, the average price duration is between 2 and 4 quarters.[19] The main difference lies in the prices of non-tradable goods and services, which in Malta are estimated to change every 2 quarters compared to 4 quarters in the euro area. Turning to the labour market, the average duration of wage contracts in Malta is estimated at around 3.5 quarters compared to slightly more than 6 quarters in the euro area.

Second, price indexation in Malta is broadly similar to that observed in the euro area but wage indexation is higher. The degree of backward-looking behaviour in the Phillips Curve is somewhat lower than the prior information, suggesting that inflation expectations by economic agents play an important role in the price setting process in both economies. These findings are also in line with those from the literature which estimate inflation persistence in Malta to be comparable to other euro area countries. Similarly, estimates of backward-lookingness in wage formation are lower than the prior information for both economies, though Malta's estimates are larger than those of the euro area. This result is not surprising given the partial wage indexation mechanism present in Malta.

Overall, these results are fully consistent with the micro evidence, for instance, the Inflation Persistence Network and the Wage Dynamics Report (WDR). Estimates of price stickiness for the euro area are in line with Rabanal and Rubio-Ramirez (2007) but significantly lower than those reported by Smets and Wouters (2003) and Christoffel et al (2008).[20] According to the WDR (see Appendix B), most changes in wages in Malta occur on an annual basis due to the COLA mechanism and tenure (related to the length of service of the employee). Responses on the frequency of price changes are more heterogeneous: 25% of respondents replied that they change prices on an annual basis, another 25% change prices more than once a year, 20% less than once a year and around 30% suggesting that they have no predefined pattern.

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[19] Duration $= \frac{1}{1-\theta}$

[20] Both Smets and Wouters (2003) and Christoffel et al (2008) report estimates of price stickiness in excess of 0.9, which implies an average price duration of more than 10 quarters (2.5 years). This is clearly in contrast with micro evidence. Christoffel et al (2008) explain that such a high estimate is reflective of a flat Phillips Curve rather than an extremely high degree of nominal rigidity.

Table 5

Calvo and Indexation Parameter Estimates

Parameter	Description	Prior mean	Post. mode	Conf. interval	
MALTA					
θ_H	Calvo prices (T)	0.67	0.43	0.35	0.52
θ_F	Calvo prices (T)	0.67	0.57	0.43	0.69
θ_N	Calvo prices (NT)	0.75	0.52	0.46	0.58
θ_W	Calvo wages	0.83	0.71	0.68	0.79
φ_H	Price indexation (T)	0.50	0.34	0.19	0.48
φ_F	Price indexation (T)	0.50	0.44	0.26	0.62
φ_N	Price indexation (NT)	0.50	0.33	0.19	0.47
φ_W	Wage indexation	0.75	0.34	0.25	0.44
EURO AREA					
θ_{H^*}	Calvo prices (T)	0.67	0.68	0.60	0.77
θ_{F^*}	Calvo prices (T)	0.67	0.49	0.43	0.55
θ_{N^*}	Calvo prices (NT)	0.75	0.74	0.69	0.79
θ_{W^*}	Calvo wages	0.83	0.84	0.82	0.87
φ_{H^*}	Price indexation (T)	0.50	0.51	0.34	0.67
φ_{F^*}	Price indexation (T)	0.50	0.33	0.20	0.47
φ_{N^*}	Price indexation (NT)	0.50	0.44	0.29	0.60
φ_{W^*}	Wage indexation	0.75	0.16	0.10	0.22

The estimates for the price indexation and stickiness parameters allow us to construct an aggregate NKPC for each of the two economies[21]:

$$\text{MT:} \quad \pi_t = 0.3\pi_{t-1} + 0.7E_t\pi_{t+1} + 0.4\widetilde{mc}_t$$
$$\text{EA:} \quad \pi_t = 0.3\pi_{t-1} + 0.7E_t\pi_{t+1} + 0.1\widetilde{mc}_t$$

The aggregate NKPCs imply a moderate and broadly similar degree of intrinsic (backward-looking) inflation persistence in both economies and that expectations of future inflation are an important determinant of the price-setting behaviour in both economies. The main difference clearly lies in the degree of extrinsic persistence, with inflation in Malta being more sensitive to the marginal cost component compared to the euro area, where inflation reacts more sluggishly to costs.

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[21] The aggregation is conditional on the calibrated values of γ and λ.

So what are the implications on HICP inflation of higher flexibility in price and wage setting behaviour in response to a shock? We can answer this question by simulating the model and running impulse response functions to assess the propagation mechanism, that is, how variables of interest respond to a particular shock. Figure 8 plots the response of inflation to one standard deviation in the estimated country-specific cost-push shock.

Figure 8
RESPONSE OF INFLATION TO COUNTRY SPECIFIC COST-PUSH SHOCK
(percentage points)

Source: own calculations
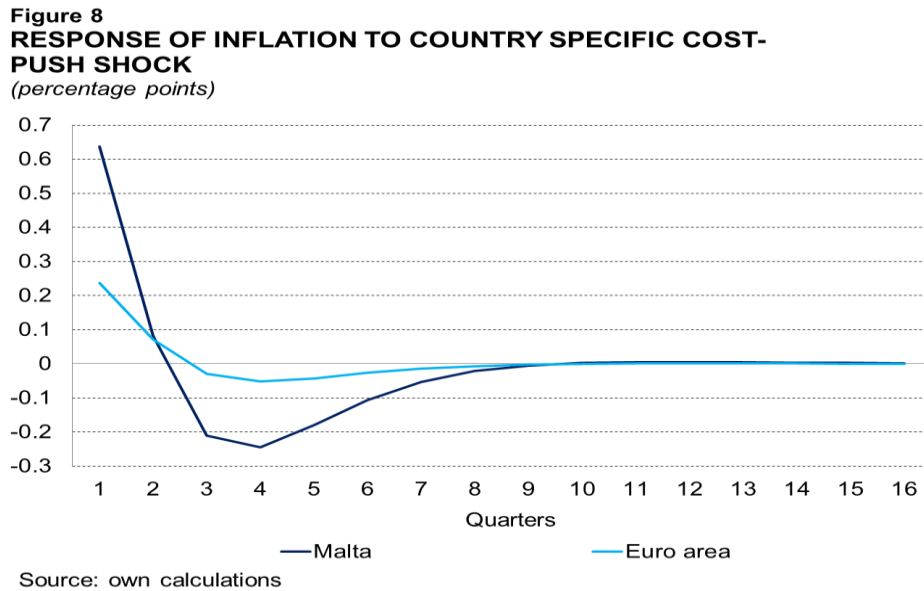
The simulation shows that the response of inflation in Malta to a cost-push shock is more pronounced on impact, with a tendency to undershoot after a few quarters. The impact of the shock dies gradually and inflation returns to its long run value after around two years. Euro area inflation behaves similarly, though the magnitude is two to three times less pronounced than that observed in Malta. In general, the response of inflation is broadly in line with our a priori expectations from the stylized facts identified in Section 2, with the effect of a cost-push shock being more pronounced (and volatile) in Malta than in the euro area.

We will now use the estimated DSGE model to decompose the sources of inflation differentials and HICP inflation between the two economies over the past decade. The variance decomposition decomposes the fluctuations in inflation and inflation differentials to the contribution of each structural shock. The shocks have been aggregated in broad categories. Since we have included wage rigidities in the model, we also distinguish between cost-push and wage mark-up shocks. In addition, we include the monetary shock from the monetary policy reaction function.

