New Models in the MMB 3.1

The MMB 3.1 features 25 new models and thus raises the number of models that are available for comparison to a total of 153. The new models were designed to address a variety of central issues for macroeconomists.

List of the New Models Available*

A List of New Models Available in the Macroeconomic Model Data Base Version 3.1

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1 Calibrated Models

1.1 NK_DT12: De Fiore and Tristani (2013)

De Fiore and Tristani (2013) extend an otherwise standard New Keynesian model by introducing financial market imperfections: (wholesale) Firms need to pay wages prior to production, thus external financing is required. Asymmetric information and costly state verification between borrowers and lenders generate financial frictions in nominal terms. These frictions contribute to the propagation of the response of macroeconomic key variables to real and nominal shocks. The economy is populated by households owning retail sector firms, and entrepreneurs owning wholesale sector firms.

- Aggregate Demand: Households gain utility from consumption and leisure. Optimization leads to a standard forward-looking IS-Curve, augmented by a feed-back term on expected future spread increases. Additionally, a term including the current nominal rate is added, since this increases the financial mark-up and thus entrepreneurs' consumption.

- Aggregate Supply: The wholesale sector produces a homogeneous good under perfect competition, but subject to asymmetric information and monitoring costs. The retail sector uses the wholesale good to sell differentiated goods under monopolistic competition and Calvo Pricing.

- Shocks: The model exhibits a technology shock, the common monetary policy shock, a shock to the endowment of wholesale firms.

- Calibration: The model is calibrated at quarterly frequency, following the calibration of Woodford(2003).

1.2 NK_JO15ht, NK_JO15lt: Jang and Okano (2015)

Jang and Okano (2015) examine the effects of foreign productivity shocks on monetary policy in a symmetric two-country New Keynesian model, following Gali and Monacelli (2005). In response to asymmetric productivity shocks, firms in one country achieve a more efficient level of production and the terms of trade are directly affected by changes in both economies' output levels. International trade creates a transmission channel for inflation dynamics to which domestic monetary authority should react. Authors conclude that duration of output and inflation responses to changes in the level of foreign productivity is strongly affected by trade openness and that a monetary authority should be cautious about changes in foreign productivity level. Moreover, open economies should coordinate their policy responses to asymmetric shocks.

- Aggregate Demand: The representative household in both economies seeks to optimize its utility that is separable in 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. The dynamic IS equation is similar to that found for a closed economy but with the degree of openness influencing its coefficients.

- Aggregate Supply: Differentiated goods are produced from a typical firm using a linear technology with labor as input. Firms face price stickiness a la Calvo as in the case of a closed economy. The degree of country openness affects the slope of the New Keynesian Phillips curves in both economies. Additionally, firms borrow from households at the gross

nominal interest rate in order to pay wages. Nominal wage, therefore, corresponds to the discounted value of the nominal payoff in period t+1 generated by the portfolio held by households (Ravenna and Walsh (2006)).

- Shocks: Foreign productivity shock, but domestic productivity shock, as well as foreign and domestic monetary policy shocks, could be considered.

- Calibration: The model calibration is based on open-economy DSGE literature, with the parameter values as in Smets and Wouters (2002), Faia and Monacelli (2008), and Rabanal and Tuesta (2010).

2 Estimated U.S. Models

2.1 US_CET15: Christiano et al. (2015)

Christiano et al. (2015) develop a medium-scale New Keynesian model that entails a detailed labor market and financial friction. They estimate the model, and use it to account for US dynamics in and after the Great Recession.

- Aggregate Demand: Households consume, supply labor and hold capital assets, riskless bonds, and money. Their utility function is separable in consumption and money. Consumption is composed of goods from home production and market production. The utility function features habit formation in both consumption types. Next to the labor income and capital income, households derive income from firms' profits, and potentially unemployment benefits. Furthermore, they have to pay lump sum taxes. Households can either be employed, unemployed or out of the work force. Their labor market state is determined in a search and matching framework similar to Mortensen and Pissarides (1994). Wages are determined in an Alternative Offer Bargaining, developed by Christiano et al. (2016, Econometrica).

- Aggregate Supply: The production sector is comprised of final good producers, and retailers and wholesalers. Wholesalers employ labor as determined in the search and matching process and sell their product (intermediate goods) in perfect competition to retailers. Retailers produce their goods via a Cobb-Douglas production function employing capital and intermediate goods. The production function features fixed costs. Retailers are monopolistically competitive and face price stickiness as in the Calvo framework. Nonoptimizing retailers index their prices to inflation. Final good producers act in perfect competition. They buy retailers goods and bundle them to a homogenous final good. Capital accumulation (by the households) is subject to investment adjustment costs.

