Macroeconomic effects of EU Competition Policy

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Macroeconomic effects of EU Competition policy: A replication exercise

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Abstract

I estimate the macroeconomic impact of competition policy to deter collusion and merger control in the EU using two dynamic macroeconomic model, the one used in Dierx and Ilzkovit [2] and a model that includes Central Bank quantitative easing policies [4].

1 Introduction

There is a growing interest in the macroeconomic impact of competition and regulatory authorities, but very little research has been done in this subject [2]. Previous papers estimate the direct impact of competition policy on consumers [2], leaving aside indirect deterrent effects[1]. This paper studies the effects of competition policy on production, employment and productivity in the EU. The direct effects are due to the interventions of the authorities against cartels or anticompetitive mergers, which end situations that would have reduced competition and increased prices. On the other hand, the indirect effects are divided between those that affect productivity, innovation and growth, and the dissuasive effects that are associated with the interventions of the authorities. For example, penalties on collusive agreements not only mean ending the infringement, but also discourage other companies from committing infringements. Because of the complexity of analysis indirect effects are usually excluded from the studies, although there is consensus as to the undoubted benefits of deterrent effects [2].

In this paper I follow [2], to estimate the impact of interventions for the EU between 2010 and 2018. I first explain the model, the mark-up shock simulation and the macroeconomic effects of the mark-up shock. I then explain an extension of the same model that includes Central Bank quantitative easing policies by Priftis and Vogel [4] to conclude with a comparison of results in both models [2].

2 Model

The effects of competition policy are transferred to a dynamic stochastic general equilibrium model as a permanent shock in the mark-up as a result of interventions made by the competition authority to increase the level of competition in the national market. We assume that companies operate in a monopolistic competition market and each company produces a variety of a national product that is an imperfect substitute for varieties produced by other companies [3].

[1]An exception is [3] who applied a model that includes not only static effects but also dynamic, and the differences between the effects in the short and long term. For this, they used a long-term general equilibrium model and calculated the positive effects that the Competition Agency policies had between 1998 and 2007 on the production, employment and labor productivity of the Netherlands.

[2]The comparative is done using a database of macroeconomic models [7] and Dynare/Matlab [1]. I would like to thank Adrien Dierx et al. and the authors of the Macroeconomic Model Database for their help.

[3]See Annex for a detailed explanation of the model

2.1 Aggregate Demand

According to [2] there are two types of households: liquidity- and non-liquidity-constrained households. They possess the same utility function, non-separable in consumption and leisure with habit persistence in both consumption and leisure. Liquidity-constrained households do not optimize, they just consume their labor income. On the other side, non-liquidity-constrained households have access to domestic and foreign currency denominated assets, accumulate capital subject to investment adjustment costs and rent it to firms, earn profits from owning the firms and pay taxes. Income from foreign financial assets is subject to an external financial intermediation risk premium while real asset holdings are subject to an equity risk premium. Both types of households supply differentiated labor to a trade union which sets the wages by maximizing their joint utility (weighted by the share of each type). The wage setting process is subject to a wage mark-up and to slow adjustments in the real consumption wage. The wage mark-up arises because of wage adjustment costs and the fact that a part of workers index the growth rate of wages to past inflation.

2.2 Aggregate Supply

The final production of firm j in time t (Y_t^j) used capital (K_t^j) and labour (L_t^j) with Cobb-Douglas production function, with fixed cost (FC_Y^j):

$$Y_t^j = (L_t^j - FC_L^j)^\alpha (u_t^j K_t^j)^{1-\alpha} - FC_Y^j \tag{1}$$

The firm maximizes present value of profits (PR_t^j):

$$PR_t^j = P_t^j Y_t^j - W_t^j L_t^j - i_{K,t} P_{I,t} K_t^j \tag{2}$$

where P_t^j are firm prices, W_t salaries and $i_{K,t}$ cost of capital. In equilibrium where $P_t^j = P_t, \forall j$, firms use a mark up over marginal cost (MC):

$$P_t^j = (1 + \tau_t^j) MC_t^j \tag{3}$$

where τ_t^j is the mark-up over the price, that depends on elasticity of substitution between varieties $\triangle^d$, and the mark-up shock $\epsilon_{mpk,t}$:

$$\tau_t^j = 1/(\triangle^d - 1) + \epsilon_{mpk,t}. \tag{4}$$

I then simulate the impact of interventions of a competition authority as a reduction in mark-up through $\epsilon_{mpk,t}$ in the previous equation 4.

2.3 Foreign Sector

According to [5] the Foreign Sector: Demand behavior is considered the same for the home country and the rest of the world, therefore export demand and import demand are symmetric. Both equations are characterized by a lag structure in relative prices which captures delivery lags. Export firms buy domestic goods, transform them using a linear technology and sell them in the foreign market, charging a mark-up over the domestic prices. The same situation is faced by importer firms. Mark-up fluctuations arise because of price adjustment costs in both sectors. Markup equations are given as a function of past and future inflation and are also subject to random shocks.

2.4 Monetary Policy

Monetary policy is modelled using a Taylor rule, which allows for some smoothness of the interest rate response to the inflation and output gap

3 Mark-up shock simulation

We can obtain antitrust policy effects on savings by multiplying price reduction as a direct result of competition policy by market size.

