New Models in the MMB 3.0

The MMB 3.0 features 14 new models and thus raises the number of models that are available for comparison to a total of 128. The new models were designed to address a variety of central issues for macroeconomists.

A decade after the financial crisis, modelling alternative ways to capture financial frictions within macroeconomic models still remains a central line of research. Gambacorta and Signoretti (2014) introduce a simplified version of the model by Gerali et al. (2010). Gilchrist, Schoenle, Sim, and Zakrajšek (2017) propose a model in which financial frictions create incentives for firms to raise prices in an economic downturn, thereby mitigating deflationary effects of negative demand shocks. Poutineau and Vermandel (2015) analyse the role of banks loans for the endogenous firms entry and exit dynamics, in a model estimated on US data.

New challenges for central banks are to evaluate the effects of quantitative easing and the role of international policy spillovers spillovers. Priftis and Vogel (2016) and Priftis and Vogel (2017) employ extensions of the QUEST III model to analyse the effects of quantititive easing in the Eurozone. Filardo, Lombardi, Montoro, and Ferrari (2018) investigate on how monetary policy spillovers complicate the tradeoffs faced by central banks in their reactions to commodity price shocks.

On the fiscal side, Michaillat (2014) develops a model with search frictions in the labor market and finds that the public employment multiplier is countercyclical. Gnocci and Pappa (2016) argue that taking account of home production affects both the government spending multiplier and the welfare effects of fiscal policy. Krause and Moyen (2016) in turn analyse the interaction between a higher inflation target set by the central bank and the real debt burden of the government.

Next to these models, which analyse the effects of monetary and fiscal policy, some of the new models in the MMB 3.0 take a step back and revisit price and wage frictions as well as the role of money. Bils, Klenow, and Malin (2012) challenges modern macroeconomic models by contrasting findings from micro data with the too high persistence and stability in reset price inflation and the way it is converted to actual inflation in macroeconomic models. Galí and Monacelli (2016) revisits the gains of nominal wage flexibility in a currency union and finds that increases in wage flexibility often reduce welfare. Benchimol (2015) and Benchimol and Fourçans (2017) investigate on the role of endogenous money in the households' utility function and in the production function of firms in models of the Eurozone.

Lastly, the MMB 3.0 features the AINO II model by Kilponen, Orjasniemi, Ripatti, and Verona (2016), which is a workhorse of the Finnish central bank.

List of the 14 New Models Available*

A List of New Models Available in the Macroeconomic Model Data Base Version 3.0

1. Calibrated Models (7 NEW MODELS)

1.1	NK_FLMF18	Filardo et al. (2018)
1.2	NK_GM16	Galí and Monacelli (2016)
1.3	NK_GHP16	Gnocci and Pappa (2016)
1.4	NK_GS14	Gambacorta and Signoretti (2014)
1.5	NK_GSSZ17	Gilchrist et al. (2017)
1.6	NK_KM16	Krause and Moyen (2016)
1.7	NK_M14	Michaillat (2014)

2. Estimated US Models (2 NEW MODELS)

2.1	US_BKM12	Bils et al. (2012)
2.2	US_PV15	Poutineau and Vermandel (2015)

3. Estimated Euro Area Models (4 NEW MODELS)

3.1	EA_BE15	Benchimol (2015)
3.2	EA_BF17	Benchimol and Fourçans (2017)
3.3	EA_PV16	Priftis and Vogel (2016)
3.4	EA_PV17	Priftis and Vogel (2017)

5. Estimated Models of other Countries (1 NEW MODEL)

4.1	FI_AINO	Kilponen et al. (2016), the AINO II model

1 Calibrated Models

1.1 NK_FLMF18: Filardo et al. (2018)

Filardo et al. (2018) analyse the implications of monetary policy reacting to commodity prices in the presence of the risk of misdiagnosing the drivers of commodity price developments. They use a global economic model that builds on Nakov and Pescatori (2010), and in which the global economy is split into commodity importers and exporters and commodity prices are determined endogenously by global supply and demand. The economic performance of monetary authorities depends on their ability to identify whether commodity prices are driven by global supply or demand shocks.