- Shocks: The model features an interest rate shock, a TFP shock, an investment-specific shock and a government spending shock.

- Estimation: The model is estimated on US data from 1951:1-2008:4 using Bayesian methods such that the IRFs of the monetary policy shock and the two technology shocks match their counterparts derived form a VAR that is estimated on the same dataset.

2.2 US_DEFK17: Del Negro et al. (2017)

Del Negro et al. (2017) introduce a liquidity friction into an otherwise standard DSGE model. This friction comes in two forms. First, a borrowing constraint for entrepreneurs so that they can only

borrow up to a fraction of the value of their current investment. Second, a resaleability constraint that limits the amount of "illiquid" assets that can be sold. With this setup, the importance of a shock to the liquidity of private paper on the economy is examined. Can it generate a shock similar to the one in 2008 and can the government, through an increase in liquidity, effectively intervene in the economy? They find that the financial shock and the liquidity policy can have quantitatively large effects.

- Aggregate Demand: Households consist of a continuum of members each drawn to be either a worker supplying labor or an entrepreneur with an opportunity to invest. At the end of each period they share their consumption purchases and assets. Entrepreneurs want to sell as much equity and government bonds as possible to finance new capital, which yields a higher return. Hence, a negative liquidity shock affects entrepreneurs, who are not able to sell their equity anymore, thus reducing investment.

- Aggregate Supply: Intermediate good producers combine labor and capital services to produce their goods while paying a fixed cost of production. Prices are set in a staggered way, following Calvo (1983). The goods market is characterized by monopolistic competition. Labor unions set the wage for each type of labor on a staggered basis. Competitive final good producers combine intermediate goods to sell a homogeneous final good. Finally, perfectly competitive capital producers produce investment goods that are sold to the entrepreneurs.

- Shocks: The liquidity shock comes through a change in the parameter of the resaleability constraint.

- Estimation: The model is calibrated at quarterly frequency with U.S. data from 1953:Q1 to 2008:Q3.

2.3 US_FU19: Fratto and Uhlig (forthcoming)

Fratto and Uhlig investigate on the missing deflation puzzle by estimating versions of the Smets and Wouters (2007) on different samples of US data that include or exclude the years after the Financial Crisis. They find that markup shocks account for the almost all of the variation in inflation before and after the crisis. In the MMB, we parametrize the model according to the estimates on 1984-2015 data.

- Aggregate Demand: Households maximize their lifetime utility, where the utility function is nonseparable in consumption and leisure, subject to an intertemporal budget constraint. Smets and Wouters (2007) include external habit formation to make the consumption response in the model more persistent. Households own firms, rent capital services to firms and decide how much capital to accumulate given certain capital adjustment costs. They additionally hold their financial wealth in the form of one-period, state-contingent bonds. Exogenous spending follows a first-order autoregressive process with an iid-normal error term and is also affected by the productivity shock.

- Aggregate Supply: The final goods, which are produced under perfect competition, are used for consumption and investment by the households and by the government. The final goods producer maximizes profits subject to a Kimball (1995) aggregator of intermediate goods, which introduces monopolistic competition in the market for intermediate goods and features a non constant elasticity of substitution between different intermediate goods, which depends on their relative price. A continuum of intermediate firms produce differentiated

goods using a production function with Cobb-Douglas technology and fixed costs and sell these goods to the final-good sector. They decide on labor and capital inputs, and set prices according to the Calvo model. Labor is differentiated by a union using the Kimball aggregator, too, so that there is some monopoly power over wages, which results in an explicit wage equation. Labor packers buy the labor from the unions and resell it to the intermediate goods producer in a perfectly competitive environment. Sticky wages à la Calvo are additionally assumed. The Calvo model in both wage and price setting is augmented by the assumption that prices that can not be freely set, are partially indexed to past inflation rates.

- Shocks: A total factor productivity shock, a risk premium shock, an investment-specific technology shock, a wage and a price mark-up shock and two policy shocks: the common fiscal policy shock entering the government spending equation and the common monetary policy shock.

- Estimation: The model is estimated for the U.S. with Bayesian techniques for the period 1984Q1-2015Q4 using seven key macroeconomic variables: real GDP, consumption, investment, the GDP deflator, real wages, employment and the nominal short-term interest rate. The replication package additionally contains the baseline version of the model estimated on a shorter sample (1984Q1-2007Q4).

2.4 US_HL16: Hollander and Liu (2016)

Hollander and Liu (2016) analyse the role of the equity price channel in business cycle fluctuations. They incorporate the financial accelerator channel and the bank equity channel into a medium-scale New-Keynesian DSGE model. Through these two channels, the equity price channel amplifies shocks to the real economy. The model reproduces the procyclicality of the equity price found in the data.