Figure 9
VARIANCE DECOMPOSITION OF INFLATION DIFFERENTIALS
(contribution of shocks explaining inflation differentials in the estimated structural model)
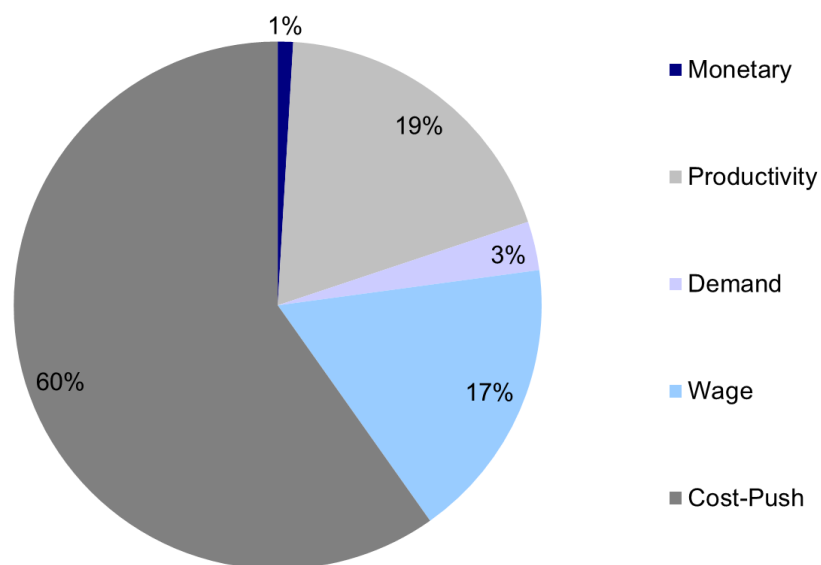
Source: own calculations

Figure 10
VARIANCE DECOMPOSITION OF HICP INFLATION IN MALTA AND EURO AREA
(contribution of structural shocks to HICP inflation; percent)
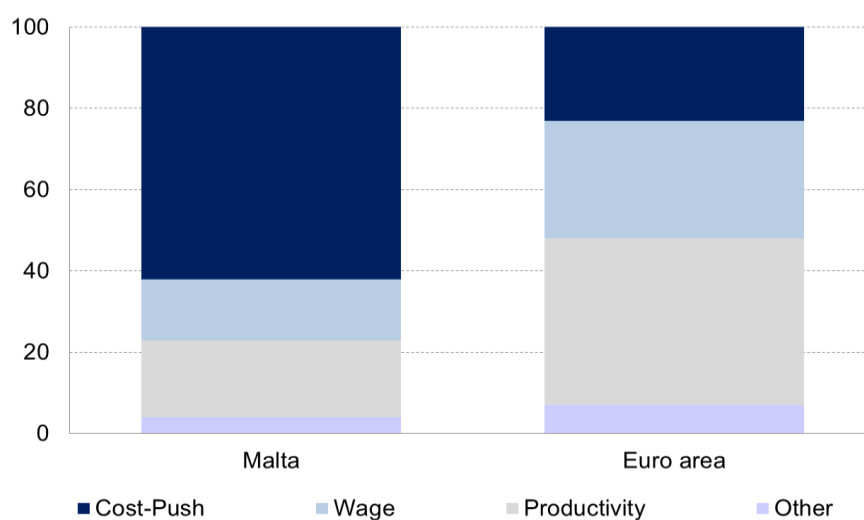
Source: own calculations

The results are summarized below:

Cost-push shocks are by far the most influential shock explaining inflation differentials between Malta and the euro area over the estimation period (see Figure 9).[22] This category explains around 60% of the fluctuations in inflation and inflation differentials, respectively. This is consistent with the decomposition in the stylized facts, since cost-push shocks capture the impact on inflation other than wages, productivity and relative prices, thereby including the effects of international commodity prices. Indeed, we observe a relatively high correlation between the four-quarter moving average of the estimated cost-push shock and the year-on-year increase in the Energy and Unprocessed Food HICP sub-index (EFOODUNP), with the correlation coefficient standing at 0.47. Given that both economies are importers of commodities, the dominant role of cost-push shocks in explaining inflation differentials points to differences in the pass-through – possibly both in terms of timing and magnitude – of foreign commodity prices to inflation in the two economies.

There are important differences in the variance decomposition of headline HICP inflation in Malta and the euro area (see Figure 10). In Malta's case, cost-push shocks are by far the most important shock explaining fluctuations in HICP inflation, followed by productivity and wage shocks. In the long-run, the latter two shocks explain round a third of developments in Malta's HICP inflation. In the euro area, productivity shocks constitute the largest category, followed by wage mark-ups and cost-push shocks.
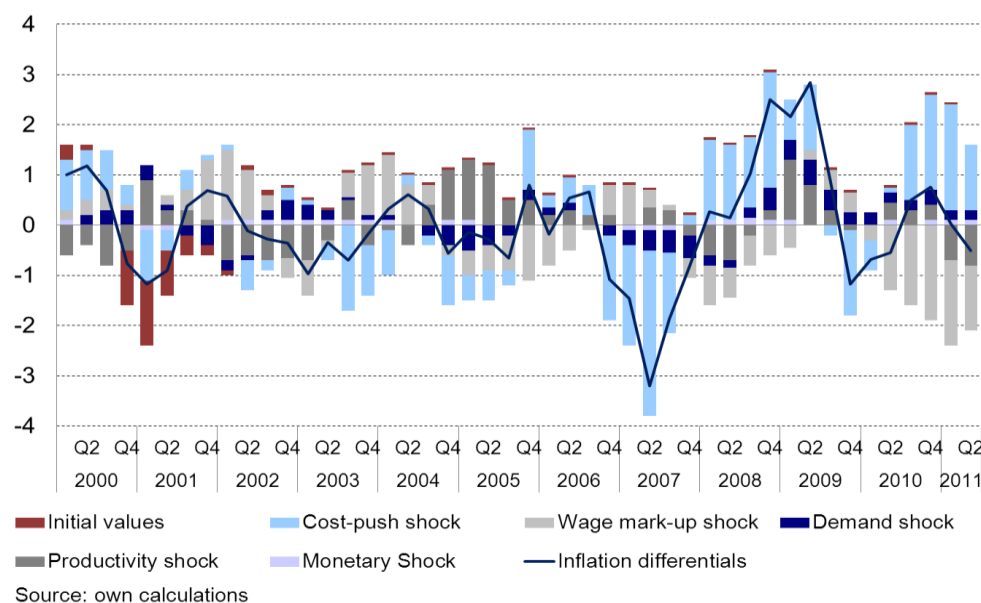
These findings are in line with what one would expect a priori given the size and structure of both economies: the high import content in domestic consumption, given Malta's size and openness, implies that foreign prices constitute an important element in domestic firms' cost structure and price setting behaviour. On the contrary, the euro area as a whole is a large and relatively closed economy and, hence, supply and domestic cost factors play a more important role in shaping inflation developments.

Figure 11 plots the historical contributions of the shocks to inflation differentials. While such decompositions should be treated with caution, they shed light on how the estimated model interprets the observed developments in the data. The story from the historical decomposition is broadly consistent with the stylized facts identified in Section 2. In particular (i) cost-push shocks are found to have been particularly important in explaining inflation differentials between 2007 and 2009 and (ii) wage mark-up shocks seem to have played a more important role in the early part of the last decade compared to more recent years, when they have been contributing negatively to inflation differentials following a period of wage moderation.