Mark-up aggregate change ($\triangle MUP_N$) due to N antitrust measures can be defined as:

$$\epsilon_{mpk,t} = \triangle MUP_N = \sum_k \left[\frac{\triangle P_k}{P_k} (1 + MUP_k) \right] \frac{GO_k}{GO} \tag{5}$$

where K_n are total sectors k where these interventions have reduced prices, equation $\triangle P_k / P_k$ 5 shows that aggregate mark-up is weighted by the relative mark-up in the specific sector $(1 + MUP_k)$ and its share in total production k of the economy, $\frac{GO_k}{GO}$.

3.1 Direct effect of antitrust decisions

We can make a distinction between shocks that only have direct effects and other that have deterrent effects on other firms. In the first case, price changes in each sector k is computed as a weighted average of price changes in all affected markets n:

$$\frac{\triangle P_k}{P_k} = \sum_M \frac{\triangle P_n}{P_n} MS_{nk} + \sum_C \frac{\triangle P_n}{P_n} MS_{nk} \tag{6}$$

where $M_k y C_k$ are decisions on cartels and mergers that impact sector k. In each decision Competition Authority defines a relevant market. The weights MS_{nk} used to estimate price changes for each sector is defined as a share in the affected market n in sector $k(mkt_{nk})$ over the total value of production in that sector at a two digit level (GO_k):

$$MS_{nk} = \frac{mkt_{nk}}{GO_k} \tag{7}$$

We estimate merger decisions to reduce prices in 3 per cent and antitrust decisions 10 per cent against non intervention. Equation (6) is also:

$$\frac{\triangle P_k}{P_k} = -0,03 \sum_M MS_{nk} - 0,1 \sum_C MS_{nk} \tag{8}$$

Substituting equations (7) and (8) in (5), mark-up changes due to merger and antitrust decisions can be estimated in the following way:

$$\triangle MUP_N = -\frac{1}{GO} \sum_{k_N} \left[0,03 \sum_M mkt_{nk} + 0,1 \sum_C mkt_{nk} \right] \tag{9}$$

3.2 Deterrent effects of antitrust decisions

In general, only direct effects of decisions are estimated leaving deterrent effects due to the complexity of estimating unknown cartels that dissappear without being detected. As in [2] we assume that in each decision of a competition agency, price reduction impacts all the sector. An airline merger decision, for example, would have deterrent effects over total passenger air transport sector. Deterrent effects would impact all firms of the same sector.

When estimating mark-up shocks it is assumed that deterrent effects spill to the whole 4 digit NACE rev2 sector. The weights MS_{nk} are the proportion between the value added at four digit divided by the value added at 2 digit value and is used to calculate the price change in sector k due to n competition decisions.

$$MS_{nk} = \frac{VA4_{nk}}{VA2_k} \tag{10}$$

3.3 Size and duration of shock

One can obtain the direct impact of interventions by adding markup changes as a result of the merger and cartel decisions. Given that effects on prices have an impact in several years, consumers will benefit not only from the interventions in that year, but also from those carried out in previous years. [2] take into account decisions of 2015, that is, all the decisions made in 2014, in addition to the decisions made in previous years that still have an impact in 2015. The reduction in the markup MUP_N associated with these decisions is obtained from the equation 9 and added to reach a total effect in 2014 of 0.04 percentage points. This figure includes the effects of anticartel decisions.

However, the simulations presented consider not only the direct effect but also deterrent effects. Using the equation (9), the reduction of markup MUP_N derived from the decisions that still have an impact in 2015 can be calculated: the reduction of the markup is 0.57 percentage points in 2014, which corresponds to a reduction of 4.49 percentage points at the markup level. [2] consider that the magnitude of the shock and the simulation results come essentially from the deterrent effects of competition policy and not from the direct effects.

The competition authority is supposed to continue interventions at the same rate in the near future. This permanent shock can be applied to a baseline scenario where interventions are not performed. The assumption of a permanent shock reflects the idea that a single intervention by the authority will have little effect on firms. The deterrent effects of interventions of a competition authority mainly come from the expectation of firms that the antitrust authority will sanction if competition law is violated.

4 Macroeconomic effects of a mark-up shock using QUEST III

We apply the same permanent negative mark up shock as in [2] of 0,57 per cent to a perfect foresight QUEST III model. The increase in consumption due to a fall in prices, will increase real salaries and employment due to competition. On the other hand, investment would be determined by production scale, while increasing factor remuneration. Regarding external demand, export and export increase similarly, due to respectively an increase in competitiveness of firms, and an internal demand increase. From the supply side, it is obtained an increase of employment above GDP increase in the four initial years after the measure is implemented, while on the long run it is slightly lower. This higher increase is due to the higher dynamism of an increase in competition. A more competitive environment, will not only reduce prices but increase efficiency as they reach their optimal scale while searching for new resources and lower cost technologies In general, competition will stimulate innovation, technological progress and more efficient ways to provide services to society. The transmission mechanism is as follows: the interventions of the competition authority generate an increase in competition and a reduction in markups which leads to a decrease in prices (Equation 4). As companies think about the future when making decisions today, their demand for labor and capital is based on the future flow of benefits, taking into account the effect of markups on prices and demand. They take into account the direct effect of markups on future benefits, which will be negative due to lower markups, and at the same time they also take into account the increase in future demand for their products due to lower prices. To meet a greater demand, companies require more work and capital. However, the fall in the future profitability of the companies partially mitigates the increase in demand for the inputs since higher production costs and lower pre-payments can lead to lower profits generated by companies (Equation 12) .

