New Models in the MMB 2.3

The MMB 2.3 features 21 new models and thus raises the number of models that are available for comparison to a total of 114. The new models were designed to address a variety of central issues for macroeconomists.

In the aftermath of the recent financial crisis, central banks around the world expanded their toolkits to stimulate and stabilize the economy. **Carlstrom, Fuerst, and Paustian (2017)** analyse the effects of long-term bond purchases and of term-premium targeting in a model with segmented financial markets. **Paoli and Paustian (2017)** study optimal monetary and macroprudential policies. Additionally, most of the new models feature an analysis of conventional monetary policy.

Many of the new models in the MMB 2.3 analyze the role of different types of financial frictions for business cycles. **Ajello (2016)** develops a medium-scale model in which ideosyncratic shocks determine the investment behaviour of agents to analyze the role of the the financing gap of nonfinancial firms for US business cycles and vice versa. **Rannenberg (2016)** combines the financial frictions developed by Bernanke, Gertler, and Gilchrist (1999) and by Gertler and Karadi (2011). Focussing on the Euro Area, **Poutineau and Vermandel (2015)** evaluate how cross-border capital flows shape business cycles in a monetary union. Other examples of new models in the MMB 2.3, which focus on financial frictions are **Carlstrom, Fuerst, and Paustian (2010)**, **Stracca (2013)**, **Goodfriend and McCallum (2007)**, and **Pancrazi, Seoane, and Vukotic (2016)**.

The importance of another type of friction for business cycles is emphasized by **Reis (2009)**: sticky information. He presents a model in which information stickiness affects all markets and revisits the effects of conventional monetary policy shocks.

With central banks being constrained by the zero lower bound on nominal rates, government spending was another important tool to tackle the Great Recession. The MMB 2.3 features two new models, which highlight very different determinants of the size of the spending multiplier. **Kirchner and van Wijnbergen (2016)** show that a balance sheet constrained financial sector reduces the multiplier. In contrast, **Galí, López-Salido, and Vallés (2007)** point out that the presence of rule-of-thumb consumers can raise the multiplier substantially above one. Additionally, **Monacelli, Perotti, and Trigari (2010)** investigate the role of government spending for unemployment.

The conclusions that can be drawn from economic models depend on the econometric method which is used for the estimation of their parameters. **Fernández-Villaverde (2010)** estimate a version of the model by Smets and Wouters (2007) linearly, taking account of time-variation in the parameters. **Fernández-Villaverde, Guerrón-Quintana, and Rubio-Ramírez (2015)** estimate a very similar model non-linearly. The resulting differences in the dynamics can be compared in the MMB 2.3.. **Leeper, Walker, and Yang (2013)** point out the problem of fiscal foresight for macroeconometricians. Estimating a Smets and Wouters model with distorting taxes on capital and labor income, they show that the parameter estimates depend crucially on the assumed foresight capacity of agents.

Furthermore, the MMB 2.3 features the term structure model by **Ireland (2015)** in which bond yields are driven by observable and unobservable macroeconomic factors and which highlights a range of channels through which monetary policy, risk premia and the economy interact.

Lastly, the MMB 2.2 included the benchmark model by **Del Negro, Giannoni, and Schorfheide (2015)**, which was used to analyse the dynamics of the US economy in the Great Recession. In the MMB 2.3, we add versions of the model that are stripped of financial frictions and/or time varying inflation target as well as the Smets and Wouters model that the authors re-estimate.

List of the 21 New Models Available*

A LIST OF NEW MODELS AVAILABLE IN THE MACROECONOMIC MODEL DATA BASE VERSION 2.3

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1. CALIBRATED MODELS (9 NEW MODELS)

1.1	NK_CFP10	Carlstrom et al. (2010)
1.2	NK_GM07	Goodfriend and McCallum (2007)
1.3	NK_GLSV07	Galí et al. (2007)
1.4	NK_KW16	Kirchner and van Wijnbergen (2016)
1.5	NK_MPT10	Monacelli et al. (2010)
1.6	NK_PP17	Paoli and Paustian (2017)
1.7	NK_PSV16	Pancrazi et al. (2016)
1.8	NK_RA16	Rannenberg (2016)
1.9	NK_ST13	Stracca (2013)

2. ESTIMATED US MODELS (11 NEW MODELS)

2.1	US_AJ16	Ajello (2016)
2.2	US_CFP17exo	Carlstrom et al. (2017) - exogenous level of long-term debt
	US_CFP17endo	Carlstrom et al. (2017) - endogenous level of long-term debt
2.3	US_DNGS15_SW	Del Negro et al. (2015) w/o financial frictions
	US_DNGS15_SWpi	Del Negro et al. (2015) w/o financial frictions and time-varying inflation target
	US_DNGS15_SWSP	Del Negro et al. (2015) reestimation of Smets and Wouters (2007) with longer time-series
2.4	US_FV10	Fernández-Villaverde (2010)
2.5	US_FV15	Fernández-Villaverde et al. (2015)
2.6	US_IR15	Ireland (2015)
2.7	US_LWY13	Leeper et al. (2013)
2.8	US_RE09	Reis (2009)

3. ESTIMATED EURO AREA MODELS (1 NEW MODEL)

3.1	EA_PV15	Poutineau and Vermandel (2015)

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* There are 21 new models available out of which 4 are model variations, hence there are 17 distinct new models.