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[22] The model used by Rabanal (2009) does not distinguish between price mark-up (cost-push) and productivity shocks. Therefore, what is attributed as a productivity shock can also be attributed to a mark-up shock, and hence, the role found for productivity in his paper can be considered as an upper bound of the role played by productivity.

Figure 11
MODEL DECOMPOSITION OF INFLATION DIFFERENTIALS
(percentage point contributions to inflation differentials (demeaned))

Legend:
- Initial values
- Cost-push shock
- Wage mark-up shock
- Demand shock
- Productivity shock
- Monetary Shock
- Inflation differentials

Source: own calculations

6A. Sensitivity Analysis

To assess the sensitivity of the results to the assumed priors, we changed the model in two directions and re-estimated the model in each case. The results are presented in Appendix C. For both changes, we report not only the point estimates but also the variance decomposition of the inflation rate in both economies and the inflation differentials.

In Case I, the prior means for the price and wage stickiness parameters were centred at 0.75, a common assumption in the literature, which implies that prices and wages are re-optimized every four quarters. The standard deviation of the wage stickiness parameters are also set equal to the price stickiness parameters. In Case II, we set a looser standard deviation to the price and wage stickiness parameters, which we set at 0.1, similar to the indexation parameters.

Despite some changes in the point estimates, the main findings and conclusions remain broadly unchanged. Prices in Malta remain less sticky than those observed in the euro area: the average duration of price changes in Malta is estimated between 1 and 3 quarters compared to 1.5 and 4.5 quarters in the euro area. Differences in the estimates of wage stickiness are more pronounced and thus more sensitive to the prior used: wages in Malta are now estimated to change every 2 and 2.5 quarters, which is lower than the baseline

result of 3.5 quarters. On the contrary, estimates of wage stickiness for the euro area are higher than in the baseline case.

Turning to the variance decomposition, the sensitivity analysis confirms the importance of cost-push shocks in explaining inflation differentials between the two economies. Moreover, in both cases, the share of Maltese inflation explained by cost-push shocks is higher than the combined share of productivity and wage mark-up shocks, as opposed to the situation in the euro area, as also found in the baseline case.

Overall, therefore, while we observe some changes in the point estimates of some parameters, these do not change the overall conclusions of the report, suggesting that the qualitative findings are quite robust to changes in our priors.

7. Conclusion and Policy Recommendations

In this paper we use a medium-scale DSGE model of a monetary union to better understand Malta's inflation dynamics. The model is an extension of Rabanal (2009) with some added features to make it more relevant for Malta's structural characteristics.

Despite these additions, important caveats still apply to our results. Any model, irrespective of how complex or detailed, still remains a simplified version of reality. For instance, the monetary union dimension of the model implies that the exchange rate is irrevocably fixed. The model, therefore, is unable to capture the impact of exchange rate pass-through on inflation. In addition, the model does not include commodity prices, though high frequency movements in commodities, which have been one of the main drivers of inflation in recent years, are captured by the cost-push shocks.

The estimation of the structural model provides new insights on the dynamics of price setting behaviour in Malta. One of the main findings of this paper is that price and wage setting behaviour in Malta is less sticky than in the euro area. Estimates of inflation persistence are broadly similar in both economies but wage indexation in Malta is higher. Within the context of the New Keynesian Phillips Curve, these results suggest that inflation expectations play an important role in the price setting decisions in both economies but that Maltese firms are more sensitive to costs than their European counterparts. In light of these findings, an argument can be made for a business environment where production costs for firms are kept in check, while government-induced costs should be kept to a minimum. Expectations of lower inflation will eventually feed in the wage formation process, thereby assisting exporting firms to remain competitive.

Structural shock decomposition suggests that cost-push shocks are by far the most important shock explaining inflation differentials between the two economies. The importance of cost-push shocks and the sensitivity of domestic inflation to cost pressures suggest that developments along the supply-chain could be key to understand the relatively higher inflation in Malta. These elements can also lead to differences in the pass-through – possibly both in terms of timing and magnitude – of foreign commodity prices to inflation between the two economies.

In this regard, more detailed information on the determination of mark-ups, the pricing practices of firms in the importation and distribution chains of the production process and their impact on the cost structure of retailers, possibly from a micro perspective, is warranted. This will enhance our understanding of the underlying determinants of the inflationary process in Malta.[23]

Finally, it should also be emphasized that inflation differentials should not be analysed in isolation but rather assessed from a holistic perspective in which they are possibly a symptom of wider macroeconomic rigidities. For instance, in recent years, wage developments in Malta have been broadly in line with those in the euro area but productivity growth has been lagging behind. Addressing these supply-side rigidities, for example through policies designed to increase competition in some market segments or providing incentives to promote higher investment in ICT technologies in the distribution sector, are likely to spur productivity growth and enhance the economy's potential growth rate. In the process, this should exert downward pressure on prices.

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[23] In this regard, Borg (2009) and ECB (2011) provide evidence that product market mark-ups in Malta are relatively high when compared with other European countries.

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Appendix A: Estimation results of autoregressive terms and innovation processes

Parameter	Distribution	Prior mean	Prior Stdev.	Post. mode	Conf. interval	
		Autoregressive terms				
ρ_{ZT}	Beta	0. 75	0.1	0.49	0.32	0.66
ρ_{ZN}	Beta	0.75	0.1	0.78	0.66	0.91
ρ_{GT}	Beta	0.75	0.1	0.80	0.74	0.85
ρ_W	Beta	0.75	0.1	0.94	0.90	0.98
ρ_P	Beta	0.75	0.1	0.59	0.42	0.76
		Shocks				
ε_R	Gamma	1.50	0.20	0.41	0.28	0.54
ε_Z	Gamma	0.15	0.10	0.60	0.02	1.26
ε_{ZT}	Gamma	0.15	0.10	1.81	0.09	2.46
ε_{ZT*}	Gamma	0.15	0.10	1.08	0.03	1.75
ε_{ZN}	Gamma	0.15	0.10	1.70	1.18	2.24
ε_{ZN*}	Gamma	0.15	0.10	0.42	0.03	0.80
ε_{GT}	Gamma	1.50	0.50	5.78	5.06	6.49
ε_{GT*}	Gamma	1.50	0.50	3.95	3.41	4.48
ε_W	Gamma	1.00	0.20	3.10	2.57	3.64
ε_{W*}	Gamma	1.00	0.20	1.28	1.03	1.53
ε_P	Gamma	2.00	0.50	1.84	1.35	2.29
ε_{P*}	Gamma	2.00	0.50	0.94	0.60	1.27

Appendix B: Frequency of wage changes in Malta

Frequency of Wage Changes in Malta
% of respondents

	Tenure	Inflation	Other
More than once a year	2%	1%	2%
Once a year	42%	85%	47%
Once every two years	15%	3%	12%
Less frequently	12%	1%	19%
Don't know	29%	10%	20%