- Aggregate Demand: There are two types of representative households, saver and borrower households. Both maximize their expected lifetime utility that depends on consumption, labour, deposits and equity investments, subject to budget constraints. Households' consumption preferences exhibit habit formation. In addition to the budget constraint, borrower households also face a borrowing constraint. Households supply labour and wages are flexible in the model.

- Aggregate Supply: Entrepreneurs produce the wholesale good using capital and labour as inputs. They face direct costs of adjusting their capital stock. Retailers buy the intermediate goods at the wholesale price, differentiate them at no cost, and sell the final good with a mark-up. Prices are subject to nominal rigidities à la Calvo (1983).

- Banking sector: The banking sector in the model builds on Gerali et al. (2010). Each bank consists of two monopolistically competitive retail branches (a loan and a deposit branch) and one perfectly competitive wholesale branch that manages the consolidated balance sheet of the respective bank.

- Shocks: There are nine shocks in the model: a technology, a monetary policy, a deposit, a loan markup (firms), a loan markup (households), households' LTV, an equity price, and a price markup shock.

- Estimation: The model is estimated with Bayesian techniques using US data from 1982Q1 to 2015Q1 on nine variables: output, inflation, equity price, household loans, entrepreneur loans, deposits, the Fed funds rate, the mortgage rate, and the Baa corporate rate.

2.5 US_KK14: Kliem and Kriwoluzky (2014)

Kliem and Kriwoluzky (2014) set up a New Keynesian model that entails a fiscal sector with several instruments, estimate it on US data and analyze the empirical plausibility and welfare properties of feedback rules for labor and capital income tax rates.

- Aggregate Demand: Households consume, supply labor and invest in capital and riskless bonds. Their utility function is separable in consumption and leisure and features habit formation as well as an exogenous consumption demand shifter. Next to the labor income and capital income (which are both taxed), it derives income from firm's dividends (which are also taxed) and fiscal transfers. They set their wages in monopolistic competition as in Erceg et al. (2000). Those households, which cannot update their wages in a given period index it to the steady state inflation rate.

- Aggregate Supply: The production sector is comprised of final good producers, and intermediate good producers. Intermediate good producers produce their goods via a Cobb-Douglas production function employing labor and capital. The production function features variable capital utilization and fixed costs. They are monopolistically competitive and face price stickiness as in the Calvo framework. Final good producers act in perfect competition. They buy intermediate goods and bundle them to a final good. Capital accumulation (by the households) is subject to investment adjustment costs.

- Monetary and Fiscal authorities: Monetary policy is conducted using an interest rate rule that exhibits interest rate smoothing and a response to inflation and the output gap. The government raises taxes on labor and capital income which are modelled as feedback rules reacting to the levels of government debt and output. Government consumption and transfers evolve according to exogenous AR(1) processes.

- Shocks: A preference shock, a technology shock, an investment-specific efficiency shock, a price markup shock, a wage markup shock, a monetary policy shock, a transfer shock, a government spending shock, a shock to the resource constraint and shocks to the labor and capital income tax rates.

- Estimation: The model is estimated on US data for the period of 1983:1 -2008:3 using Bayesian methods. As 12 observables are used in the estimation, additional to the 11 structural shocks, the authors add measurement error to the observation equation for tax revenues.

2.6 US_KS15: Kriwoluzky and Stoltenberg (2014)

Kriwoluzky and Stoltenberg (2014) incorporate an explicit transaction role for money in a standard cashless new Keynesian model (Woodford (2003)) and compare the role of money in the pre-Volcker period (before 1979) with the period from 1982 on. They estimate that before 1979, money played an important role in facilitating transactions while after 1982, the importance of money declined sharply. They argue that this shift can possibly explain the switch in US interest rate policy from a passive to an active setting.

- Aggregate Demand: In the model there is a continuum of infinitely lived households that maximize expected lifetime utility subject to a budget constraint that incorporates transaction costs for purchasing consumption goods. The instantaneous utility function is increasing in consumption and decreasing in labour that the households supply to firms.

- Aggregate Supply: Using the labour supply from households as the sole input, monopolistically competitive firms produce differentiated goods that are aggregated to the final consumption good. Price setting by the firms follows Calvo (1983), leading to nominal rigidities in the model.

- Shocks: There is a technology, a government spending, a wage mark-up, a taste, a monetary policy shock and a shock to transaction costs.

- Estimation: The model is estimated using Bayesian techniques on US data using real output, real consumption, annual inflation, the federal funds rate, real money balances, and real wages as observable variables. The quarterly data ranges from 1964Q1 to 2008Q2 and is split into two parts: from 1964Q1 to 1978Q4 and from 1983Q1 to 2008Q2, excluding the disinflation years.