1 Calibrated Models

1.1 NK_CFP10: Carlstrom et al. (2010)

Carlstrom et al. (2010) build a small-scale calibrated New Keynesian DSGE model with agency costs, which are modelled as constraint on the firm's hiring of labour as in the holdup problem of Kiyotaki and Moore (1997).

- Aggregate demand: Households maximize their lifetime utility, where the per-period utility function is separable in consumption and two types of labour. They can buy standard one-period bonds and firm shares, with the latter paying dividends.
- Aggregate Supply: Entrepreneurs have linear consumption preferences and operate the intermediate good firms. These firms combine both types of labour into the intermediate good using a Cobb-Douglas production function. Due to a hold-up problem, entrepreneurs face a collateral constraint on their hiring of one labour input, in that the wage bill cannot exceed a Cobb-Douglas combination of net worth and profits. This introduces a credit friction. Monopolistically competitive final goods firms purchase intermediate goods from entrepreneurs and create final goods using a linear production function. Final goods pricing is subject to Rotemberg quadratic adjustment costs. The final goods are aggregated to an output bundle according to a CES function.
- Shocks: A productivity shock, a mark-up shock, a net worth shock and a monetary policy shock.
- Calibration/Estimation: The model is calibrated using standard values in the literature, in particular following Woodford (2003). Credit-related parameters are calibrated using the average spread between BB+ and 10-year Treasury bonds from 1996 to present.
- Replication: We simulated the impulse response functions to a monetary policy shock and a technology shock under a simple Taylor rule, Figure 1 and Figure 2 in the paper.

1.2 NK_GM07: Goodfriend and McCallum (2007)

Goodfriend and McCallum (2007) develop a small New Keynesian model with a banking sector and several interest rates to analyze the role of the banking sector for the evaluation of monetary policy. There are two versions of the model: one in which monetary policy is represented by a money supply rule, and one in which it is represented by a rule for the short-term nominal interest rate. Here, we focus on the latter. The model in the original article contains a mistake, which is detailed in the replication package. We implement the corrected version of the model in the MMB.

- Aggregate Demand: A representative household-firm maximizes expected utility derived from consumption and labor. The utility function is additive separable. Its budget constraint features capital accumulation, real balances and government bonds. Furthermore it receives the income derived from wages and (in its function as a monopolistically competitive firm) from selling its good on the market. Furthermore, consumption is constrained via a transaction constraint by the amount of deposits in the bank.
- Aggregate Supply: Goods are produces with a standard Cobb-Douglas production function, featuring labor and capital. In the linearized system, the capital stock is held constant. The model features a standard New Keynesian Phillips Curve.
- Banking System and Interest Rates: The balance sheet of the bank features loans and money holdings on the asset side and deposits on the liability side. The bank produces loans with a Cobb-Douglas production function featuring labor for monitoring loans as well as collateral. Collateral is a function of the amount of capital and bonds in the economy. The model features interest rates on a hypothetical riskless bond without collateral value, the rate on bonds, on capital (both determined by the respective collateral values of bonds and capital), on loans, and the interbank rate, which serves as a policy instrument in the interest rate rule.
- Shocks: The model features an interest rate shock, a TFP shock, a shock to the collateral value of capital, and a shock to the monitoring efficiency of banks.
- Calibration/Estimation: The model is calibrated to match features of US data. The non-banking parameters are standard. The parameters in the banking system are set such as to match interest rate spreads, the reserve ratio and the velocity of money in the US.

1.3 NK_GLSV07: Galí et al. (2007)

Galí et al. (2007) extend the standard New Keynesian model to allow for the presence of rule-of-thumb consumers for which consumption equals labor income. This enables them to generate an increase in consumption in response to a rise in government spending, in a way consistent with much of the recent evidence. Rule-of-thumb consumers partly insulate aggregate demand from the negative wealth effects generated by the higher levels of (current and future) taxes needed to finance the fiscal expansion, while making it more sensitive to current disposable income. The article

considers two labor market structures. Here, the version of the model with imperfect labor markets is replicated and implemented in the MMB.

- Aggregate demand: Households gain utility from consumption and leisure subject to appropriate budget constraints. A fraction $(1 - \lambda)$ of households have access to capital markets where they can trade a full set of contingent securities, and buy and sell physical capital (Ricardian households). The remaining fraction Îż of households do not own any assets nor have any liabilities, and just consume their current labor income (rule-of-thumb households). Additionally, two alternative labor market structures are considered in the paper. The first one assumes a competitive labor market, with each household choosing the quantity of hours supplied given the market wage. Under the second labor market structure wages are set in a centralized manner by an economy-wide union. In that case hours are assumed to be determined by firms (instead of being chosen optimally by households), given the wage set by the union.
- Aggregate supply: Intermediate firms act under monopolistic competition and set nominal prices in a staggered fashion a la Calvo (1983). Their products are used as inputs by firms which produce final goods. Perfectly competitive final-good firms produce with a constant returns technology.
- Shocks: This paper presents responses to a government spending shock.
- Calibration/Estimation: The model is calibrated at quarterly frequency.