5 Extension of QUEST III including Quantitative Easing (QE)

[4] extend the QUEST III to include assets and QE in the following channels: (1) term premium channel (purchase by the central bank of long-term bonds reduces their return for given expectations about future short-term interest rates); (2) safety channel (falling return on government bonds leads to increasing demand for riskier assets, such as corporate equity); (3) exchange rate channel (falling return on government bonds leads to increasing demand for foreign-currency assets and depreciation of the euro); (4) liquidity channel (growth in base money to finance balance sheet expansion); (5) inflation expectations channel (exchange rate

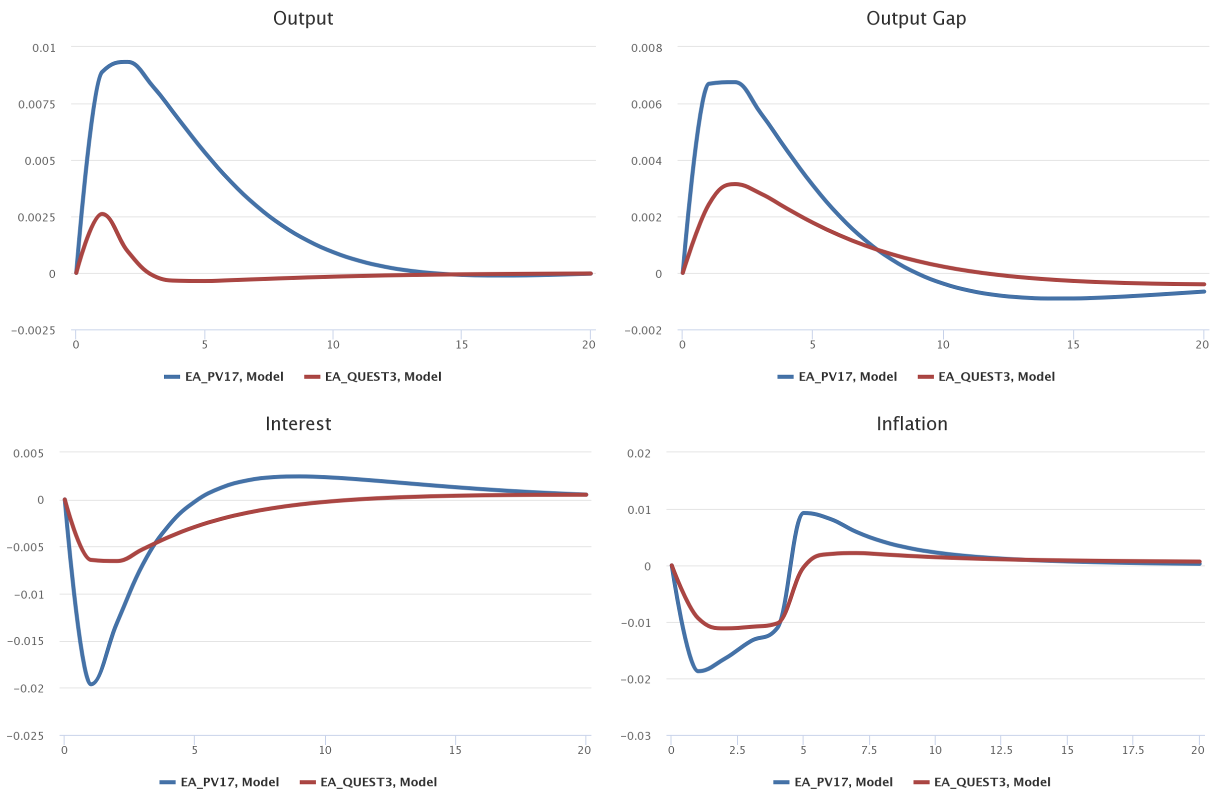

Figure 1: Macroeconomic Effects of the markup shock

depreciation and demand stimulus raise inflation expectations); (6) fiscal channel (lower financing costs for new debt issuance) QE is modelled as purchases of domestic long-term bonds in exchange for central bank liquidity. Next to physical capital and money, the model features long-term and short-term bonds. The assets are held by the household and long-term and short-term bond holdings are subject to portfolio adjustment costs. When the central bank intervenes by purchasing long-term bonds, private investors that aim at re-establishing the portfolio mix of short term and long-term assets can respond by holding more corporate equity and foreign bonds, and by lowering their savings. The first response means portfolio reallocation towards equity and foreign-currency assets that increases the prices of corporate equity (rising stock market) and foreign currency (euro depreciation). Regarding transmission to the real economy, following [4] rising stock markets reduce the financing costs of corporations and lower the required return to capital, which translates into stronger investment and capital accumulation. Exchange rate depreciation strengthens net exports provided trade is sufficiently price elastic. The decline in savings associated with the general decline in returns on savings strengthens contemporaneous consumption demand. The figure and table below illustrate that competition policy interventions increase output, price reduction increase consumption. The table shows that the model that includes bond purchases (PV17) is more expansive than the benckmark model QUESTIII as GDP increases 0.3 percent after five years and 0.55 percent in 20 years. QUEST III estimates are slightly lower, 0.27 percent growth in five years and 0.47 percent in 20 years.