Source: Wage Dynamics Report

Appendix C: Sensitivity analysis

Prior and Posterior Estimates of Sensitivity Analysis

Parameter	Case I			Case II		
	Prior mean	Prior St.Dev	Post. mode	Prior mean	Prior St.Dev	Post. mode
θ_H	0.75	0.05	0.41	0.67	0.10	0.21
θ_F	0.75	0.05	0.67	0.67	0.10	0.57
θ_N	0.75	0.05	0.54	0.75	0.10	0.34
θ_W	0.75	0.05	0.60	0.83	0.10	0.53
φ_H	0.50	0.10	0.32	0.50	0.10	0.42
φ_F	0.50	0.10	0.46	0.50	0.10	0.49
φ_N	0.50	0.10	0.33	0.50	0.10	0.41
φ_W	0.75	0.10	0.50	0.75	0.10	0.55
θ_{H^*}	0.75	0.05	0.76	0.67	0.10	0.65
θ_{F^*}	0.75	0.05	0.51	0.67	0.10	0.37
θ_{N^*}	0.75	0.05	0.73	0.75	0.10	0.69
θ_{W^*}	0.75	0.05	0.85	0.83	0.10	0.90
φ_{H^*}	0.50	0.10	0.50	0.50	0.10	0.50
φ_{F^*}	0.50	0.10	0.34	0.50	0.10	0.41
φ_{N^*}	0.50	0.10	0.46	0.50	0.10	0.46
φ_{W^*}	0.75	0.10	0.21	0.75	0.10	0.15

Variance decomposition

	Case I			Case II		
	Inflation differentials	MT Inflation	EA Inflation	Inflation differentials	MT Inflation	EA Inflation
Monetary	1.4	5.2	8.1	4.1	8.0	8.9
Productivity	25.2	28.5	41.7	20.2	27.4	38.3
Demand	5.2	3.1	0.6	9.2	5.6	0.6
Wage	7.8	8.6	17.1	12.7	10.0	12.2
Cost-Push	60.5	54.7	32.7	53.7	49.0	40.0

Appendix D: Description of the model

The monetary union, represented by the interval [0,1] is composed of two regions, with the Home economy (Malta) indexed over [0, s] and the Foreign economy (the rest of the euro area) indexed over [s, 1]. Parameters for the foreign economy are denoted analogously to the Home economy and marked with an asterisk. The tradable sector accounts for a share γ and produces goods sold domestically and abroad, while the non-tradable sector, with a share of $(1 - \gamma)$, produces goods for the domestic economy. The model features a productivity shock for each sector and a common European-wide productivity shock to the tradable sectors. Monetary policy is common for both economies and is specified via a Taylor rule with interest rate smoothing.

The next section briefly describes the main features the Home economy. The Foreign economy is modelled analogously. We refer to the interested reader to Rabanal (2009) for a detailed derivation of the model. Below, we will just outline the main equations of the log-linearized model. A complete list of the model equations are available in the Appendix H.

Solving household's intertemporal utility maximisation gives the usual log-linearized Euler equation:

$$c_t = \frac{h}{1+h} c_{t-1} + \frac{1}{1+h} E_t c_{t+1} - \frac{1-h}{(1+h)\sigma}(r_t - E_t \pi_{t+1}) \tag{1}$$

where c_t is current consumption and the term $(r_t - E_t \pi_{t+1})$ is the the real interest rate. h denotes habit formation and σ is the intertemporal elasticity of substitution. The Euler equation suggests that current consumption depends on past and expected consumption and the real interest rate.

The overall consumption index aggregates between non-tradable c_t^N and tradable consumption c_t^T, with the latter being further disaggregated into tradable consumption for the domestic economy c_t^H and exports c_t^F. The log-linearized consumption demand functions are defined as follows:

$$c_t^T = \lambda c_t^H + (1 - \lambda)c_t^F \tag{2}$$

$$c_t^H = -\nu t_t^H - (\epsilon - \nu)t_t^T + c_t \tag{3}$$

$$c_t^F = -\nu t_t^F - (\epsilon - \nu)t_t^T + c_t \tag{4}$$

$$c_t^N = -\nu t_t^N + c_t \tag{5}$$

where λ represents the share of home produced tradables, ν is the elasticity of substitution between tradable goods and ϵ is the elasticity of substitution between traded and non-traded goods. t_t^H, t_t^T, t_t^F and t_t^N are relative price indices which are defined as follows: $t_t^N = -\frac{\gamma}{1-\gamma}t_t^T$, $t_t^T = \lambda t_t^H + (1-\lambda)t_t^F$, $t_t^H = t_{t-1}^H +$

$\pi_t^H - \pi_t$, $t_t^F = t_{t-1}^F + \pi_t^F - \pi_t$. Intuitively, the above equations suggest that demand for a particular good depends on its (i) price elasticity, (ii) relative prices and (iii) overall demand.

The assumption of complete international financial markets implies that households can fully insure themselves across countries, which means that Euler condition of both areas can be combined to obtain the perfect risk sharing condition:

$$rer_t = -(\lambda_t - \lambda_t^*) \ \text{ and } \ \Delta rer_t = \pi_t^* - \pi_t \tag{6}$$

where λ_t^* and λ_t denote the marginal utility of consumption in both areas. The second equation illustrates that, in the absence of the nominal exchange rate, changes in the real exchange rate are due to inflation differentials.

The Maltese CPI price index is defined as:

$$\pi_t = \gamma \pi_t^T + (1 - \gamma)\pi_t^N \tag{7}$$

with π_t, π_t^T, π_t^N stand for overall HICP inflation, tradable inflation and non-tradable inflation, respectively. The parameter $\gamma \in [0,1]$ represents the share of tradable goods in the HICP index. The tradable index is further sub-divided between domestic tradables π_t^H and imported goods π_t^F:

$$\pi_t^T = \lambda \pi_t^H + (1 - \lambda)\pi_t^F \tag{8}$$

Price setting decisions are based *a la* Calvo (1983), where every period intermediate firms receive a stochastic signal that determines whether they can re-optimize their prices or not. This signal arrives to a producer with a probability $1 - \theta_k$, where θ_k is specific to the sector, $k = \{N, H, F\}$. N refers to the non-tradable sector, H to tradable goods sold domestically and F to tradable goods sold abroad. As in Gali and Gertler (1999), the model also includes price indexation to past inflation, φ_k, to introduce inertia and therefore provide a better fit to inflation dynamics.

The sectoral New Keynesian Phillips Curve (NKPC) is defined as:

$$(1 + \varphi_k \beta)\pi_t^k = \varphi_k \pi_{t-1}^k + \beta E_t \pi_{t+1}^k + \frac{(1-\theta_k)(1-\beta\theta_k)}{\theta_k}\left(w_t - z_t^k - t_t^k + E_t^P\right) \tag{9}$$

where π_t^k is sectoral price inflation, w_t is the real wage, z_t^k is a sectoral productivity shock, t_t^k is a relative price component and E_t^p is a price mark-up shock. The price mark-up shock is defined as an AR(1) process. Since labour is the only input in the production function, the real marginal cost depends positively on real wages and negatively on the sector specific productivity shock. The model incorporates the Balassa

Samuelson effect: a productivity shock in the tradable sector will raise real wages in the economy, which will lead to higher inflation in the non-tradable sector in the absence of similar productivity gains in this sector. On the contrary, the relative price component implies that higher sectoral inflation will lead to a decline in demand for the particular sectoral output as consumer shift towards cheaper prices, thereby acting as a correcting mechanism.

The NKPC states that sectoral inflation is related to expected future inflation through the discount factor β, lagged inflation through the indexation parameter φ_k and to real marginal costs via the term $\frac{(1-\theta_k)(1-\beta\theta_k)}{\theta_k}$. The latter term determines the sensitivity of inflation to marginal costs or, in other words, the slope of the Phillips Curve.