1.4 NK_KW16: Kirchner and van Wijnbergen (2016)

Kirchner and van Wijnbergen extend the model by Gertler and Karadi (2011) such that banks are allowed to hold government bonds in addition to capital assets. In this model, the authors analyze the effects of a government spending shock. The main point of the paper is that when banks are balance sheet constrained, debt-financed fiscal expansions trigger a crowding out of loans to private firms on the banks' balance sheet and reduce the government spending multiplier. Additionally the effects of equity injections into the banking system by the government are evaluated.

- Aggregate Demand: as in NK_GK11
- Aggregate Supply: as in NK_GK11
- Financial Sector: similar to NK_GK11, but in addition to loans to private firms, banks hold government bonds on their balance sheet. Thus, fiscal policy becomes relevant and enters the model in form of balanced budget rule and a feedback rule for lump sum taxes.
- Shocks: The model features a government spending shock, a capital quality shock, a monetary policy shock, and a TFP shock.
- Calibration/Estimation: The the calibration of most parameters in the paper follows NK_GK11. The divertibility parameter for government bonds is the same as for capital assets. The debt-to-GDP ratio is set to 60

1.5 NK_MPT10: Monacelli et al. (2010)

Monacelli et al. (2010) employ a model with search and matching frictions in the labor markets to analyze the effects of government spending on the unemployment rate in the US. While the main analysis in the model is conducted in an RBC model, the replicated and implemented model in the MMB is the version of the model with sticky prices that is discussed in section 7 of Monacelli et al. (2010). While in most versions of the model, which the authors discuss, the unemployment multiplier is small, they show that large effects of government spending on unemployment can be obtained, when complementarities between consumption and leisure in the utility function is coupled with price stickiness.

- Aggregate Demand: The representative household is modelled as a large family with a continuum of members. They pool income and consumption and maximize a common utility function. There are complementarities between consumption and leisure in the utility function. Households consume, work, and invest in bonds and capital assets, where investment in capital is subject to adjustment costs. They search for vacant jobs and engage in wage bargaining with hiring firms.
- Aggregate Supply: Firms produce output goods with a Cobb-Douglas production function featuring capital and labor. The model version implemented here, additionally features monopolistically competitive retailers, which are subject to nominal rigidities a la Calvo. Firms engage in wage bargaining as well.
- Labor market: Matches in the labor markets are produced with a Cobb-Douglas function of unemployed workers and vacancies. The probabilities of finding a job and of filling a vacancy are endogenous. The separation rate is exogenous. Wages are the result of Nash bargaining between households and firms. The respective reservation wages for households and firms are functions of the disutility of labor, the marginal product of labor and the respective search costs for households and firms.

- Shocks: The model features a government spending shocks and an interest rate shock.
- Calibration/Estimation: In the replication file, the model is calibrated to monthly frequency. In the file that is implemented in the MMB, the calibration is adjusted to quarterly frequency. The model is calibrated to US data. The parameters specific to the labor market are chosen such that is matches the average job finding probability and the average tightness in the data, and to satisfy the Hosios condition.

1.6 NK_PP17: Paoli and Paustian (2017)

Paoli and Paustian (2017) study optimal monetary and macroprudential policies in a small-scale calibrated New Keynesian DSGE model with a moral hazard problem between banks and depositors in the spirit of Gertler and Karadi (2011). The possibility of banks diverting funds from depositors implies that banks are constrained in the amount they can lend to firms. This financial friction motivates the use of macroprudential instruments.

- Aggregate demand: Households maximize their lifetime utility, where the per-period utility function is separable in consumption and two types of labour. They can hold deposits at financial intermediaries.
- Aggregate Supply: Intermediate firms combine both types of labour into the intermediate good using a Cobb-Douglas production function. The entrepreneurs operating the intermediate firms must pay the wage bill associated with one of the inputs before production. Monopolistically competitive final goods firms purchase intermediate goods from entrepreneurs and create final goods using a linear production function. Final goods pricing is subject to Rotemberg quadratic adjustment costs. The final goods are aggregated to an output bundle according to a CES function.
- Financial intermediaries: Banks lend to intermediate goods producers and collect deposit. They also receive a direct subsidy from the macroprudential authority. Bankers maximize terminal net wealth and have the possibility to divert a certain fraction of assets. This yields an endogenous leverage constraint such that the incentive compatibility constraint is satisfied. Together with the borrowing-in-advance constraint, this introduces a credit friction.
- Shocks: A productivity shock, a mark-up shock, a net worth shock, a moral hazard shock and a monetary policy shock.
- Calibration/Estimation: The model is calibrated at quarterly frequency.