2.7   US_LTW17, US_LTW17nu, US_LTW17rot: Leeper et al. (2017)

Leeper et al. (2017) implement a new Keynesian model, based on Smets and Wouters (2003, 2007), yet add distorting tax rates on capital and labor income and consumption. The additional features of the model are that utility also depends on government consumption and saver households have also access to a portfolio of long-term government zero-bonds with maturity decaying at a constant rate (not only to short-term bonds). The model is used to assess the fiscal multiplier in the US.

- Aggregate Demand: The model economy is populated by a continuum of infinitely lived households of which a fraction is non-saver. Non-saver households do not have access to any savings technology, thus they consume their entire disposable income every period. The firms and the capital stock are owned entirely by saver households. The utility function is separable in consumption and leisure and assumes external habits that depend on aggregate consumption in the last period. In addition, household consumption also depends on government consumption in an additive manner.

- Aggregate Supply: Production is carried out in two stages, by a perfectly competitive final goods producer and a continuum of monopolistically competitive intermediate goods producers using capital and labour as input factors. Households provide uniquely differentiated labor in monopolistic competition. Saver households set wages optimally while non-savers follow a rule-of thumb to set their wage rates to be the average wage rates chosen by savers. Wages and prices are allowed to adjust only gradually by assuming Calvo pricing with partial adjustment of the contracts to past inflation.

- Monetary and Fiscal authorities: Monetary authorities follow a Taylor-type rule with lagged policy rates. Fiscal authorities levy distortionary taxes on income from capital, labor and consumption taxes and sell the nominal bond portfolio to finance its interest payments, government consumption and lump-sum transfers to households. Fiscal rules include a response of fiscal instruments to the market value of the debt-to-GDP ratio and an autoregressive term to allow for serial correlation. The model was restricted such that only public consumption and transfers potentially respond to debt. Tax distortions enter only the steady state.

- Shocks: Government consumption shock, transfer shock, total factor productivity shock, preference shock, investment adjustment costs shock, monetary policy shock, wage markup shock, price markup shock.

- Estimation: The baseline model, implemented into the MMB, is estimated for the U.S. by means of Bayesian techniques for the period 1955:1-2007:4 using eight key macroeconomic variables: log differences of aggregate consumption, investment, real wages, real government consumption, the real market-value of government debt, and the GDP deflator; log hours worked; the federal funds rate. Data are neither detrended nor demeaned. Drawing on the information from the prior predictive analysis, the authors eliminated rule-of-thumb agents. They also did not include tax revenues or tax rates in the observables because quarterly measures of marginal tax rates are problematic.

- Replication: The original NK-model was separated from the Matlab based code provided by the authors and translated into Dynare. The baseline scenario (solid line) among the impulse response functions in Figure 5 was replicated and compared also with the implemented version of the model. The IRFs in the model base appear to match those from the original Matlab code if one eliminates the autoregressive coefficient in the error term of the monetary policy rule in the original code. In addition to the baseline setting two counterfactual models were added, two from Figure 5 (1. lower habit formation coefficient with no government spending in utility (US_LTW17nu); 2. Inclusion of rule of thumb consumers (US_LTW17rot)).

2.8 US_MI07: Milani (2007)

Milani (2007) presents an estimated model with learning and provides evidence that learning can improve the fit of popular monetary DSGE models and endogenously generate realistic levels of persistence. The rational expectations version of the model is based on the those applied by Boivin and Giannoni (2003), Giannoni and Woodford (2003), and also described in Woodford (2003). The model incorporates some of the structural sources of persistence, such as habit formation in consumption and inflation indexation. The main finding of the paper is that the empirical results show that when learning replaces rational expectations, the estimated degrees of habits and indexation drop near zero. This finding suggests that persistence arises in the model economy mainly from expectations and learning.

- Aggregate Demand: The representative household maximizes lifetime utility subject to an intertemporal budget constraint. Utility from consumption and disutility from labor is separable. Preferences for consumption are subject to habit persistence. The representative household offers a continuum of different types of labor to the firms.

- Aggregate Supply: There exists a continuum of monopolistically competitive firms. Price stickiness is embedded into the model via the Calvo (1983) framework. Each good is produced using a decreasing return to scale technology and capital is assumed to be fixed, leaving labor as the only variable factor of production. The natural real rate of interest is modeled as an exogenous AR(1)-process.

- Shocks: Natural real interest rate shock, cost-push shock, monetary policy shock

- Estimation: The model is estimated using likelihood-based Bayesian methods to fit the series for output gap, inflation, and the nominal interest rate as used in a number of papers, surveyed in An and Schorfheide (2006). Yet, the paper provides an example of estimation of a simple DSGE model with non-fully rational expectations and learning. The data are quarterly for the period 1960:I to 2004:II.