In conclusion, the expansive effect of a mark up shock due to competition policy is slightly greater if Quantitative Easing policies are taken into account than in standard tranditional macroeconomic model.

Table 1: Macroeconomic Effects of the markup shock

	1 year		5 years		10 years		20 years	
	PV17	QUESTIII	PV17	QUESTIII	PV17	QUESTIII	PV17	QUESTIII
GDP	0.081	0.156	0.310	0.269	0.486	0.359	0.552	0.470
Inflation	-0.162	-0.007	-0.507	-0.03	-0.220	-0.02	-0.1373	-0.023
Consumption	0.041	0.161	0.184	0.239	0.300	0.327	0.296	0.431
Output Gap	0.060	0.003	0.218	0.0128	0.297	0.0195	0.237	0.019

6 Conclusion

This essay aims to apply a general equilibrium dynamic model to show quantitative effects of competition policy interventions. Its implementation for impact assesment for antitrust policies is not common. Nevertheless, its dynamic and general equilibrium approach is better suited to explain and forecast the effects of interventions than partial equilibrium static models. Besides, the paper shows that the positive macroeconomic effects due to competition policy interventions are estimated to be higher when quantitative easing are included in the macroeconomic model.

7 Annex

This annex explains the model used in this paper is QUEST III [5] extended with quatittative easing [4] [6].Tthe model is a New-Keynesian Dynamic Stochastic General Equilibrium (DSGE) macroeconomic model developed for macroeconomic policy analysis and research. QUEST III has microeconomic foundations derived from utility and profit optimisation and includes frictions in goods, labour and financial markets. The model distinguishes between Ricardian households that have full access to financial markets and liquidity-constrained households that do not access financial markets. In each region there are monetary and fiscal authorities, both following rule-based stabilisation policies. Monetary policy in normal times follows a Taylor rule reacting to inflation and the output gap. In case of QE, the central bank purchases long-term (government) bonds, with the aim of reducing the interest spread between short and long maturities (i.e. flattening the yield curve). Central bank finances the bond purchases by providing additional liquidity to the private sector rather than by reducing central bank profits.

7.1 Firms

Firms produce a variety of a good imperfectly substitute for other varieties produced by other firms. They are monopolistically competitive for the variety they sell and face then the demand function for that variety. Output is produced by a Cobb Douglas technology using capital (K_t), production workers ($N_t - LO_t$) and public infrastructure (KG_t):

$$Y_t = \left(ucap_t {K_t}^{1-\alpha}\right) + \left(N_t - LO_t\right)^{\alpha} KG_t^{\alpha_g} \tag{11}$$

Variables $UCAP_t$ and LOL_t are respectively capacity utilisation and overhead labour. Firm level employment N_t is a CES aggregate of labour supplied by households h. Parameter $\theta > 1$ is the degree of substitutability among different labour types.The objective of the firm is to maximize real profits (Pr_i): The firm maximizes present value of profits (PR_t^j):

$$PR_t^j = P_t^j Y_t^j - W_t^j L_t^j - i_{K,t} P_{I,t} K_t^j - (adj^P(P_t^j) + adj^N(N_t^j + adj^{ucap}) \tag{12}$$

where $i_{K,t}$ is the rental rate of capital. Firms face technological and regulatory constraints which restrict their price setting, employment and capacity utilisation decisions. Price setting rigidities can be the result of the internal organisation of the firm or specific customer-firm relationships associated with certain market structures. The constraints are modelled as adjustment costs with convex forms:

$$adj^{N}\left(N_t\right) = \frac{\gamma_N}{2} w_t \left(\Delta_{N_t}\right)^2 \tag{13}$$

$$adj^{P}\left(P_t\right) = \frac{\gamma_P}{2}\left(\frac{P_t - P_{t-1}}{P_{t-1}}\right)^2 Y_t \tag{14}$$

$$adj^{ucap}\left(ucap_t\right) = p_t^I K_t \left(\gamma_{ucap,1} + \gamma_{ucap_t-1} + \frac{\gamma_{ucap,2}}{2}\left(ucap_t - 1\right)^2\right) \tag{15}$$

Lower case letters denote ratios and rates. In particular, w_t is the real wage from a wage-cost perspective, *ucap* is actual relative to steady-state capital utilization. The firms determine labour input, capital, capacity utilisation and goods prices optimality in each period given the technology and administrative constraints and demand conditions. First order conditions (FOC) are:

$$\frac{\partial P_t}{\partial N_t} => \frac{\partial Y_t}{\partial N_t}\eta_t - \gamma_N w_t \Delta N_t + \gamma_N E_t\left(\beta \lambda^r_{t,t+1} w_{t+1} \Delta N_{t+1}\right) = w_t \tag{16}$$

$$\frac{\partial P_t}{\partial K_t} => \frac{\partial Y_t}{\partial K_t}\eta_t => i_t^k p_t^I \tag{17}$$

$$\frac{\partial P_t}{\partial ucap_t} => \frac{\partial Y_t}{\partial ucap_t}\eta_t = K_t \phi_t^I \left(\gamma_{ucap,1} + \gamma_{ucap,2}(ucap_t - 1)\right) \tag{18}$$