1.7 NK_PSV16: Pancrazi et al. (2016)

Pancrazi et al. (2016) consider the so-called financial accelerator mechanism used in many articles since Bernanke et al. (1999) and show that the procedure of approximating the price of old capital by the net-of-depreciation price of new capital has profound implications when the capital depreciation rate is positive. When accounting for the appropriate price of capital, the effects of the financial accelerator are even stronger than originally assessed. Since the setup is the same as in Bernanke et al. (1999) where entrepreneurs borrow in credit markets to finance their investment in capital, the strength of the financial accelerator turns out to depend crucially on the dynamics of the price of capital. This conclusion has important first-order effects on the solution of a model that assumes a positive depreciation rate of capital together with investment adjustment costs.

- Aggregate demand: Households gain utility from consumption, leisure and real money balances. They work, consume, pay taxes, hold money, and invest their savings, in form of deposits, in a financial intermediary that pays the riskless rate of return. These deposits are transferred to entrepreneurs in the form of loanable funds. Entrepreneurs use capital and labor to produce wholesale goods that are sold to the retail sector. Each period, entrepreneurs have to accumulate capital that becomes available for production in the subsequent period. Entrepreneurs have to borrow from households via a financial intermediary to finance capital purchases. Since the financial intermediary has to pay some auditing costs to observe the idiosyncratic return to capital, an agency problem arises. The optimal contract leads to an aggregate relationship of the spread between the external finance costs and the risk-free rate and entrepreneurs' financial conditions represented by the leverage ratio.
- Aggregate supply: Retail firms act under monopolistic competition. They buy wholesale goods produced by entrepreneurs in a competitive market and differentiate them at zero cost. Price stickiness is introduced via the Calvo (1983) framework. Bernanke et al. (1999) assume that reoptimizing firms have to set prices prior to the realization of shocks in that period, so that previous period's expectations of the output gap and future inflation enter the New Keynesian Phillips curve.
- Shocks: This paper presents responses to a technology shock, as well as to a monetary policy shock.
- Calibration/Estimation: The model is calibrated at quarterly frequency.

1.8 NK_RA16: Rannenberg (2016)

Rannenberg (2016) develops a model, which combines the financial frictions developed by Bernanke et al. (1999) and by Gertler and Karadi (2011), and analyses the effects of contractionary shocks, to capture features of the Great Recession. The role of both financial frictions are illustrated by comparing model variants, in which one, none or both frictions are turned off. The model matches the relative volatility of the external finance premium and the procyclicality of bank leverage observed in US data. Here, the full model with both financial frictions is replicated and implemented.

- Aggregate Demand: Representative households consume, work, and invest in riskless one-period bonds. Utility is separable in consumption and leisure. The utility function features habit formation.
- Aggregate Supply: Perfectly competitive capital good producers invest in new capital, subject to convex investment adjustment costs. Retailers produce output with a Cobb-Douglas production function featuring capital and leisure. They finance a fraction of their factor costs by working capital loans from banks. They act under monopolistic competition and set their prices subject to Calvo frictions. The model used in the simulation additionally features variable capital utilization.
- Financial Sector: Banks extend riskless loans to retailers and risky loans to entrepreneurs. When bankers exit the sector, they consume a fraction of their net worth. The initial net worth that new bankers receive is a constant. In all other features they are identical to banks in Gertler and Karadi (2011). While banks are risk averse, entrepreneurs are risk-neutral. They accumulate capital, take loans from banks and can default. In all other features they are modelled as in Bernanke et al. (1999). The optimal contract is between the bank and the entrepreneur.
- Shocks: The implemented model features a TFP shock, a government spending shock, and an interest rate shock.
- Calibration/Estimation: The model is calibrated to US data over the period from 1990Q1 to 2013Q4. Rannenberg highlights some of the targets for the calibration in the data. Among them the risk free rate, the spread of the loan rate over the risk-free rate, the leverage ratio of the non-financial sector, the quarterly bankruptcy rate of entrepreneurs, and the bank capital ratio.

1.9 NK_ST13: Stracca (2013)

Stracca (2013) develops a New Keynesian model with money endogenous and exogenous money. While exogenous money is base money supplied by the central bank, endogenous money is equivalent to bank deposits that affect macroeconomic dynamics due to a deposit in advance constraint for households. In the model, the presence of inside money attenuates the effects of technology and monetary policy shocks.

- Aggregate Demand: A representative households chooses consumption, labor supply, bond holdings and deposit holdings. The utility function is additive separable in consumption, labor and deposit holdings, where quadratic adjustment costs for deposit holding are introduced into the utility function. Next to its budget constraint, it faces a deposit-in-advance constraint that generates a motive for deposit supply.
- Aggregate Supply: Intermediate good producers produce output with a Cobb-Douglas function featuring labor and capital. They finance the wage bill and investments with loans from banks. They are monopolistically competitive and set prices. Price setting and capital accumulation are subject to quadratic adjustment costs. Final good producers repackage the intermediate goods and sell them as final goods.
- Financial Sector: The bank finances itself with deposits, bonds and central bank credit. It extends loans and holds base money. The two components of the cost of financial intermediation are proportional to the amount of loans and the amount of deposits, respectively.
- Shocks: The model features a policy rate shock, a TFP shock, a shock to the demand for inside money and a shock to the supply of inside money.
- Calibration/Estimation: The model is calibrated to US data.