2.9 US_VI16bgg and US_VI16gk: Villa (2016)

Villa (2016) assesses the empirical relevance of financial frictions in the US and in the Euro Area, where the above versions of the model refer to the US. It develops a medium-scale closed economy DSGE-model based on Smets and Wouters (2007) and two different financial sector extensions of this framework, in particular Bernanke et al. (1996) and the Gertler and Karadi (2011) types.

- US_V16bgg model:

    - Aggregate Demand: Households maximize their lifetime utility, where the utility function is separable in consumption and leisure, subject to an intertemporal budget constraint. In addition, the external habit formation makes the consumption response more persistent. Households own firms, rent capital services to firms and decide how much capital to accumulate given certain capital adjustment costs. They additionally hold their financial wealth in the form of one-period, state-contingent government bonds.

    - Aggregate Supply: Intermediate good firms maximize their profits by choosing factors of production and by signing a financial contract to obtain additional funds from lenders. Since lenders have to pay some auditing costs to observe the idiosyncratic return to capital, an agency problem arises. The financial contract implies external finance premium that depends on the inverse of the firm's leverage ratio. Retailers buy goods from intermediate good firms, differentiate them, and sell them in a monopolistically competitive market according to the Calvo model. The aggregate final good is assembled by perfectly competitive final good firms, and is used for consumption and investment by the households and by the government. The final goods producer maximizes profits subject to a Dixit-Stiglitz aggregator of intermediate goods, which introduces monopolistic competition in the market for intermediate goods and features a constant elasticity of substitution between individual, intermediate goods. Labor is differentiated by a union using the Dixit-Stiglitz aggregator, too, so that there is some monopoly power over wages, which results in an explicit wage equation. Labor packers buy the labor from the unions and resell it to the intermediate goods producer in a perfectly competitive environment. Sticky wages à la Calvo are additionally assumed.

- US_V16gk model:

    - Aggregate Demand: The representative household's utility is separable in consumption and leisure and allows for habit formation in consumption. Households postpone their consumption by holding deposits with the financial intermediaries. The amount of deposits is determined in such a way as to guarantee that the bankers' incentive constraint is satisfied. Expected-lifetime utility is maximized by choosing consumption and labor supplied to intermediate firms.

    - Aggregate Supply: Competitive firms produce intermediate goods using labor services and capital. They face adjustment costs for varying their utilization rate of capital. They finance the capital stock with loans from the financial intermediaries and buy it from capital producing firms to which they re-sell it at the end of the period after having used it. Capital producers face investment adjustment costs. The intermediate goods are bought by retail firms, which act under monopolistic competition and face nominal rigidities as in Calvo (1983). Non-reoptimizing retailers index their prices to the previous period's inflation rate.

- Banking sector: Banks receive their funds in the form of deposits from households and lend to non-financial firms. A moral hazard/costly enforcement problem constrains the ability of banks to obtain funds from households, while they are able to perfectly monitor firms and enforce contracts.

- Shocks: Seven structural shocks: the technology shock, the investment-specific technology shock, the capital quality shock, the price mark-up shock, the wage mark-up shock, and two policy shocks - the common fiscal policy shock entering the government spending equation and the common monetary policy shock.

- Estimation: The model is estimated for EA and US with Bayesian techniques for the period 1983:Q1-2008:Q3 using seven key macroeconomic variables: real GDP, real investment, real private consumption, hours worked, GDP deflator inflation, real wage, and the nominal short-term interest rate.

- Replication: The impulse response functions to negative one-standard-deviation shocks were replicated, similar to those in Figures 3-6 in Villa (2016). The variables include output, investment, inflation, net worth and spread.

2.10 US_YR16: Rychalovska (2016)

Rychalovska (2016) incorporates financial frictions combined with an imperfectly rational expectation formation mechanism into a medium-scale DSGE model based on Smets and Wouters (2007). The financial frictions are integrated in the form of the financial accelerator as originally applied in Bernanke and Gertler (1989) and Bernanke et al. (1999). The model contains a number of nominal and real rigidities such as monopolistic competition on goods and labor markets, Calvo price and wage stickiness, habit formation in consumption and capital adjustment costs. The paper explores the properties of the model assuming, on the one hand, complete rationality of expectations and, alternatively, several learning algorithms that differ in terms of the information set used by agents to produce the forecasts. The results suggest that the learning scheme based on small forecasting functions is able to amplify the effects of financial frictions relative to the model with Rational Expectations.