$$\frac{\partial Pr_t}{\partial Y_t} => \eta = 1 - \frac{1}{\sigma} - \gamma_P E_t\left(\beta \lambda^r_{t,t+1}\phi_{t+1} - \phi_t\right) \tag{19}$$

with $\pi_t = \frac{P_t}{P_{t-1} - 1}$

where η_t is the Lagrange multiplier of the technological, β is the rate of time preference, and $E_t\left(\beta \lambda^r_{t,t+1}\right)$is the stochastic discount factor of households. Firms equate marginal product of labour, without marginal adjustment costs, to wage costs. As can be seen from the left hand side of equation (16), the convex part of the adjustment cost function penalises in cost terms accelerations and decelerations of changes in employment. Equations (17,18) jointly determine the optimal capital stock and capacity utilisation by equating the marginal value product of capital to the rental price and the marginal product of capital services to the marginal cost of increasing capacity. Equation (19) defines the mark-up factor as a function of the elasticity of substitution and changes in inflation. The average mark up is equal to the inverse of the price elasticity of demand. We follow the empirical literature and allow for additional backward looking elements by assuming that a fraction $(1 - sfp)$ of firms index price increases to inflation in t-1. Finally we also allow for a mark up shock. This leads to the following specification of the aggregate price mark-up:

$$\eta_t = 1 - \frac{1}{\sigma} - \gamma_P E_t\left(\beta \sigma^r_{t,t+1}(sfp\pi_{t+1} + (1 - sfp)\pi_{t-1} - \pi_t\right) 0 \leq sfp \leq 1 \tag{20}$$

8 Long-Term Government Bonds

Long-term government debt is modelled through bonds for which the nominal coupon c, which is a fraction of the principal, depreciates over time at rate δ_b. The price in period t of a long-term bond issued in t (P_t^N) equals the discounted value of future payments:

$$P_t^N = \sum_{n=0}^{T} \frac{\delta_b^n}{(1+i)^{1+n}} c \tag{21}$$

where T is the maturity period of the bond. Analogously, the price in period t of a long-term bond issued in $t-1(P_t^O)$ equals the discounted sum of outstanding payments:

$$P_t^0 = \sum_{n=0}^{T-1} \frac{\delta_b^{1+n}}{(1+i)^{1+n}} c \tag{22}$$

If $\delta_b/(1+i) < 1$ and T is large, the price in t of long-term bonds issued in $t-1$ corresponds (approximately) to the price of newly issued long-term bonds times the depreciation rate:

$$P_t^0 = \delta_b P_t^N \tag{23}$$

Equation (23) shows that the price of the long-term bond that pays a declining coupon declines over time at the rate δ_b . In the full model version with cross-border bond holdings, total government debt consists of long-term bonds B_t^L held by domestic $B_t^{L,H}$ and foreign private agents $B_t^{L,F}$, and by the central bank $B_t^{L,C}$, and of short-term bonds B_t^S:

$$B_t = B_t^{L,H} + B_t^{L,F} + B_t^{L,CB} + B_t^S \tag{24}$$

Short-term and long-term bonds are imperfect substitutes in the model. In particular ,households have a preference for holding a mix of short-term and long-term bonds, and deviations from the target value κ for the ratio of long-term over short-term debt induce quadratic adjustment costs (γ_b). An analogous formulation for (net) foreign assets relative to the target $\overline{B}^*$closes the international finance part of the model.

8.1 Households

The household sector consists of a continuum of households $h \in [0,1]$. There are $s^l \leq 1$ households that are liquidity-constrained and indexed by l. These households do not trade on asset markets and simply consume their disposable income each period. A fraction $1-s^l$ of all households is Ricardian and indexed by r. The period utility function is identical for each household type. It is separable in consumption (C_t^h) and leisure ($1-N_t^h$), allows for habit persistence in consumption and is given by:

$$U\left(C_t^h, N_t^h\right) = ln\left(C_t^h - hC_{t-1}\right) + w\left(1-N_t^h\right)^{1-\kappa} \tag{25}$$

where w is the weight of the utility of leisure in total period utility and k the inverse of the elasticity of labour supply.Both types of households supply differentiated labour services to unions that maximise a joint utility function for each type of labour h. It is assumed that types of labour are distributed equally across both household types. Nominal wage rigidity is introduced through adjustment costs for changing wages. These adjustment costs are borne by the households.

8.2 Ricardian Households

Ricardian households receive labour income, returns on financial assets, income i_k^t from lending capital to firms net of an (exogenous) risk/insurance premium given revenue uncertainty ϕt, and dividends D_t from firm ownership. $K_t = I_t + (1\delta_k)K_{t-1}$ is the capital stock as the sum of new effective investment I_t and the pre-period capital stock depreciated at rate δ_k. The government levies taxes t_t^w on income from labour, t_t^k on corporate income and t_c^t on consumption. The price in period t of a short-term (1-period) bond of nominal value B_t^S is $B_t^S/(1+i_t)$, with i_t being the short-term nominal interest rate. Analogously, $e_t B_t^*/(1+i_t^*)$ is the price in domestic currency of a foreign bond B_t^* , where e_t is the nominal exchange rate as the value in foreign currency of one unit of domestic currency.