2 Estimated U.S. Models

2.1 US_AJ16: Ajello (2016)

Ajello (2016) develops a medium-scale model with financial frictions to analyze the role of US firm financing, in particular the financing gap, for business cycles and vice versa. In the model, shocks to financial intermediation play a major role for GDP and investment.

- Aggregate Demand: The representative household is composed of a continuum of members. Household consume, hold bonds and accumulate net worth. The utility function is separable in consumption and leisure and features habit formation. Each period, all members receive an idiosyncratic shock that determines the productivity of their investments, and thus their investment behavior. In equilibrium, the members of the household can be divided into three subgroups: sellers who take up credit from banks and invest in new capital, keepers, who install new capital, but do not borrow funds, and buyers, who supply labor to firms, forego investment into own productive capital and buy equity claims on other members' capital stock instead. The leverage of households is limited by a collateral constraint. Additionally, their financial claims are illiquid. Labor markets feature monopolistic supply and sticky nominal wages with wage indexation.
- Aggregate Supply: Intermediate good producers have a Cobb-Douglas Production function that features capital and labor. They are monopolistically competitive and set price subject to a Calvo friction with price indexation. Final good producers repackage intermediate goods and sell them as final goods. Investment good producers face convex investment adjustment costs.
- Financial Sector: Banks buy claims from sellers and sell them to buyers. Financial intermediation is subject to resource costs that create a spread between the ask and bid price of financial claims.
- Shocks: The model features seven shocks: a TFP shock, a government spending shock, an interest rate shock, a shock on the spread, a discount factor shock, a price markup shock, and a wage markup shock.
- Calibration/Estimation: The log-linear model is estimated for the U.S. by means of Bayesian techniques for the period 1989Q1−2008Q2 using eight variables: GDP, consumption, investment, labor, wage rate, the nominal interest rate, inflation, the spread between BAA corporate bonds and ten-year Treasury notes, and the financing gap share. Measurement errors are introduced into the observation equations for the spread and the financing gap share.

2.2 US_CFP17exo, US_CFP17endo: Carlstrom et al. (2017)

Carlstrom et al. (2017) build a quantitative DSGE model which features long-term bond purchases by the central bank, in order to analyze the effect of financial market segmentation and of term-premium targeting on the effectiveness of monetary policy. The model features private financial intermediaries within segmented financial markets in which the net worth of financial institutions limits the degree of arbitrage across the term structure. This is caused by a hold-up problem between households and banks. Through portfolio adjustment costs, central bank purchases of long-term bonds have a significant effect on long yields and thereby effect capital investment and the real economy.

- Aggregate Demand: The representative household's utility is separable in consumption and leisure and features habit formation in consumption. Expected lifetime utility is maximized by choosing consumption and labor supply. The household has two options of intertemporal savings (short-term deposits and accumulation of physical capital). Also short-term government bonds can be held by households but are perfectly substitutable by deposits.
- Aggregate Supply: Perfectly competitive capital producers transform investment goods into new capital, facing investment adjustment costs. Monopolistic intermediate goods producers process labor and capital within a Cobb-Douglas production and set their price subject to nominal rigidities (Calvo, 1983). The generated output is sold to final goods producing firms which repackage intermediate output and finally provide a consumption good.
- Financial Sector: Banks engage in fund channeling and maturity transformation, i.e. they buy short- and long-term government bonds which are financed by accumulated net worth and deposits. There is no direct interaction between banks and firms in this model, effects of changes on the intermediaries' balance sheet are thus always channeled to firms via household investment. The bank‘s objective is to maximize the stream of dividends to the households. The financial intermediary's net worth, however, and thereby also the size of its portfolio is subject to adjustment costs, which dampens the possibility to react to shocks. In addition, banks face a financial constraint: Their ability to attract deposits is limited by its net worth. A so called hold-up problem is used to implement this leverage constraint into the economy. Before shocks are realized, at the beginning of period t + 1, the bank may decide to default and not to repay its depositors. As a result, the fraction of financial intermediaries' assets which can still be utilized by depositors is limited. Hence, there is a compatibility constraint to ensure repayment of the depositing household. Generally, bank intermediation is required because new household investment must be financed via new debt issuance.
- Shocks: There are eight shocks in the model: productivity shock, credit shock, investment shock, monetary policy shock, natural rate shock, wage markup shock, price markup shock, QE shock.
- Calibration/Estimation: Several parameters are calibrated to match long-run features of US data. Evidence on interest rate spreads and leverage is used to pin down the steady-state loan-to-deposit spread and the leverage

ratio in the model. Parameters are calibrated as to match a term premium of 100 annual basis points and a steady-state leverage ratio of 6. This is the same calibration as in Gertler and Karadi (2013). Government bonds are calibrated to a duration of 40 quarters. The steady state balance sheet of financial intermediaries is calibrated to consist of 40

The difference between the two model versions is rooted in the behaviour of the level of long-term debt on the balance sheet of the financial intermediaries. In US_CFP17exo, central bank bond purchases and changes to the mix of short-term and long-term debt by the fiscal authority are modeled by exogenous movements in long-term debt. Consequently, the long-term yield will be endognous. Contrary, in US_CFP17endo, the central bank pegs the term premium and hence the level of long-term debt will be endogenous.