- Aggregate Demand: The representative household in the commodity-importing countries maximizes lifetime utility over consumption and labor subject to a standard budget constraint. The representative household in the commodity-exporting countries owns the exporting firm wholly and its utility function depends only on the consumption of final goods subject to the constraint that consumption expenditures equal dividends from commodity production. Cross-border financial autarky is assumed.

- Aggregate Supply: The commodity supply stems from two types of commodity-exporting countries: a competitive and a monopolistic one. The latter one sets prices above marginal costs, the competitive ones take prices as given. The commodity is produced using final goods sold by commodity-importing countries. There are no nominal rigidities in the commodity-exporting countries. Final goods are produced in the commodity-importing country using labor and commodities as inputs. Final-good producers act under monopolistic competition and set prices according to Calvo (1983). Monetary policy is conducted only from the perspective of the commodity-importing country.

- Shocks: The model features aggregate demand and supply shocks..

- Calibration: The model is calibrated at a quarterly frequency and mostly in line with the literature. The commodity share in the consumption basket matches the share of primary commodity inputs in the US CPI (10%). The share of commodities in the production function is set to 10%, following Arseneau and Leduc (2013). The competitive commodity production sector has a size of 10% relative to GDP.

1.2 NK_GM16 Galí and Monacelli (2016)

Gali and Monacelli (2016) study the gains from increased wage flexibility using a small open economy model with staggered price and wage setting and comparing the cases of an independent monetary policy versus a currency union. The model builds on the framework developed in Gali and Monacelli (2005), extended by introducing sticky nominal wages (in addition to sticky prices) and additional shocks (labor tax shock, domestic demand, exports, and world interest rate). Two results stand out: (i) the effectiveness of labor cost reductions as a means to stimulate employment is much smaller in a currency union, and (ii) an increase in wage flexibility often reduces welfare, more likely so in an economy that is part of a currency union or with an exchange rate-focused monetary policy.

- Aggregate Demand: The representative household (that has a continuum of members) in a small open economy seeks to optimize its utility separable between consumption and leisure subject to its budget constraint. Consumption is a composite of domestic and foreign goods,

weighted by the degree of home bias in preferences, which represents the index of country openness. Each household member is specialized in a differentiated occupation and supplies labor. Workers specialized in each occupation (or a union representing them) set the corresponding nominal wage, subject to an isoelastic demand function for their services. Each period only a fraction of labor types, drawn randomly from the corresponding population, have their nominal wage reset.

- Aggregate Supply: Differentiated goods are produced from a typical firm using a technology and constant elasticity of substitution (CES) function of the quantities of the different types of labor services employed. Firms face price stickiness a la Calvo (1983). Employment is subject to a proportional payroll tax, common to all labor types.

- The Foreign Sector: As in Gall and Monacelli (2005), the size of the home economy is presumed to be negligible relative to that of the world economy, which allows taking world aggregates as exogenous. Furthermore, it is assumed that the law of one price holds and that financial markets (both domestic and international) are complete.

- Monetary Regime: Equilibrium behavior of the small open economy under two monetary policy regimes is considered. Under the first, which they refer to as inflation targeting, the central bank focuses on stabilizing domestic inflation. Under the second monetary regime, the home economy is assumed to be part of a world currency union, where domestic nominal interest rate will move one-for-one with the world interest rate, independent of domestic economic conditions.

- Shocks: Domestic productivity and demand shock, two types of global shocks (export shock and world interest rate shock) and the labor tax shock.

- Calibration: The model is calibrated mostly to fit some characteristics of the Euro Area and its peripheral countries.

1.3 NK_GHP16: Gnocci and Pappa (2016)

Gnocchi et al. (2016) introduce housework in an otherwise standard business cycle model. Introducing substitutability between home-produced and market goods, they generate com-plementarity between market consumption and hours worked and analyse how it affects the size of the fiscal multiplier.

- Aggregate demand: Households maximize their lifetime utility, subject to an intertemporal budget constraint, where the utility function is increasing in both consumption and leisure and concave. They can consume home produced goods and market goods. Leisure is the residual time after subtracting hours worked at home and on the market from the time endowment.