The Lagrangian of the maximisation problem is:

$$\begin{aligned} maxL^r = E_0 \sum_{t=0}^{infty} \beta^t U\left(C_t^r, N_t^r\right) - E_0 \sum_{t=0}^{infty} \lambda_t \beta^t \Bigg(& \frac{\left(1+t_t^c\right) P_t^c}{P_t} C_t^r \\ & + \frac{P_t^c\left(K_t-\left(1-\delta_k\right) K_{t-1}\right)}{P_t} + \frac{B_t^S}{\left(1+i_t\right) P_t} + \frac{P_t^N B_t^{L,H}}{P_t}\left(1+\frac{\gamma_b}{2}\left(\kappa \frac{B_t^S}{B_t^{L,H}-1}\right)^2\right) \\ & + \frac{e_t B_t^*}{\left(1+i_t^*\right) P_t} + \frac{\sigma_f}{2}\left(\frac{\left(e_t(B_t^*-B^*\right)}{P_t}\right)^2 \\ & + \frac{e_t P_t^{N*} B_t^{L,H*}}{P_t}\left(1+\frac{\gamma_b^*}{2}\left(\kappa^* \frac{B_t^{L,H}}{B_t^{L,H*}}-1\right)^2\right) - \frac{TR_t}{P_t} - \frac{cB_{t-1}^{L,H}}{P_t} - \frac{c^* e_t B_{t-1}^{L,H*}}{P_t} \\ & - \frac{\delta_b P_t^N B_{t-1}^{L,H}}{P_t} - \frac{\sigma_b^* e_t P_t^{N*} B_{t-1}^{L,H^*}}{P_t} - \frac{e^t B_{t-1}^*}{P_t} - \frac{(1-t_t^w) W_t N_t^r}{P_t} \\ & - \left(i_{t-1}^k - \left(i_{t-1}^k-\gamma_k\right) t_{t-1}^k - \varphi_{t-1}\right) \frac{P_t^C}{P_t} Kt-1 - \frac{D_t}{P_t} \Bigg) \end{aligned} \tag{26}$$

Investment in physical capital is subject to convex adjustment costs, introducing a distinction between real investment expenditure (It) and physical investment net of adjustment costs (J_t) :

$$I_t = J_t\left(1+\frac{\sigma_K J_t}{2K_t}\right) + \frac{\sigma_I}{2}\left(\Delta J_t^2\right) \tag{27}$$

The maximisation problem (26) provides the following first-order conditions (FOC):

$$\frac{\partial L^r}{\partial B_t^S} = \beta E_t\left(\frac{\lambda_{t+1}}{\lambda_t}\right) = E_t\left(\frac{P_{t+1}}{P_t}\right)\left(\frac{1}{1+i_t} + \gamma_b \kappa P_t^N\left(\kappa \frac{B_t^S}{B_t^{L,H}}-1\right)\right) \tag{28}$$

$$\begin{aligned} \frac{\partial L^r}{\partial B_t^{L,H}} &= \beta E_t\left(\frac{\lambda_{t+1}}{lambda_t}\frac{P_t}{P_{t+1}}\right) \\ &= E_t\left(\frac{P_t^N}{\sigma_b P_{t+1}^N + c}\right)\left(1+\frac{\gamma_b}{2}\left(\kappa \frac{B_t^S}{B_t^{L,H}}-1\right)^2\right. \\ &\quad - \gamma_b \kappa\left(\kappa \frac{B_t^S}{B_t^{L,H}}-1\right)\frac{B_t^S}{B_t^{L,H}} \\ &\quad \left. + \gamma_b^* \kappa^*\left(\kappa^* \frac{B_t^{L,H}}{B_t^{L,H*}}-1\right) e_t \frac{P_t^{N*}}{P_t^N}\right) \end{aligned} \tag{29}$$

$$\frac{\partial L^r}{\partial B_t^*} = \beta E_t\left(\frac{\lambda_{t+1}}{\lambda_t}\right) = E_t\left(\frac{e_t P_{t+1}}{e_{t+1} P_t}\right)\left(\frac{1}{1+i_t^*} + \gamma_f \frac{e_t\left(B_t^*-B^*\right)}{P_t}\right) \tag{30}$$

$$\frac{\partial L^r}{\partial K_t} = \beta E_t\left(\frac{\lambda_{t+1}}{\lambda_t}\right) = E_t\left(\frac{P_{t+1}}{P_t}\frac{P_t^c}{P_{t+1}^c}\right)\frac{1}{\left(1+i_t^k-\varphi_t-\lambda_k\right) - t_t^k\left(i_t^k-\gamma_k\right)} \tag{31}$$

$$\frac{\partial L^r}{\partial C_t^r} = U_t^C = \frac{\left(1+t_t^c\right) P_t^c}{P_t}\lambda_t \tag{32}$$

$$\frac{\partial L^r}{\partial N_t^r} = U_t^N = \frac{(1-t_t^w)\,W_t}{P_t}\lambda_t \tag{33}$$