2.3 US_DNGS15 : Del Negro et al. (2015)

Del Negro et al. (2015) build a medium-scale New Keynesian model that can predict a sharp contraction in economic activity along with a protracted but relatively modest decline in inflation, following the Great Recession. They build upon a standard DSGE model (like in Smets and Wouters (2007)) enriched with financial frictions and a time-varying target inflation rate.

- Aggregate Demand: As in Smets and Wouters (2007), households maximize a nonseparable utility function with two arguments (goods and labor effort) over an infinite life horizon, subject to an intertemporal budget constraint. Preferences for consumption are subject to habit persistence. Households supply labor monopolistically and wage stickiness is introduced via the Calvo framework.
- Aggregate Supply: Monopolistically competitive firms produce intermediate goods, which a competitive firm aggregates into a single final good that is used for both consumption and investment. The intermediate goods firms decide on labor and capital inputs, and set prices according to the Calvo model.
- Financial Sector: Building on the work of Bernanke et al. (1999), Christiano, Motto, and Rostagno (2014), and De Graeve (2008), a financial intermediary, capital producers and entrepreneurs are introduced in the model in addition to the intermediate and final goods firms as in Smets and Wouters (2007). Financial frictions come into play by the presence of entrepreneurs and the financial intermediary. Banks collect deposits from households and lend to entrepreneurs who use these funds as well as their own wealth to acquire physical capital, which is then rented to intermediate goods producers. Entrepreneurs are subject to idiosyncratic disturbances that affect their ability to manage capital which leads to the costly state verification framework as in Bernanke et al. (1999) and gives rise to a spread, above the risk-free rate. This spread is thus a function of the entrepreneurs' leverage and riskiness.
- Shocks: The model features a preference shock, a financial friction shock, a total factor productivity shock, an investment specific technology shock, a government spending shock, an inflation target shock, a monetary policy shock, a wage and price mark-up shock.
- Calibration/Estimation: The model is estimated using Bayesian methods on quarterly U.S. data for the period 1964:Q1 - 2008:Q3.

We furthermore include three variants of the model proposed and estimated by DNGS: A version without financial frictions and time-varying inflation target (DNGS15_SW), a version without financial frictions (DNGS15_SWpi) and the Smets-Wouter 2007 model estimated using the same variables as the original authors using 2012Q3 data.

2.4 US_FV10: Fernández-Villaverde (2010)

Fernández-Villaverde (2010) employs a canonical medium-scale closed economy DSGE-Model similar to Smets and Wouters (2007), estimated on U.S. data. The model features a deterministic growth rate driven by labor-augmenting technological progress, so that the data do not need to be detrended before estimation. The code is written in non-linearized form.

- Aggregate demand: Households maximize their lifetime utility, where the utility function is separable in consumption, leisure and real money balances, subject to an intertemporal budget constraint. Consumption utility is subject to habit formation. Households own firms, rent capital services to firms and decide on investment given certain investment adjustment costs.
- Aggregate Supply: The final goods, which are produced under perfect competition, are used for consumption and investment by the households. The final goods producer aggregates intermediate goods using a constant elasticity of substitution (CES) production function. A continuum of monopolistically competitive 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 CES 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 á la Calvo are additionally assumed. The Calvo model in both wage and price setting is augmented by the assumption that prices that cannot be freely set, are partially indexed to past inflation rates.

- Shocks: A total factor productivity shock, an investment-specific technology shock, an intertemporal preference shock, an intratemporal preference shock and a monetary policy shock.
- Calibration/Estimation: The model is estimated for the U.S. with Bayesian techniques for the period $1959:12007:1$ using five key macroeconomic variables: relative price of investment, real output per capita growth, real wages per capita, CPI inflation and the federal funds rate.
- Replication: We simulated the impulse response functions to a positive one standard deviation monetary policy shock and technology shock. While FV (2010) does not show any impulse responses, our simulated IRFs are very similar to the impulse responses provided in the technical appendix to FV (2015).

2.5 US_FV15: Fernández-Villaverde et al. (2015)

Fernández-Villaverde et al. (2015) employs a canonical medium-scale closed economy DSGE-Model similar to Smets and Wouters (2007), estimated on U.S. data, but augmented with time-varying volatility in the shocks. The model features a deterministic growth rate driven by labor-augmenting technological progress, so that the data do not need to be detrended before estimation. The code is written in non-linearized form.