- Aggregate supply: There are infinitely many monopolistically competitive firms that buy market capital and hours worked to produce varieties of the market good. Prices are set following Calvo (1983).

- Shocks: This paper presents responses to a government spending shock.

- Calibration: The model is calibrated at quarterly frequency in order to match especially the sample averages of the ratio of investment to the capital stock, the capital-output ratios, the hours worked at home and on the market, and the share of government expenditure in GDP.

The time series used refer to the time period 1950:Q1 to 2007:Q2, excluding the financial crisis.

1.4 NK_GS14: Gambacorta and Signoretti (2014)

Gambacorta and Signoretti (2014) simplify the model by Gerali et al. (2010), which introduces a monopolistically competitive banking sector into a DSGE model with financial frictions a la Iacoviello (2005) . This simplified version focuses on two frictions: a borrowing constraint, depending on the collateral's value, and a bank leverage constraint.

- Aggregate demand: Additionally to banks, there are two types of agents in the model: patient households and impatient entrepreneurs. Subject to a budget constraint, the households maximize their lifetime utility, choosing the levels of consumption, labor supply and bank deposits. Entrepreneurs are net borrowers and maximize their lifetime utility, choosing levels of consumption, labor demand and bank loans, subject to budget and borrowing constraints.
- Aggregate supply: Entrepreneurs produce a wholesale good using household's labor and own physical capital. Retailers buy the intermediate goods, brand them and sell the differentiated goods at a price including a mark-up over the purchasing cost. Sticky prices a la Rotemberg (1982) imply a New Keynesian Phillips curve.
- Banking sector: Each bank consists of two units: a wholesale and a retail branch. The wholesale unit collects deposits from households and issues loans, paying the interest rate set by the central bank and earning a wholesale loan rate. There exists a target leverage ratio and for deviating the bank has to pay a cost. The retail unit acts under monopolistic competition. It buys wholesale loans, differentiates them and resells them, applying a constant mark-up.
- Shocks: There is a technology shock and a cost-push shock.
- Calibration: The calibration is based on Gerali et al. (2010).

1.5 NK_GSSZ17: Gilchrist et al. (2017)

Gilchrist et al. (2017) present a small-scale DSGE models with financial frictions to explain inflation dynamics during the financial crisis. In response to contractionary financial or demand shocks, financial frictions create incentives for firms to raise prices, therefore mitigating the deflationary effects of shocks.

- Aggregate demand: Households maximize their lifetime utility, where the per-period utility function is separable in consumption and labour. Household utility from consumption is subject to good-specific external habits a la Ravn, Schmitt-Grohe and Uribe (2006).
- Aggregate supply: Intermediate goods production is done by a continuum of monopolistically competitive firms using a production function with decreasing returns to scale and fixed operating costs. Firms maximize the present value of discounted dividends and must commit to pricing and production decisions prior to realizations of their idiosyncratic shock. Depending on the shock realization, firms must raise external funds in order to pay workers. Firms can obtain external funds by issuing new equity subject to dilution costs reflecting agency problems in the financial markets. Firms also face Rotemberg (1982) quadratic adjustment costs when changing nominal prices.

- Shocks: Technology shock, demand shock, financial shock and a monetary policy shock.
- Calibration: The model is calibrated for the US using standard values for the core block and following previous literature for the deep habits, the elasticities of substitution and financial market frictions.
- Replication: We simulated the impulse response functions to a demand shock in the economy with financial frictions and nominal rigidities, Figure 5 (red line) in the paper.

1.6 NK_KM16: Krause and Moyen (2016)

The aim of the authors is to study the effects of an inflation target increase on real public debt. For this purpose, they employ a standard New Keynesian model augmented with long term debt with stochastic maturity.