Following Erceg, Henderson and Levin (2000), we assume that households are monopolistic suppliers of labour. Nominal wage stickiness is introduced in the model by assuming a staggered setting *a la* Calvo, similar to the Phillips Curve equation above. The log-linearized wage equation is expressed as:

$$\pi_t^w = \beta E_t \pi_{t+1}^w + \varphi_w \pi_{t-1} - \varphi_w \beta \pi_t + \frac{(1-\theta_w)(1-\beta\theta_w)}{\theta_w(1+\varphi\omega_w)}(\varphi l_t - \lambda_t - w_t + E_t^w) \tag{10}$$

where π_t^w is nominal wage inflation, which is partly indexed to consumer price inflation through the indexation parameter φ_w. Similar to the price mark-up shock, the wage mark-up shock is also defined as an AR (1) process. φ is the Frisch elasticity, which represent the sensitivity of the labour supply to changes in the real wages. The term $\varphi\omega_w$ is the ratio of labour demand and supply elasticities.

Labour is supplied to the traded and the non-traded sector in the following way:

$$l_t = (1-\gamma)l_{N,t} + \gamma l_{T,t} \tag{11}$$

where γ represent the share of the traded sector and subscripts N and T stand for non-traded and traded sectors, respectively. Labour is completely mobile across sectors which means that wages in both sectors are identical.

On the supply side, there exists a continuum of monopolistically competitive firms in both sectors $k=\{T,N\}$. The log-linearized production function is expressed as:

$$y_{k,t} = z_{k,t} + l_{k,t} \tag{12}$$

with $z_{k,t}$ representing sectoral productivity which is assumed to follow an AR (1) process. In addition, there is also a Euro-area wide technology shock in the tradable sector that is common to both economies, z_t^T, which is also modelled as an AR (1) process.

Market clearing conditions imply that demand is equal to supply in both sectors. The log-linearized aggregate output aggregates tradable and non-tradable output, using appropriate relative prices, and is expressed as follows:

$$y_t = \gamma(t_t^{PPI} + y_t^T) + (1 - \gamma)(t_t^N + y_t^N) \tag{13}$$

with tradable output y_t^T and non-tradable output y_t^N being defined as:

$$y_t^T = (1 - \gamma_G)[\lambda(c_t^H + t_t^H - t_t^{PPI}) + (1 - \lambda)(c_t^{H*} + t_t^{H*} - t_t^{PPI} + rer_t)] + \gamma_G g_t^T \tag{14}$$

$$y_t^N = (1 - \gamma_G)c_t^N + \gamma_G g_t^N \tag{15}$$

with γ_G being the share of government expenditure in output and t_t^{PPI} is the producer price index, defined as $t_t^{tppi} = p_t^{tppi} - p_t = \lambda t_t^H + (1 - \lambda)(t_t^{H*} + rer_t)$. The latter is different from the consumer price index due to price discrimination, which allows us to identify between price mark-up and productivity shocks. The inclusion of the real exchange rate in the tradable equation implies that positive inflation differentials improves the competitiveness of the domestic economy, thereby exerting a positive effect on output.

Euro area wide inflation and output are a weighted average of the respective variables in Malta and the rest of the Euro area:

$$\pi_t^{EMU} = M_{share}\pi_t + (1 - M_{share})\pi_t^* \tag{16}$$

$$y_t^{EMU} = M_{share}y_t + (1 - M_{share})y_t^* \tag{17}$$

with M_{share} being the size of Malta in the Euro area.

Monetary policy is conducted by the single monetary authority via a Taylor Rule, with the central bank targeting euro wide inflation and output:

$$r_t = \rho_r r_{t-1} + (1 - \rho_r)(\gamma_\pi \pi_t^{EMU} + \gamma_Y y_t^{EMU}) + \varepsilon_t^R \tag{18}$$

where ρ_r is the degree of interest rate smoothing, γ_π and γ_Y are the relative weights on inflation and output, respectively. ε_t^R is an iid monetary policy shock.