- Aggregate Demand: As in Smets and Wouters (2007), households maximize their lifetime utility function, non-separable in consumption and leisure, subject to an intertemporal budget constraint. Preferences for consumption are subject to habit persistence. Households own firms and supply labor monopolistically. Wage stickiness is introduced via the Calvo framework.

- Aggregate Supply: Apart from the intermediate and final goods firms as in Smets and Wouters (2007), following Bernanke et al. (1999) and Christiano et al. (2003), capital goods producers and entrepreneurs are introduced into the model. Competitive capital-goods producers, owned by households, produce new capital goods which are sold to entrepreneurs. Capital-goods producers combine investment goods, purchased from the final good producers, with the existing capital stock, rented from the entrepreneurs, to produce new capital goods. Capital-goods producers are subject to quadratic adjustment costs. In the formal representation of the entrepreneurs' problem the paper follows Christiano et al. (2010) and deviates from the original Bernanke et al. (1999) specification, assuming that entrepreneurs are not directly involved in the production of intermediate goods. In addition, banks are

also introduced into the model, which interact with entrepreneurs and bring financial frictions into play. Entrepreneurs, who are risk neutral and survive until the next period with a certain probability, use their own funds (the net worth) and loans from the bank to finance capital that is rented to the production sector. Competitive banks finance the loans by accepting deposits from the households at the risk-free rate while entrepreneurs have to pay an external finance premium over the riskless rate in order to borrow funds.

- Shocks: total factor productivity shock, investment-specific shock, external financing premium shock, fiscal shock, a monetary policy shock, a wage and price mark-up shock.

- Estimation: The model is estimated using seven macroeconomic quarterly U.S. time series: real GDP, real consumption, real investment, real wage, hours worked, GDP deflator and the federal funds rate. The data are quarterly for the sample period 1954:1-2008:3.

3   Estimated Euro Area Models

3.1   EA_ALSV06: Andrés et al. (2006)

Andrés et al. (2006) develop a small-scale New Keynesian model with real money balances entering both the forward-looking IS curve and the Phillips curve. The model is used to assess the role played by money in the joint evolution of output, interest rates and inflation in the euro area economy. The authors find no effect of real balances on marginal utility of consumption and that prices, output and interest rates are mainly explained by real shocks and not money demand shocks.

- Aggregate Demand: A representative household maximizes expected utility, non-separable between consumption and real money balances while separable in hours worked, subject to a budget constraint. The utility function features habit formation in consumption. The optimizing behavior leads to a forward looking IS curve in which real balances enter. This is due to the intra-temporal non-separability of real balances and consumption in the utility function. Further, due to the habit formation in consumption, the IS curve includes a lag in output and two period leads in output, real balances, as well as the money demand and preference shocks.

- Aggregate Supply: A continuum of firms produces goods according to Cobb-Douglas production functions using labor as input. Firms sell their output in a monopolistically competitive market. Nominal prices are set on a staggered basis as in Calvo. Further, some of the adjusting firms use a backward-looking rule of thumb while the rest of the firms adjust their prices based on optimization of expected future revenues. The optimizing behavior of firms leads to a forward-looking Phillips curve. Due to the rule-of-thumb adjusting firms, the Phillips curve also has a backward-looking component. Via real marginal costs, besides the technology shock, also output and real balances enter the Phillips curve; under habits also lags and/or leads in output, real balances as well as money demand and preference shocks enter the specification.

- Shocks: An overall preference shock, a real money balances preferences (velocity) shock, a productivity (technology) shock, and a monetary policy shock.

- Estimation: Estimated via maximum likelihood using EA quarterly data over the period 1980:1-1999:4 for logs of detrended output, detrended real balances, inflation and gross nominal interest rates. Output, inflation and interest rate data come from the Area Wide Model dataset, while real balances are measured dividing M3 by the GDP deflator.

3.2   EA_SWW14: Smets et al. (2014)

Smets et al. (2014) uses the Gali, Smets and Wouters (2012) model. It is estimated on euro area data using Bayesian estimation techniques.

- Gali, Smets and Wouters (2012) is based on Smets and Wouters (2007) and differs from the latter in the following ways:

  - labor decision on the extensive margin (whether to work or not) rather than the intensive margin (how many hours to work), unemployment is included as an observable variable

  - logarithmic consumption utility, the utility function is separable in consumption and leisure

  - the error term in the wage equation captures only the wage markup shock and not the preference shock (as in SW07)

  - Dixit-Stigliz type aggregator functions for aggregate labor demand and aggregate nominal wage (SW07 uses Kimball).

- Shocks: A total factor productivity shock, a risk premium shock, an investment-specific technology shock, a labor supply shock, a wage and a price mark-up shock and two policy shocks: the common fiscal policy shock entering the government spending equation and the common monetary policy shock.