- Aggregate Demand: As in Rotemberg and Woodford (1997), households maximize lifetime utility from consumption leisure and money holdings subject to an intertemporal budget constraint while they own the firms. They have access to one-period bonds payed at the policy interest rate rule and to long term bonds with stochastic maturity.
- Aggregate Supply: Final good producing firms operate under perfect competition, combining the intermediate goods in final good. Intermediate firms are monopolistic competitors with a linear production function on labour, facing price rigidity a la Calvo.
- Financial Authority: The government follows a tax rule that reacts to deviations of real debt from its steady state level. Revenues come from a labour tax and newly issued debt while expenditures consist of exogenous government spending, interest payments on bonds and principal payments of the redeemed bonds.
- Monetary Authority: The Central Bank follows a Taylor interest rate rule with high persistence, that responds to output gap as well as to deviations of the inflation target from its steady state.
- Shocks: The model incorporates various shocks such as a monetary policy shock, an inflation target shock, a government spending shock and finally a debt shock. A debt shock is assumed to increase debt by 65% from the current debt- to GDP ratio. All variables responses are expressed as percentage deviations from the steady state values apart from inflation and interest rates which are reported in annualized absolute deviations.
- Calibration: EThe model is parametrized at quarterly frequency. Basic parameters values follow Smets and Wouters (2007). The stochastic maturity of bonds is set to 0.0472 so as to match the average maturity of US debt accounting to 5.3 years..

1.7 NK_M14: Michaillat (2014)

Michaillat (2014) embeds a search-and-matching model into a New Keynesian model to analyse the effects of an increase in public employment at different stages of the business cycle. In this model, the public-employment multiplier is positive and countercyclical.

- Aggregate Demand: A representative large household maximizes expected lifetime utility by choosing an optimal consumption stream subject to a budget constraint. Workers in a household pool their income before choosing their consumption of the final good and how

much to save via one-period bonds. The government does not consume in the form of purchasing goods from the private sector but compensates public employees.

- Aggregate Supply: Final-Good firms produce the final good using intermediate goods and sell it on a perfectly competitive market. The intermediate good is produced by a monopolist using labor as the sole input. The monopolist faces a price-adjustment cost following Rotemberg (1982) and needs to pay a hiring cost.

- Labour Market: The labor market has a search-and-matching structure in which the number of matches is given by a Cobb-Douglas function of vacancies and unemployment. The probability of finding a job and the rate of filling vacancies both for the private and the public sector depend on the labor market tightness. The fraction of destroyed worker-job matches is constant and exogenous and the real wage is a function of technology.

- Shocks: In the model there is a technology shock that directly affects real wages.

- Calibration: The model is calibrated to a weekly frequency to US data. The calibration in the replication file remains weekly, but the model that is implemented in the MMB is calibrated to a quarterly frequency.

2 Estimated U.S. Models

2.1 US_BKM12: Bils et al. (2012)

Bils et al. (2012) construct a two-sector model based on the model by Smets and Wouters (2007) and re-estimate it on bimonthly data from 1990-2009. This is for comparing the behavior of actual and reset price ination to that for series simulated from the models, as the authors construct an empirical measure of reset price inflation on a bimonthly basis using US CPI micro data. They find that the models generate too much persistence and stability both in reset price inflation and in the way reset price inflation converted into actual inflation.

- Aggregate Demand: The same as in US_SW07, except that the consumption good demanded by the households is now a composite of the goods of the two sectors.

- Aggregate Supply: The same as in US_SW07, except that in US_BKM12 there are two sectors that produce goods. Firms in the one sector faces sticky prices and aggregate their goods according to a Kimball aggregator, firms in the other sector can set their prices flexibly and their goods are aggregated according to a CES aggregator.

- Shocks: The same as in US_SW07, except that the price markup shock in US_SW07 is now replaced by a sector specific productivity shock to the sector with flexible price setting.

- Estimation: In the paper, the SW model is reestimated with Bayesian methods using seven bimonthly US observables over the period 1990:1 to 2009:10. Also, different from US_SW07, the personal consumption deflator is used for price inflation instead of the GDP deflator. To be consistent with the MMB system, some parameters are adjusted to correspond to quarterly frequency.