- Aggregate demand: Households maximize their lifetime utility, where the utility function is separable in consumption, leisure and real money balances, subject to an intertemporal budget constraint. Consumption utility is subject to habit formation. Households own firms, rent capital services to firms and decide on investment given certain investment adjustment costs.
- Aggregate Supply: The final goods, which are produced under perfect competition, are used for consumption and investment by the households. The final goods producer aggregates intermediate goods using a constant elasticity of substitution (CES) production function. A continuum of monopolistically competitive 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 CES 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 Ãă la Calvo are additionally assumed. The Calvo model in both wage and price setting is augmented by the assumption that prices that cannot be freely set, are partially indexed to past inflation rates.
- Shocks: A total factor productivity shock, an investment-specific technology shock, an intertemporal preference shock, an intratemporal preference shock and a monetary policy shock. The standard deviations of the structural innovations are subject to stochastic volatility shocks. The model also includes shocks to the two parameters in the monetary policy rule.
- Calibration/Estimation: The model is estimated for the U.S. with Bayesian techniques for the period $1959:12007:1$ using five key macroeconomic variables: relative price of investment, real output per capita growth, real wages per capita, CPI inflation and the federal funds rate.
- Replication: We replicated the impulse response functions to a positive one standard deviation monetary policy shock and technology shock, as shown in Figure 6.1 and 6.2 of the technical appendix.

2.6 US_IR15: Ireland (2015)

Ireland (2015) considers a model of the term structure of interest rates, where bond yields are driven by observable and unobservable macroeconomic factors. Restrictions on the model parameters help identify the effects of monetary policy and other structural disturbances on output, inflation, and interest rates and decompose movements in long-term rates into terms attributable to changing expected future short rates versus risk premia. The model is estimated on US data and highlights a broad range of channels through which monetary policy, risk premia and the economy interact.

- Model: Bond yields in this pricing model get driven by five state variables: two unobservable (a risk variable which governs all variation in bond risk premia and the central bank's inflation target) and three observable (short-term nominal interest rate, the inflation rate, and the output gap). The inflation and output gaps are allowed to depend on their own lagged values and lagged values of the model's other variables, as they would in a more conventional macroeconomic vector autoregression. The structural shocks are identified by restrictions on the parameters implied by a) no-arbitrage considerations, b) the assumption that the risk premium is solely driven by the unobservable risk variable, and c) the assumption of a Taylor-rule type interest rate policy. The

estimates of the correlation and volatility parameters, together with an analysis of the impulse responses and forecast error variance decompositions implied by those estimates, are used to assess the extent to which movements in bond risk premia are driven by monetary policy and macroeconomic shocks or whether they reflect, instead, disturbances that appear purely financial in origin.

- Shocks: There are 5 structural shocks in the model: on the short-term nominal interest rate, on inflation, output gap, the inflation target and the risk premium. Furthermore there are measurement errors for the one, two and four-year bond yields.
- Calibration/Estimation: The model is estimated with US quarterly data from 1959Q1 to 2007:4 for the short-term nominal interest rate, the inflation rate, the output gap, and yields on discount bonds with one through five years to maturity.

2.7 US_LWY13: Leeper et al. (2013)

Leeper et al. (2013) implement a new Keynesian model, similar to those in Smets and Wouters (2003, 2007), yet add distorting tax rates on capital and labor income. The model is used to assess the effect fiscal foresight entails to a naive econometrician who estimates impulse-response functions conditioning solely on the variables observed and disregards fiscal foresight.

- Aggregate demand: The model economy is populated by a continuum of infinitely lived households of which a fraction is non-Ricardian. Non-Ricardian 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 Ricardian households. The utility function is separable in consumption and leisure and assumes external habits that depend on aggregate consumption in the last period. Households provide uniquely differentiated labor in monopolistic competition. Ricardian households have also access to state-contingent claims to eliminate the income differentials due to differentiated labor.
- Aggregate supply: Production is carried out in two stages, by a perfectly competitive final good producer and a continuum of monopolistically competitive intermediate goods producers using capital and labour as input asfactors. Wages and prices are allowed to adjust only gradually by assuming Calvo pricing with partial adjustment of the contracts to past inflation.
- Government: Monetary authorities follow a Taylor-type rule. Fiscal authorities levy distortionary taxes on income from capital and labor and pay lump-sum transfers to households.
- Shocks: Total factor productivity shock, preference shock, investment adjustment costs shock, monetary policy shock, wage markup shock, price markup shock, government spending shock, capital tax rate shock, labour tax rate shock and government transfers shock .
- Calibration/Estimation: The model is estimated for the U.S. by means of Bayesian techniques for the period 1984:1−2007:4 using ten key macroeconomic variables: consumption, investment, labor, wage rate, the nominal interest rate, inflation, capital tax revenues, labor tax revenues, the sum of real government consumption and investment, and government transfers. Government data include all federal, state, and local levels.
- Replication: Unfortunately there were no impulse response functions to be replicated. Therefore, the original NK-model was separated from the code and translated to Dynare. The impulse response functions of output and the interest rate were replicated and compared also with the implemented version of the model. The IRFs in the model base seemed to match those from the original Matlab code which were calculated manually.