The arbitrage condition for investment provides an investment rule linking capital formation to the shadow price of capital:

$$\left(\gamma_K \frac{J_t^K}{K_{t-1}} + \gamma_I \Delta J_t^K\right) - E_t\left(\frac{1}{1+r_t+\phi_{t+1}^{GDP}-\phi_{t+1}^I}\Delta J_{t+1}^K\right) = \frac{\xi_t}{p_t^I} - 1 \tag{34}$$

where the shadow price of capital corresponds to the present discounted value of the rental income from physical capital:

$$\frac{\xi_t}{p_t^I} = E_t\left(\frac{1}{1+r_t+\pi_{t+1}^{GDP}-\pi_{t+1}^I}\frac{\xi_{t+1}}{p_{t+1}^I}(1-\delta_K)\right) + \left(\left(1-t_t^K\right)i_t^k + t_t^k\gamma_k\right) = 0 \tag{35}$$

8.3 Liquidity-Constrained Households

Liquidity-constrained households do not optimise, but simply consume their entire disposable income at each date. Real consumption of household l is thus determined by the net wage and transfer income minus a lump-sum tax:

$$(1+t_t^c)\,P_t^c C_t^l = (1-t_t^w)\,W_t N_t^l + TR_t^l - T_t^{LS,l} \tag{36}$$

The liquidity-constrained households share the same utility function as Ricardian households.

8.4 Wage Setting

A trade union is maximising a joint utility function for each type of labour h. It is assumed that types of labour are distributed equally over Ricardian and liquidity constrained households with their respective population weights. The trade union sets wages by maximising a weighted average of the utility functions of these households. The wage rule is obtained by equating a weighted average of the marginal utility of leisure to a weighted average of the marginal utility of consumption times the net real consumption wage of both household types, adjusted for a wage mark-up $\left(\eta_t^W\right)$:

$$\frac{\left(1-s^l\right)U_{1-N,t}^r + s^l U_{1-N,t}^l}{(1-s^l)_{c,t}^r + s^l U_{c,t}^l} = \frac{1-t_t^w}{1+t_t^c}\frac{W_t}{P_t^C}\eta_t^W \tag{37}$$

Wage mark-ups fluctuate around $\frac{1}{\theta}$, which is the inverse of the elasticity of substitution between different varieties of labour services. The ratio of the marginal utility of leisure to the marginal utility of consumption is a natural measure of the reservation wage. If the ratio is equal to the consumption wage, the household is indifferent between supplying an additional unit of labour and spending the additional income on consumption, or not increasing labour supply. Fluctuations in the wage mark-up arise from wage adjustment costs and the fact that a fraction $1-sfw$ of workers indexes wage growth π_t^W to inflation in the previous period:

$$\eta_t^W = \frac{1-1}{\theta-\gamma_W}\frac{\theta-\gamma_w}{\theta E_t}\left(\beta\gamma_{t,t+1}^r\left(\pi_{t+1}^W-(1-sfw)\,\pi_t\right)-\left(\phi_t^W-(1-sfw)\,\phi_{t-1}\right)\right) 0 \le sfw \le 1 \tag{38}$$

The (semi-)elasticity of wage inflation with respect to employment is given by /W, i.e. it is positively related to the inverse of the elasticity of labour supply and inversely related to wage adjustment costs.

8.5 Aggregation

The aggregate value of any household specific variable X_t^h in per-capita terms is given by $X_t \equiv \int_0^1 X_t^h dh = \left(1-s^l\right)X_t^r + s^l X_t^l$

since the households within each group are identical in their consumption and labour supply decisions. Hence, aggregate consumption is given by:

$C_t = (1-s^l)C_t^r + s^l C_t^l$ and aggregate employment by: $N_t = (1-s^l)N_t^r + s^l N_t^l with N_t^r = N_t^l$

8.6 Policy

Fiscal policy and monetary policy are partly rules-based and partly discretionary. The fiscal rule stabilises government debt. The monetary policy rule stabilises inflation and output.

8.6.1 Fiscal Policy

Real government purchases (Gt) and real government investment (IGt) are kept exogenous. The stock of public infrastructure, which enters the production function of firms (11), develops according to:

$$KG_t = IG_t + (1 - \delta^g)KG_{t-1} \tag{39}$$

Nominal transfers (TR_t) correspond to a CPI-adjusted exogenous transfer-to-GDP share (try):

$$TR_t = tryP_t^C \tag{40}$$

The government collects tax revenue from consumption, labour, corporate income and lump-sum taxes. The lump-sum taxes are a fixed share of GDP. Nominal government debt which is composed of short-term bonds and long-term bonds follows:

$$\frac{B_t^S}{(1+i_t)} + P_t^N B_t^L = B_{t-1}^S + (\delta_b P_t^N + c)B_{t-1}^L + P_t^C (G_t + IGt) + TR_t - t_t^c P_t^c C_t - t_t^w W_t N_t - \left(t_t^k \left(P_t Y_t - W_t N_t - \delta_k P_t^I K_{t-1}\right)\right) - T_t^{LS} \tag{41}$$

As seen previously (Eq. 12), total government debt consists of long-term bonds B_t^L held by domestic $\left(B_t^{L,F}\right)$ and foreign private agents $\left(B_t^{L,F}\right)$, and by the central bank $\left(B_t^{L,CB}\right)$, and of short-term bonds B_t^S . The labour tax is used to control the debt-to-GDP ratio according to the following rule:

$$\Delta t_t^w = \tau^B \left(\frac{B_{t-1}}{P_{t-1}Y_{t-1}} - b^{tar} + \tau^{DEF} \Delta \left(\frac{B_t}{Y_t P_t}\right)\right. \tag{42}$$

where b^{tar} is the government debt target. The consumption and corporate income tax are kept constant.