- Estimation: The model is estimated for the euro area with Bayesian techniques for the period 1985:1-2009:4. In addition to SW07, unemployment is used as an observable variable for the estimation of parameters.

3.3   EA_VI16bgg and EA_VI16gk: Villa (2016)

Villa (2016) assesses the empirical relevance of financial frictions in the US and in the Euro Area, where the above versions of the model refer to the Euro Area. It develops a medium-scale closed economy DSGE-model based on Smets and Wouters (2007) and two different financial sector extensions of this framework, in particular Bernanke et al. (1996) and the Gertler and Karadi (2011) types.

- EA_V16bgg model:

  - Aggregate Demand: Households maximize their lifetime utility, where the utility function is separable in consumption and leisure, subject to an intertemporal budget constraint. In addition, the external habit formation makes the consumption response more persistent. Households own firms, rent capital services to firms and decide how much capital to accumulate given certain capital adjustment costs. They additionally hold their financial wealth in the form of one-period, state-contingent government bonds.

  - Aggregate Supply: Intermediate good firms maximize their profits by choosing factors of production and by signing a financial contract to obtain additional funds from lenders. Since lenders have to pay some auditing costs to observe the idiosyncratic return to capital, an agency problem arises. The financial contract implies external finance premium that depends on the inverse of the firm's leverage ratio. Retailers buy goods from intermediate good firms, differentiate them, and sell them in a monopolistically competitive market according to the Calvo model. The aggregate final good

is assembled by perfectly competitive final good firms, and is used for consumption and investment by the households and by the government. The final goods producer maximizes profits subject to a Dixit-Stiglitz aggregator of intermediate goods, which introduces monopolistic competition in the market for intermediate goods and features a constant elasticity of substitution between individual, intermediate goods. Labor is differentiated by a union using the Dixit-Stiglitz aggregator, too, so that there is some monopoly power over wages, which results in an explicit wage equation. Labor packers buy the labor from the unions and resell it to the intermediate goods producer in a perfectly competitive environment. Sticky wages à la Calvo are additionally assumed.

- EA_V16gk model:

  - Aggregate Demand: The representative household's utility is separable in consumption and leisure and allows for habit formation in consumption. Households postpone their consumption by holding deposits with the financial intermediaries. The amount of deposits is determined in such a way as to guarantee that the bankers' incentive constraint is satisfied. Expected-lifetime utility is maximized by choosing consumption and labor supplied to intermediate firms.

  - Aggregate Supply: Competitive firms produce intermediate goods using labor services and capital. They face adjustment costs for varying their utilization rate of capital. They finace the capital stock with loans from the financial intermediaries and buy it from capital producing firms to which they re-sell it at the end of the period after having used it. Capital producers face investment adjustment costs. The intermediate goods are bought by retail firms, which act under monopolistic competition and face nominal rigidities as in Calvo (1983). Non-reoptimizing retailers index their prices to the previous period's inflation rate.

  - Banking sector: Banks receive their funds in the form of deposits from households and lend to non-financial firms. A moral hazard/costly enforcement problem constrains the ability of banks to obtain funds from households, while they are able to perfectly monitor firms and enforce contracts.

- Shocks: Seven structural shocks: the technology shock, the investment-specific technology shock, the capital quality shock, the price mark-up shock, the wage mark-up shock, and two policy shocks - the common fiscal policy shock entering the government spending equation and the common monetary policy shock.

- Estimation: The model is estimated for EA and US with Bayesian techniques for the period 1983:Q1-2008:Q3 using seven key macroeconomic variables: real GDP, real investment, real private consumption, hours worked, GDP deflator inflation, real wage, and the nominal short-term interest rate.

- Replication: The impulse response functions to negative one-standard-deviation shocks were replicated, similar to those in Figures 3-6 in Villa (2016). The variables include output, investment, inflation, net worth and spread.

4 Estimated Models of Other Countries

4.1 CA_TOTEM10: Murchison and Rennison (2006)

CA_ToTEM10 represents the 2010 vintage of ToTEM (Terms-of-Trade Economic Model) which is an open-economy, DSGE model developed by Murchison and Rennison (2006). The Bank of Canada uses this model as a tool for policy analysis and projections for the Canadian economy.

- Aggregate Demand: Households are classified as 'lifetime income' consumers and 'current income' consumers, reflecting the fact that not all consumers can access credit markets. Lifetime income consumers smooth their consumption across time through borrowing and saving while 'current income' consumers consume their current income each period. Lifetime income consumers choose consumption, domestic and foreign bond holdings, labor supply and wages to maximize a utility function non-separable in consumption and leisure subject to a dynamic budget constraint. Both types of households supply differentiated labor services giving them power when negotiating the wages with the domestic producers. However, renegotiation of the wages is allowed only once in six months, on average, and only a constant proportion of wage contracts are renewed every period. The dynamic wage equation is a function of past and expected future wage inflation and an error-correction component.