2.8 US_RE09: Reis (2009)

Reis (2009) presents a dynamic stochastic general-equilibrium model with a single friction in all markets: sticky information. In this economy, agents are inattentive because of costs of acquiring, absorbing and processing information, so that the actions of consumers, workers and firms are slow to incorporate news. The paper includes the details of how an economy with pervasive inattentiveness functions, then solves the model and in the end estimates it. Uncertainty in the model arises because every period there is a different realization of the random variables characterizing productivity, aggregate demand, price and wage markups, and monetary policy. While the expectations of each agent are formed rationally, they do not necessarily use all available information. More concretely, it assumes that there are fixed costs of acquiring, absorbing and processing information, so that agents optimally choose to only update their information sporadically.

- Aggregate Demand: While the discussion presents consumers (shoppers and saver-planners) and workers separately, they are all members of one household. Representative household gains utility from consumption and leisure subject to its budget constraint. Shoppers consume a continuum of varieties of goods and determine demand for them, whereas saver-planners meet each other in the bond market in order to trade one-period bonds.

In the labor market workers sell their labor. While inattentiveness occurs in all markets, not all agents in this economy are inattentive. In the goods market, the model assumes that the consumer is separated into two units: the saver-planner who updates information infrequently and the shopper who knows about the expenditure plan of the saver and observes the relative prices of the different goods. Additionally, separating consumers from workers allows them to potentially update their information at different frequencies. They do not necessarily need to share information, although belong to the same household. When workers update their information, they also learn about what the consumer has been doing, and vice-versa for consumers.

- Aggregate Supply: On the selling side of the market, there are monopolistic firms for each variety of the good. They operate a technology that uses labor in order to produce goods under diminishing returns to scale and common technology shock.
- Shocks: There are shocks in technology, monetary policy, aggregate demand, goods substitutability and labor substitutability.
- Calibration/Estimation: The model is estimated using full-information techniques that exploit the restrictions imposed by general equilibrium. Quarterly observations are used for two large economies: the United States from 1986:3 to 2006:1 and the Euro area from 1993:4 to 2005:4.

3 Estimated Euro Area Models

3.1 EA_PV15: Poutineau and Vermandel (2015)

Poutineau and Vermandel (2015) evaluate quantitatively how interbank and corporate cross-border flows shape business cycles in a monetary union. They estimate a two-country DSGE model (equal-size Eurozone core and peripheral countries) that accounts for national heterogeneities and a set of real, nominal and financial frictions. Each country is populated by consumers, labor unions, intermediate and final producers, entrepreneurs, capital suppliers and a banking system. The set of real rigidities encompasses consumption habits, investment adjustment costs and loan demand habits. Regarding nominal rigidities, they account for stickiness in final goods prices, wages and loan interest rates. Obtained results support the key role of the cross-border channel as an amplifying mechanism in the diffusion of asymmetric shocks.

- Aggregate Demand: Households in both countries consume, save and work in intermediate firms, and maximize expected lifetime utility with respect to the consumption and labor effort. They spend their incomes on consumption, bond subscription and tax payments. In addition to that, there exist quadratic adjustment costs necessary to buy new bonds (Schmitt-Grohe and Uribe, 2003). Households provide differentiated labor types, 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: Each economy is characterized by two groups of firms: intermediate firms and final firms. Intermediate firms produce differentiated goods, choose labor and capital inputs, and set prices according to the Calvo model. Final goods producers act as a consumption bundler by combining national intermediate goods to produce the homogenous final good.
- Financial Sector: In each country the banking sector finances investment projects to home and foreign entrepreneurs by supplying one-period loans. The banking system is heterogeneous with regard to liquidity and banks engage in interbank lending at the national and international levels. Thus, cross-border loans are made of corporate loans (between banks and entrepreneurs) and interbank loans. In order to introduce an interbank market, authors suppose that the banking system combines liquid and illiquid banks, where liquid banks (characterized by direct accessibility to the ECB funding) supply loans to entrepreneurs and to illiquid banks. Additionally, the intermediation process between liquid and illiquid banks is costly (convex monitoring technology). So-called financial accelerator mechanism is borrowed from De Grauwe (2010) and applied in a different context, by assuming that entrepreneurs' forecasts regarding the aggregate profitability of a given project are optimistic (these values are then compared to the critical threshold which distinguishes profitable and non-profitable projects).
- Shocks: There are in total 8 country specific structural shocks and one shock in the common monetary policy rule. Namely, a productivity shock, demand shock, time-preference shock, net wealth shock, external finance premium shock, bank rate markup shock, wage markup shock, bank liability shock and ECB monetary policy shock.
- Calibration/Estimation: The model is estimated with Bayesian methods on Euro Area quarterly data over the sample period 1999Q1 to 2013Q3.

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