8.6.2 Monetary Policy

The operating profit of the central bank equals the sum of base money issuance and interest income minus the current expenditure on buying long-term bonds, where the latter equals the change of the value of long-term bonds on the central bank's balance sheet:

$$PR_t^{CB} = \Delta M_t + cB_{t-1}^{I,CB} - (P_t^N B_t^{L,CB} - \delta_b P_t^N B_{t-1}^{L,CB}) \tag{43}$$

Under the central bank's budget constraint (43), purchases of long-term government bonds can be financed either by increasing liquidity (money issuance), or by reducing the central bank's operating profit. Purchases of long-term bonds by the central bank are modelled as an exogenous path that replicates the announced ECB programme in timing and size. Monetary policy in normal times follows a Taylor rule that allows for smoothing of the interest rate response to inflation and the output gap:

$$i_t = \rho_i i_{t-1} + (1 - \rho_i)(r + \phi^{tar} + \tau_{pi}(\pi_t^C - \pi^{tar}) + \tau_y ygap_t) \tag{44}$$

Output gap is derived from the production function, and is the deviation of capital and labour utilisation from their long run trends:

$$ygap_t = \alpha ln\left(\frac{N_t}{N_t^{SS}}\right) + (1-\alpha)ln\left(\frac{ucap_t}{ucap_t^{SS}}\right) \tag{45}$$

The variables N_t^{SS} and $ucap_t^{SS}$ are employed and capacity utilisation trends:

$$N_t^{SS} = \rho^N N_{t-1}^{SS} + (1-\rho^N)N_t \tag{46}$$

$$ucap_t^{SS} = \rho^{ucap} ucap_{t-1}^{SS} + (1-\rho^{ucap})ucap_t \tag{47}$$

restricted to move slowly in response to actual values.

9 Trade and Current Account

So far, only aggregate consumption and investment demand have been determined, but not its allocation over domestic and foreign tradable goods. In order to facilitate aggregation, private households and the government are assumed to have identical preferences across goods for consumption and investment. Let Z (C, G, I, IG) be the demand of an individual household or the government and their preferences over domestic versus imported goods given by the following utility function:

$$Z_t = ((1 - s_m)$$

where Z^D and Z^* are indexes of demand across the continuum of goods produced in the domestic economy and abroad respectively:

$$Z_t^D = \left(\sum_{d=1}^{m} m^{\frac{1}{\sigma}} Z_t^D \frac{\sigma - 1}{\sigma} \right)^{\frac{\sigma}{\sigma-1}} \tag{48}$$

$$Z_t^F = \left(\sum_{f=1}^{q} q^{\frac{1}{\sigma}} Z_t^f \frac{\sigma-1}{\sigma} \right)^{\frac{\sigma}{\sigma-1}} \tag{48}$$

The elasticity of substitution between bundles of domestic and foreign goods is σ_m. The aggregate consumer price index is given by:

$$P_t^C = \Big((1-s_m)\,(P_t)^{1-\sigma_m} + s_m \left(P_t^F e_t\right)^{1-\sigma_m} \Big)$$

11-σ_m(48)The steady-state import share (s_m), and the elasticity of substitution between domestic and imported goods (σ_m) are assumed to be constant across all expenditure components. The aggregate imports are given by:

$$M_t = s_m \left(\frac{e_t P_t^*}{P_t^C} \right)^{-\sigma_m} Z_t \tag{48}$$

Assuming equivalent demand functions in the rest of the world, exports can be treated symmetrically and are given by:

$$X_t = s_m^* \left(\frac{P_t}{e_t P_t^{C*}} \right)^{-\sigma_x} (Z_t^*) \tag{48}$$

The domestic economy´s trade balance is the net trade in value terms:

$$TB_t = P_t X_t - e_t P_t^* M_t \tag{48}$$

The law of motion for the NFA position is:

$$e_t \left(B_t^* + P_t^{N*} B_t^{L,H*} \right) - P_t^N B_t^{L,F} = \left(1 + i_{t-1}^*\right) e_t B_{t-1}^* + \left(c^* + \sigma_b^* P_t^{N*}\right) e_t B_{t-1}^{L,H*} - \left(c + \sigma_b P_t^N\right) e_t B_{t-1}^{L,F} + P_t^X - P_t^M M_t \tag{48}$$

The model's external side is closed by a (small) country risk premium ($risk$), which depends on the NFA position:

$$i_t = i_t^F + \frac{\Delta e_{t-1}}{e_t} - risk \left(\frac{e_t B_t^*}{P_t Y_t} - bwy^T \right) \tag{48}$$

rules out explosive NFA dynamics.

10 Parametrisation

The parameters are based on long-term averages (mainly national accounts data) for the EA economy as far as the steady state of the variables is concerned, and on model versions estimated with Bayesian methods [5] for the parameters governing the adjustment dynamics (price and wage stickiness, employment and investment adjustment costs, habit persistence, and others). These parameter values are also compatible with stylised facts of the EA economy, such as average price and wage durations.

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