- Aggregate Supply: The production sector is comprised of final good producers, an import sector and a commodity sector. Final goods firms produce consumption goods and services, investment goods, and export goods. The production process of these goods is analogous, differing only on the share of imported goods used in production. In this process, first a capital-labor composite is produced using CES technology, which is then combined with a commodity input to produce the domestic good. Final goods then are a combination of the domestic good and the imported good. Through these steps, the firm faces capital adjustment costs, investment adjustment costs and labor adjustment costs. Final goods firms sell their differentiated goods in a monopolistic competitive fashion having power over prices. However, not all firms can re-optimize their prices every period. A share of firms updates prices according to a geometric average of lagged core inflation and expectations of the inflation target. In ToTEM, pricing decisions are considered as strategic complements, where firms have a strong incentive to follow what other firms do. The commodity sector is represented by a domestic firm operating in a competitive market, producing commodities using capital services, labor and land under a CES technology. These raw goods are either sold to a continuum of imperfectly competitive commodity distributors or exported (for the world price of the commodity denominated in Canadian currency). The commodity distributors repackage the commodity goods and sell them to households and to the final goods producers. These distributors face nominal rigidities a la Calvo in price setting, which limits the degree of exchange rate pass-through to consumer prices in the short-run.

- The Foreign Sector: The import sector is represented by firms who buy imported goods in the world market for a given world price (law of one price holds). These goods are sold to domestic firms, which use them as inputs in their respective production functions. Imperfect exchange rate pass-through in the short-run is present as the price of imports is temporarily fixed in the currency of the importing country and because import firms face nominal rigidities a la Calvo when setting prices. As in other sectors, imported goods inflation is a function of past and expected future imported goods inflation and an error-correction component. Export goods firms are part of the final good producers sector as discussed above.

They have some degree of market power and therefore face a downward-sloped demand curve (rest of the world demand).

- Shocks: A demand shock, a risk-premium shock, an inflation target shock, a commodity price shock, a technology shock, world demand shock and a price mark-up shock.

- Calibration/Estimation: Calibrated with parametrization chosen to match univariate auto-correlations, bivariate correlations and variances estimated using Canadian data for the period 1980-2004.

4.2 ESP_MP17, GRC_MP17, IRL_MP17, PRT_MP17: Martin and Philippon (2017)

Martin and Philippon (2017) build a New Keynesian small open economy model inside a monetary union. They seek to analyse what the Eurozone crisis was caused by - overly expansive fiscal policy, excessive private debt or a sudden stop. They build these three channels into their model and estimate the structural parameters from Eurozone data. They calibrate their model with the resulting parameters and show that it fits the data well. The authors perform counterfactual experiments for 4 Euro area countries - Spain, Greece, Ireland and Portugal - to analyse if different policies could have changed the evolution of the crisis. The version of the model that is implemented here is the one provided in the authors' code - the only exception is that 3 parameter values in the country spread equation were adjusted as the code differed from the paper there - and is slightly different from the model in the paper.

- Aggregate Demand: There are patient and impatient households who maximise utility separable in consumption and labour. Impatient households borrow and are subject to a borrowing limit. Patient households own firms and save. The government taxes households and issues bonds. Households consume a basket of domestic and foreign goods. Also, they monopolistically set wages à la Calvo.

- Aggregate Supply: Differentiated goods are produced by monopolistic firms using a linear technology with labour being the only production input. Firms set their prices à la Calvo.

- Policy Channels: First, private debt evolution is modelled via an equation for the evolution of the borrowing limit over time (credit cycle). Second, fiscal policy is modelled with a rule for government expenditure and a rule for government transfers. Third, sudden stops are introduced via an equation for a country-specific spread in funding costs (relative to the eurozone average). This also depends on banks' recapitalisation needs.

- Shocks: shock to government expenditure, shock to government transfers, shock to the borrowing limit, shock to the funding cost spread, shock to banks' recapitalisation needs, shock to exports, shock to productivity.

- Estimation: The authors estimate several parameters of their specification for the three policy channels (using annual data) and use the resulting parameters for calibration. Other values are taken from the literature by the authors. This includes the two country-specific parameters openness and the share of credit-constrained households for the four countries. The model is calibrated to annual data in the paper and the replication file. In the MMB, the calibration is quarterly via adjusting the necessary intertemporal parameters.

- Implementation: Monetary policy is exogenous in this framework as the policy decision is not explicitly modelled and all variables are expressed relative to the euro area average.

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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