Appendix E: Priors and posteriors

Comparing the prior with the posterior distribution provides an indication of the information content of the observed data about the structural parameters. More specifically, observed data are informative when the posterior distribution (the black line) is different from the prior distribution (the grey line). On the contrary, data are uninformative when the posterior is very close to the prior. According to the graphical analysis in this section, the data provides additional information for most parameters, with the exception of the some indexation parameters.
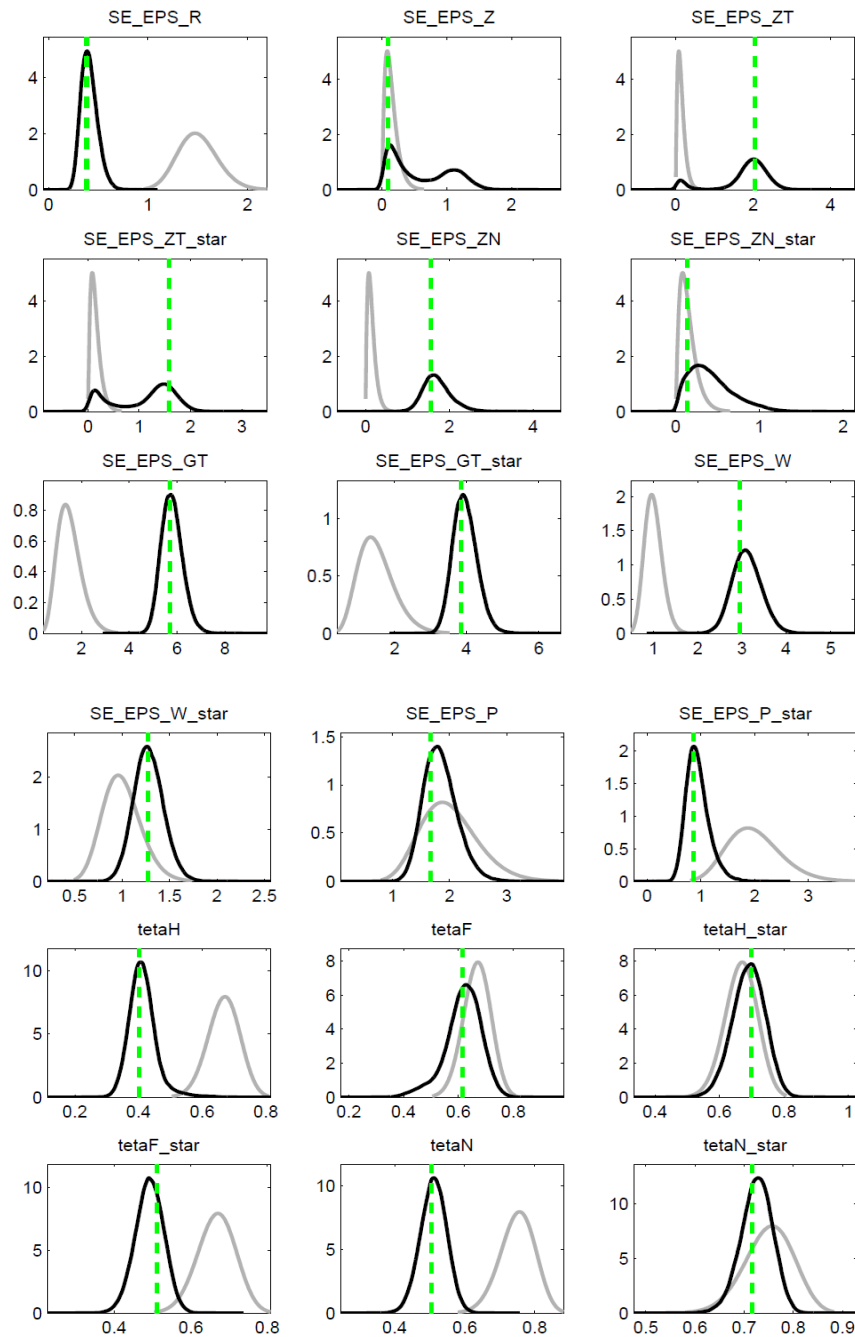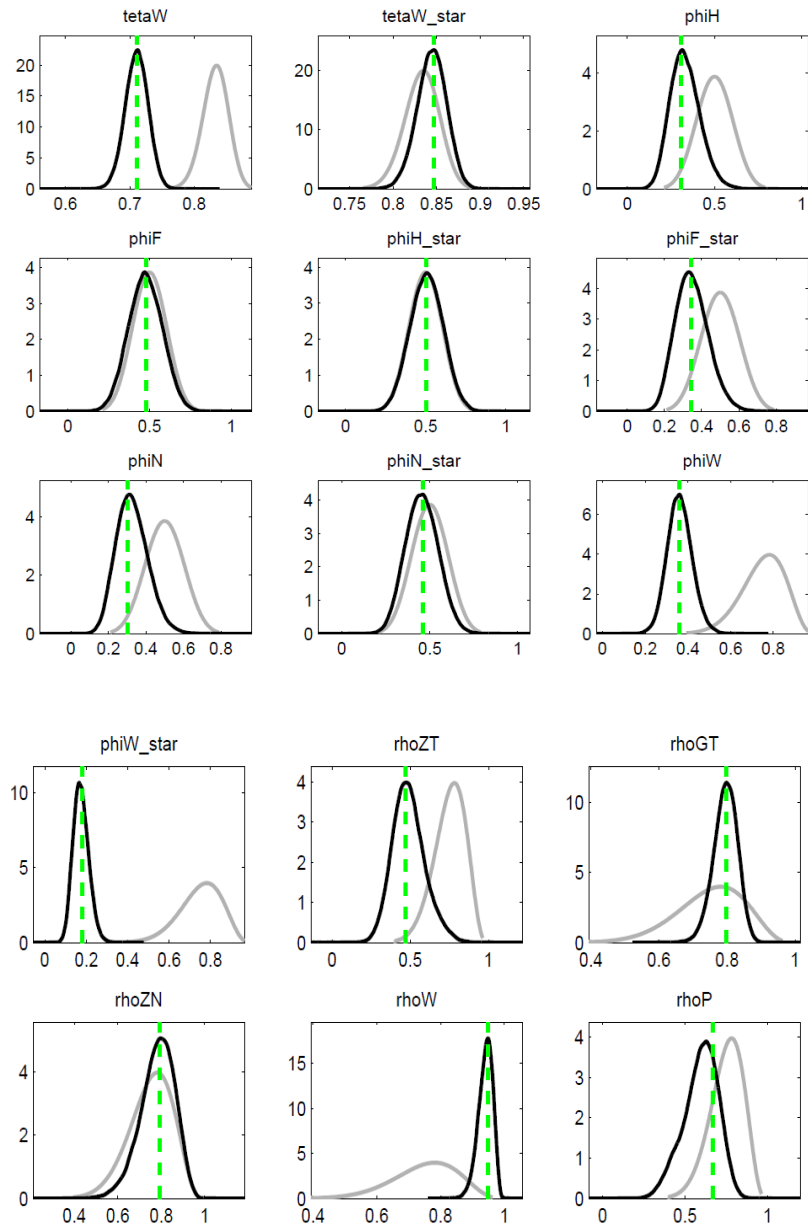
Appendix F: Convergence diagnostics

The figure below provides a diagnosis of the four distinct chains of the MH sampling algorithm. As explained in Griffoli (2007), the information is summarized in three distinct graphs, representing convergence measures both within and between the different chains. The measures are related to the analysis of parameters mean (interval), variance (m2) and thrid moments (m3). Convergence requires both lines in the three charts to converge and become stable, which is indeed the case below.
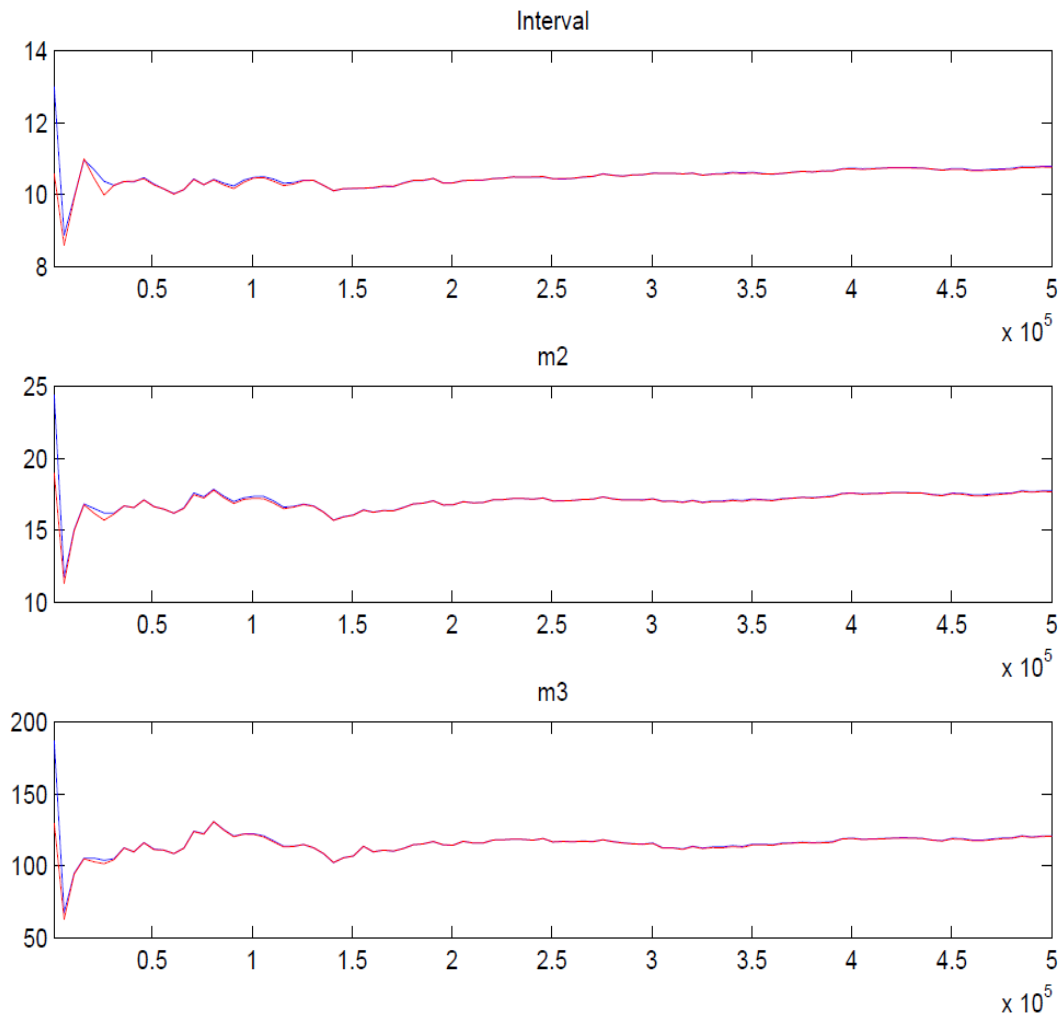
Appendix G: Observed and model generated data