2.2 US_PV15: Poutineau and Vermandel (2015)

Poutineau and Vermandel (2015) evaluate the role of financial intermediaries, such as banks, on the extensive margin of activity. They build a DSGE model that combines the endogenous determination of the number of firms operating on the goods market with financial frictions through a financial accelerator mechanism, given the fact that the creation of a new activity partly requires loans to finance spending during the setting period. Three main results have been obtained. First, financial frictions play a key role in determining the number of new firms. Second, in contrast with real macroeconomic shocks (where investment in existing production lines and the creation of new firms move in the opposite direction), financial shocks have a cumulative effect on the two margins of activity, amplifying macroeconomic fluctuations. Third, the critical role of financial factors is mainly observed in the period corresponding to the creation of new firms.

- Aggregate Demand: There is a continuum of identical households who consume, save and work in intermediate firms. To single out the determination and the dynamics of nominal wages, it is assumed that households delegate the task of negotiating their salary to labor unions. Formally, households provide differentiated types of labor, sold by labor unions to perfectly competitive labor packers who assemble them in a CES aggregator and sell the homogenous labor to intermediate firms.

- Aggregate Supply: The firm sector is populated by two groups of agents: intermediate firms and final goods firms. Intermediate firms produce differentiated goods, choose labor and capital inputs, and set prices according to the Rotemberg (1982) model. Final goods producers act as a consumption bundler by combining national intermediate goods to produce the homogenous final good. The total number of final firms/goods is normalized to 1, while the total number of intermediate firms/goods is endogenously determined in the model to define the extensive margin of activity. Each period, hence, a continuum of new firms decides to enter the market.

- Financial Sector: The economy is additionally populated by entrepreneurs, where the representative entrepreneur is a key agent for introducing financial frictions. This agent finances both the intensive margin (by renting capital to existing firms) and the extensive margin (by financing the wage bill for the creation of new firms). Entrepreneurs face a trade-off between intensive and extensive margins financing. Financial intermediaries provide funds to entrepreneurs. The representative financial intermediary collects deposits from households and lends them. From the balance sheet of the financial intermediary, the loan supply is equal to the deposits. Additionally, there is the imperfect pass-through of the policy rate on financial intermediary lending rate. It is assumed that financial intermediaries set their interest rates on a staggered basis with some degree of nominal rigidity a la Rotemberg (1982).

- Authorities: The government finances public spending by charging a tax on households. The total amount of public spending is assumed to evolve according to an AR(1) exogenous shock process. The central bank sets the interest rate in accordance with the fluctuations of price and activity imbalances.

- Shocks: There are 10 structural shocks in the model: productivity, spending, premium, investment, price cost-push, wage cost-push, rate cost-push, entry shock, collateral, and monetary policy shock.

- Estimation: The model is estimated with Bayesian methods on US quarterly data over the sample time period 1993Q1 to 2012Q3.

3 Estimated Euro Area Models

3.1 EA_BE15: Benchimol (2015)

Benchimol (2015) checks whether money is an omitted variable in the production process. For this purpose he estimates a NK-model with real money balances in the production function on European data. While he finds no strong evidence for the importance for money in production, the demand for money by firms plays a role for the economy.

- Aggregate Demand: A representative household maximizes expected lifetime utility by optimizes consumption, labor supply, money holdings and bond holdings. Money enters the utility function.
- Aggregate Supply: Firms are monopolistic competitors and prices are sticky (Calvo pricing). The production factors are labor, (exogenous) technology and real balances held by the firm. Labor markets are frictionless.
- Shocks: In the model there is a technology shock, a preference shock, a monetary policy shock, and two money demand shocks (one for households' and one for firms' demand for money).
- Estimation: The model is estimated on quarterly Eurozone data using the observables GDP per capita, GDP deflator, short term nominal interest rate and M3.

3.2 EA_BF17: Benchimol and Fourçans (2017)

Benchimol and Fourçans (2017) analyse the role of money and monetary policy as well as the forecasting performance of NK models with and without separability between consump-tion and money over three crisis periods in the Eurozone (ERM crisis, dot-com crisis and global financial crisis). For this purpose they estimate an NK-model on European data, and find that the nonseparable model generally provides better forecasting performance. Additionally, they find that the effects of monetary policy differ across the three crises.