The in-sample fit of the model is determined by comparing the one-step ahead forecast from the Kalman filter evaluated at the posterior mode with the actual. Overall, the model is able to fit all the observables reasonably well, suggesting that the overall absolute fit of the model is satisfactory.
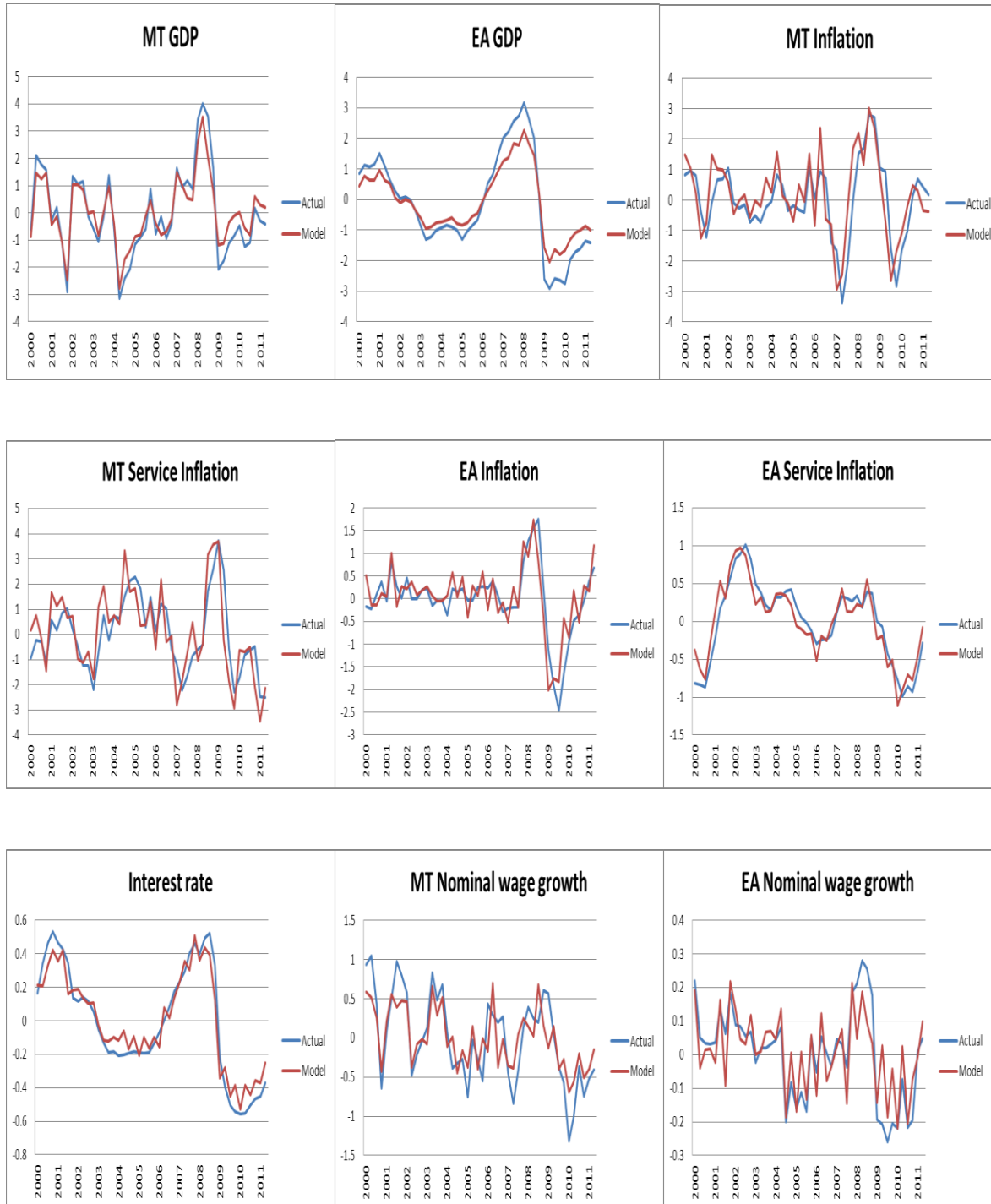
Appendix H: Model equations

Lagrange multiplier definitions:

$$-\lambda_t(1-h) = c_t - hc_{t-1} \tag{1}$$

$$-\lambda_t^*(1-h^*) = c_t^* - h^* c_{t-1}^* \tag{2}$$

Risk sharing equation:

$$rer_t = -(\lambda_t - \lambda_t^*) \tag{3}$$

Euler equation:

$$\lambda_t = \lambda_{t+1} + r_t - \pi_{t+1} \tag{4}$$

Consumption:

$$c_t^T = \lambda c_t^H + (1-\lambda)c_t^F \tag{5}$$

$$c_t^{T*} = \lambda^* c_t^{F*} + (1-\lambda^*)c_t^{H*} \tag{6}$$

$$c_t^H = -v t_t^H - (\epsilon - v)t_t^T + c_t \tag{7}$$

$$c_t^F = -v t_t^F - (\epsilon - v)t_t^T + c_t \tag{8}$$

$$c_t^N = -v t_t^N + c_t \tag{9}$$

$$c_t^{H*} = -v^* t_t^{H*} - (\epsilon - v^*)t_t^{T*} + c_t^* \tag{10}$$

$$c_t^{F*} = -v^* t_t^{F*} - (\epsilon - v^*)t_t^{T*} + c_t^* \tag{11}$$

$$c_t^{N*} = -v^* t_t^{N*} + c_t^* \tag{12}$$

Labour repartition:

$$l_t = (1-\gamma)l_t^N + \gamma l_t^T \tag{13}$$

$$l_t^* = (1-\gamma^*)l_t^{N*} + \gamma^* l_t^{T*} \tag{14}$$

Nominal wage inflation:

$$\pi_t^W = \pi_t + w_t - w_{t-1} \tag{15}$$

$$\pi_t^{W*} = \pi_t^* + w_t^* - w_{t-1}^* \tag{16}$$

Calvo wage equations:

$$\pi_t^W - \varphi_W \pi_{t-1} = \beta \pi_{t+1}^W - \varphi_W \beta \pi_t + \frac{(1-\theta_W)(1-\beta\theta_W)}{\theta_W(1+\varphi\omega_W)}(\varphi l_t - \lambda_t + E_t^W) \tag{17}$$

$$\pi_t^{W*} - \varphi_W^* \pi_{t-1}^* = \beta \pi_{t+1}^{W*} - \varphi_W^* \beta \pi_t^* + \frac{(1-\theta_W^*)(1-\beta\theta_W^*)}{\theta_W^*(1+\varphi\omega_{W*})}(\varphi l_t^* - \lambda_t^* + \omega_{W*} E_t^{W*}) \tag{18}$$