- Aggregate Demand: A representative household optimizes consumption, labor supply, money holdings and bond holdings. Money features the utility function. In the MMB the model with nonseparabilities between consumption and real balanced is implemented.
- Aggregate Supply: Firms are monopolistically competitive and face price rigidities (Calvo pricing). Labor is the only factor for production.
- Shocks: The model features a technology shock, a price markup shock as well as an interest rate shock and a shock to the money supply.
- Estimation: The model is estimated on quarterly Eurozone data using the observables GDP per capita, GDP deflator, short term nominal interest rate and M3.

3.3 EA_PV16: Priftis and Vogel (2016)

Priftis and Vogel (2016) analyse the effects of quantitative easing (QE) in a model of the Eurozone with different assets. QE is captured by asset-purchases by the central bank. They use the model to simulate the path of QE as announced in early 2015 and find an expansionary effect on output, interest rates and inflation that is larger when QE is accommodated by low interest rates. The model is the QUEST III model (which is implemented in the MMB) plus QE.

- Aggregate Demand: There are two types of households: liquidity- and non-liquidity-constrained households. They possess the same utility function, non-separable in consumption and leisure with habit persistence in both consumption and leisure. Liquidity-constrained households do not optimize, they just consume their labor income. On the other side, non-liquidity-constrained households have access to domestic and foreign currency denominated assets, accumulate capital subject to investment adjustment costs and rent it to firms, earn profits from owning the firms and pay taxes. Income from foreign financial assets is subject to an external financial intermediation risk premium while real asset holdings are subject to an equity risk premium. Both types of households supply differentiated labor to a trade union which sets the wages by maximizing their joint utility (weighted by the share of each type). The wage setting processs is subject to a wage mark-up and to slow adjustments in the real consumption wage. The wage mark-up arises because of wage adjustment costs and the fact that a part of workers index the growth rate of wages to past inflation.

- Aggregate Supply: The final goods, which are produced from monopolistically competitive firms, are used for household consumption, investment, government consumption and export. These goods are produced with a Cobb-Douglas production function with capital and production workers (labor adjusted for overhead labor) as inputs. These firms face technological and regulatory constraints, restricting their price setting, employment and capacity utilization decisions. The final goods producer maximizes profits subject to these specific adjustment costs (all having convex functional forms) and demand conditions. Investment good producers combine domestic and foreign final goods using a CES aggregator to produce investment goods which are sold to non-liquidity-constrained households in a perfectly competitive market.

- The Foreign Sector: Demand behavior is considered the same for the home country and the rest of the world, therefore export demand and import demand are symmetric. Both equations are characterized by a lag structure in relative prices which captures delivery lags. Export firms buy domestic goods, transform them using a linear technology and sell them in the foreign market, charging a mark-up over the domestic prices. The same situation is faced by importer firms. Mark-up fluctuations arise because of price adjustment costs in both sectors. Mark-up equations are given as a function of past and future inflation and are also subject to random shocks.

- Assets and QE: QE is modelled as purchases of domestic long-term bonds in exchange for central bank liquidity. Next to physical capital and money, the model features long-term and short-term bonds.

- Shocks: The model contains a large battery of shocks as in the QUEST III model as well as QE shocks.

- Calibration: The model is calibrated in line with the QUEST III model, which has been estimated on EA data.

3.4 EA_PV17: Priftis and Vogel (2017)

Priftis and Vogel (2017) analyse the effects of quantitative easing (QE) in a model of the Eurozone. QE is captured by long-term bond purchases by the central bank. The authors find that QE mildly raised output growth and inflation. The model is the QUEST III model (which is implemented in the MMB) plus QE.

- Aggregate Demand: There are two types of households: liquidity- and non-liquidity-constrained households. They possess the same utility function, non-separable in consumption and leisure with habit persistence in both consumption and leisure. Liquidity-constrained households do not optimize, they just consume their labor income. On the other side, non-liquidity-constrained households have access to domestic and foreign currency denominated assets, accumulate capital subject to investment adjustment costs and rent it to firms, earn profits from owning the firms and pay taxes. Income from foreign financial assets is subject to an external financial intermediation risk premium while real asset holdings are subject to an equity risk premium. Both types of households supply differentiated labor to a trade union which sets the wages by maximizing their joint utility (weighted by the share of each type). The wage setting process is subject to a wage mark-up and to slow adjustments in the real consumption wage. The wage mark-up arises because of wage adjustment costs and the fact that a part of workers index the growth rate of wages to past inflation.