Calvo price equations:

$$(1+\varphi_N\beta)\pi_t^N = \varphi_N \pi_{t-1}^N + \beta \pi_{t+1}^N + \frac{(1-\theta_N)(1-\beta\theta_N)}{\theta_N}(w_t - z_t^N - t_t^N + E_t^P) \tag{19}$$

$$(1+\varphi_H\beta)\pi_t^H = \varphi_H \pi_{t-1}^H + \beta \pi_{t+1}^H + \frac{(1-\theta_H)(1-\beta\theta_H)}{\theta_H}(w_t - z_t^T - t_t^H + E_t^P) \tag{20}$$

$$(1+\varphi_H^*\beta)\pi_t^{H*} = \varphi_H^* \pi_{t-1}^{H*} + \beta \pi_{t+1}^{H*} + \frac{(1-\theta_H^*)(1-\beta\theta_H^*)}{\theta_H^*}(w_t - z_t^T - (t_t^{H*} + rer_t) + E_t^{P*}) \tag{21}$$

$$(1+\varphi_N^*\beta)\pi_t^{N*} = \varphi_N^* \pi_{t-1}^{N*} + \beta \pi_{t+1}^{N*} + \frac{(1-\theta_N^*)(1-\beta\theta_N^*)}{\theta_N^*}(w_t - z_t^{N*} - t_t^{N*} + E_t^{P*}) \tag{22}$$

$$(1+\varphi_F\beta)\pi_t^F = \varphi_F \pi_{t-1}^F + \beta \pi_{t+1}^F + \frac{(1-\theta_F)(1-\beta\theta_F)}{\theta_F}(w_t - z_t^{T*} - (t_t^F - rer_t) + E_t^P) \tag{23}$$

$$(1+\varphi_F^*\beta)\pi_t^{F*} = \varphi_F^* \pi_{t-1}^{F*} + \beta \pi_{t+1}^{F*} + \frac{(1-\theta_F^*)(1-\beta\theta_F^*)}{\theta_F^*}(w_t - z_t^{T*} - t_t^{F*} + E_t^{P*}) \tag{24}$$

EMU variables:

$$\pi_t^{EMU} = M_{share}\pi_t + (1 - M_{share})\pi_t^* \tag{25}$$

$$y_t^{EMU} = M_{share}y_t + (1 - M_{share})y_t^* \tag{26}$$

Inflation definition:

$$\pi_t = \gamma \pi_t^T + (1-\gamma)\pi_t^N \tag{27}$$

$$\pi_t^* = \gamma^* \pi_t^{T*} + (1-\gamma^*)\pi_t^{N*} \tag{28}$$

$$\pi_t^T = \lambda \pi_t^H + (1-\lambda)\pi_t^F \tag{29}$$

$$\pi_t^{T*} = \lambda^* \pi_t^{F*} + (1-\lambda^*)\pi_t^{H*} \tag{30}$$

Price ratios:

$$t_t^N = -\frac{\gamma}{1-\gamma}t_t^T \tag{31}$$

$$t_t^T = \lambda t_t^H + (1-\lambda)t_t^F \tag{32}$$

$$t_t^H = t_{t-1}^H + \pi_t^H - \pi_t \tag{33}$$

$$t_t^F = t_{t-1}^F + \pi_t^F - \pi_t \tag{34}$$

$$t_t^{PPI} = \lambda t_t^H + (1 - \lambda)(t_t^{H*} + rer_t) \tag{35}$$

$$t_t^{N*} = -\frac{\gamma^*}{1-\gamma^*} t_t^{T*} \tag{36}$$

$$t_t^{T*} = \lambda^* t_t^{H*} + (1 - \lambda^*) t_t^{F*} \tag{37}$$

$$t_t^{H*} = t_{t-1}^{H*} + \pi_t^{H*} - \pi_t^* \tag{38}$$

$$rer_t = rer_{t-1} + \pi_t^* - \pi_t \tag{39}$$

$$t_t^{F*} = t_{t-1}^{F*} + \pi_t^{F*} - \pi_t^* \tag{40}$$

$$t_t^{PPI*} = \lambda^*(t_t^F - rer_t) + (1 - \lambda^*) t_t^{F*} \tag{41}$$

Production functions:

$$y_t^N = z_t^N + l_t^N \tag{42}$$

$$y_t^T = z_t^T + l_t^T \tag{43}$$

$$y_t^{N*} = z_t^{N*} + l_t^{N*} \tag{44}$$

$$y_t^{T*} = z_t^{T*} + l_t^{T*} \tag{45}$$

Market clearing:

$$y_t^N = (1 - \gamma_G)c_t^N + \gamma_G g_t^N \tag{46}$$

$$y_t^T = (1 - \gamma_G)\big(\lambda(c_t^H + t_t^H - t_t^{PPI}) + (1 - \lambda)(c_t^{H*} + t_t^{H*} + rer_t - t_t^{PPI})\big) + \gamma_G g_t^T \tag{47}$$

$$y_t^{N*} = (1 - \gamma_G^*)c_t^{N*} + \gamma_G^* g_t^{N*} \tag{48}$$

$$y_t^{T*} = (1 - \gamma_G^*)\big(\lambda^*(c_t^{F*} + t_t^{F*} - t_t^{PPI*}) + (1 - \lambda^*)(c_t^F + t_t^F - rer_t - t_t^{PPI*})\big) + \gamma_G^* g_t^{T*} \tag{49}$$

Total production:

$$y_t = \gamma(t_t^{PPI} + y_t^T) + (1 - \gamma)(t_t^N + y_t^N) \tag{50}$$

$$y_t^* = \gamma^*(t_t^{PPI*} + y_t^{T*}) + (1 - \gamma^*)(t_t^{N*} + y_t^{N*}) \tag{51}$$

Monetary policy:

$$r_t = \rho_r r_{t-1} + (1 - \rho_r)(\gamma_\pi \pi_t^{EMU} + \gamma_Y y_t^{EMU}) + \varepsilon_t^R \tag{52}$$

Shocks:

$$z_t^T = \rho_{ZT} z_{t-1}^T + \varepsilon_t^{ZT} + \varepsilon_t^Z \tag{53}$$

$$z_t^N = \rho_{ZN} z_{t-1}^N + \varepsilon_t^{ZN} \tag{54}$$

$$z_t^{T*} = \rho_{ZT*} z_{t-1}^{T*} + \varepsilon_t^{ZT*} + \varepsilon_t^Z \tag{55}$$

$$z_t^{N*} = \rho_{ZN*} z_{t-1}^{N*} + \varepsilon_t^{ZN*} \tag{56}$$

$$g_t^T = \rho_{GT} g_{t-1}^T + \varepsilon_t^G \tag{57}$$

$$g_t^N = \rho_{GT} g_{t-1}^N + \varepsilon_t^G \tag{58}$$

$$g_t^{T*} = \rho_{GT*} g_{t-1}^{T*} + \varepsilon_t^{G*} \tag{59}$$

$$g_t^{N*} = \rho_{GT*} g_{t-1}^{N*} + \varepsilon_t^{G*} \tag{60}$$

$$E_t^p = \rho_p E_{t-1}^p + \varepsilon_t^p \tag{61}$$

$$E_t^{p*} = \rho_{p*} E_{t-1}^{p*} + \varepsilon_t^{p*} \tag{62}$$

$$E_t^w = \rho_w E_{t-1}^w + \varepsilon_t^w \tag{63}$$

$$E_t^{w*} = \rho_{w*} E_{t-1}^{w*} + \varepsilon_t^{w*} \tag{64}$$

Differential definitions:

$$\pi_t^{diff} = \pi_t - \pi_t^* \tag{65}$$