- Aggregate Supply: The final goods, which are produced from monopolistically competitive firms, are used for household consumption, investment, government consumption and export. These goods are produced with a Cobb-Douglas production function with capital and production workers (labor adjusted for overhead labor) as inputs. These firms face technological and regulatory constraints, restricting their price setting, employment and capacity utilization decisions. The final goods producer maximizes profits subject to these specific adjustment costs (all having convex functional forms) and demand conditions. Investment good producers combine domestic and foreign final goods using a CES aggregator to produce investment goods which are sold to non-liquidity-constrained households in a perfectly competitive market.

- The Foreign Sector: Demand behavior is considered the same for the home country and the rest of the world, therefore export demand and import demand are symmetric. Both equations are characterized by a lag structure in relative prices which captures delivery lags. Export firms buy domestic goods, transform them using a linear technology and sell them in the foreign market, charging a mark-up over the domestic prices. The same situation is faced by importer firms. Mark-up fluctuations arise because of price adjustment costs in both sectors. Mark-up equations are given as a function of past and future inflation and are also subject to random shocks.

- Assets and QE: QE is modelled as purchases of domestic long-term bonds in exchange for central bank liquidity. Next to physical capital and money, the model features long-term and short-term bonds. The assets are held by the household and long-term and short-term bond holdings are subject to portfolio adjustment costs.

- Shocks: The model uses a large number of shocks for estimation. Discussed in the paper is the long-term bond purchases.

- Shocks: The model contains a large battery of shocks as in the QUEST III model as well as exogenous long-term bond purchases.

- Calibration: The model is calibrated in line with the QUEST III model, which has been estimated on EA data.

4 Estimated Models of Other Countries

4.1 FI_AINO16: Kilponen et al. (2016)

Kilponen et al. (2016) present the AINO 2.0 model, which is the DSGE model used at the Bank of Finland for forecasting and policy analysis. It is a small open economy model of the Finnish economy within the Euro Area and the rest of the world. The framework includes standard frictions and rigidities as well as a monopolistically competitive banking sector in the spirit of Gerali et al (2010).

- Aggregate Demand: Households maximize their lifetime utility, where the per-period utility function is separable in consumption and labour. They can invest in the domestic capital stock (via capital goods producers), in euro area bonds, rest of the world bonds and domestic bonds. Households supply labour and act as wage setters in monopolistically competitive labour markets.

- Aggregate Supply: Production of domestic intermediate goods is subject to a CES production function with time varying mark-up and Harrod-neutral technological progress under monopolistic competition. Final consumption and investment goods are produced by domestic retailers operating under perfect competition, combining both domestic and imported goods. Export goods are produced by separate exports goods producing firms with a CES production function including domestic intermediate goods and imported goods. Domestic intermediate goods and export goods producers are subject to nominal rigidities in the form of Calvo (1983) âĂŞ pricing.

- Banking sector: The economy is populated by entrepreneurs who rent capital to the domestic intermediate good firms at the beginning of the period and sell the undepreciated capital to capital producers (owned by households) at the end of the period. Entrepreneurs finance the difference between expenditures and net worth from banks. Banks have market power and set rates on loans, subject to adjustment costs.

- Shocks: Six types of technology shocks, 3 types of domestic mark-up shocks, 4 types of domestic demand shocks (including a standard government consumption shock), 7 foreign/external shocks and 4 financial shocks (among them the euro area interest rate shock).

- Estimation: The model is estimated using Bayesian methods on 24 observables of Finnish and foreign data, with the sample period being 1995Q2 to 2014Q4.

- Replication: We simulated the impulse response functions to a productivity shock and a euro area interest rate shock, Figure 6 and Figure 8 in the paper.

- Implementation: Monetary policy is exogenous in this framework, as it does not explicitly model the euro area economy and associated monetary policy decisions. Hence, the model is implemented without the option to choose among various monetary policy rules. However, the implementation allows to compare the fiscal policy shock in the model to other models.

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