

Forecasting with a Dutch Agent-Based Model and Optimally Behaving Households

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October 17, 2026

Abstract

Agent-based macroeconomic models can forecast competitively with standard benchmarks, but they typically describe household consumption with fixed rules. We replace these rules in a stock-flow consistent agent-based model of the Dutch economy (Poledna et al., 2023) with optimising households. Each household solves a two-asset consumption and portfolio problem in the style of Kaplan et al. (2018), holding liquid deposits and illiquid capital, and is internally rational in the sense of Adam and Marcet (2011): it optimises given beliefs about returns and inflation that it updates by adaptive learning. A neural network trained on approximate Euler conditions and conditioned on preferences and beliefs makes the problem tractable for a household sector calibrated to Statistics Netherlands microdata. In rolling out-of-sample forecasts over 2010–2019 under four expectation specifications, the model reduces twelve-quarter household-consumption RMSFE by 40.5–54.2% relative to matched univariate benchmarks and investment RMSFE by 14.5–15.5%. The investment gains are statistically significant ($p < 0.01$); with 28 overlapping forecast origins, the consumption test has little power ($p = 0.455$ – 0.489). The consumption gain is concentrated in the 2013–14 consumption trough: among the original agent-based model and ten heuristic consumption rules, ours is the only specification that captures it while staying within 10.2% of the benchmark afterwards. Comparisons across the heuristic rules point to dynamic household behaviour and state-dependent portfolio choice as sources of the gain.

Keywords: Macroeconomics; Agent-Based Models; Optimal Consumption Model; Forecasting.

1 Introduction

Accurate macroeconomic forecasting of household consumption is central to monetary policy, fiscal planning, and financial stability assessment. Yet no single modelling tradition captures

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all relevant dimensions. Representative-agent DSGE models commonly deployed for operational forecasting provide disciplined structural frameworks but, by construction, abstract from the distributional dynamics that drive aggregate consumption at the household level; reduced-form time-series models complement these with strong short-run fit but lack structural content for longer horizons. The Heterogeneous Agent New Keynesian (HANK) literature has demonstrated that the joint distribution of income and wealth, and the marginal propensity to consume (MPC) heterogeneity it implies, is a first-order determinant of aggregate consumption dynamics (Kaplan et al., 2018, 2014; Kaplan and Violante, 2022). This is confirmed empirically by Fagereng et al. (2021), who show that marginal propensities to consume vary systematically with liquid assets. Yet incorporating household heterogeneity does not automatically translate into forecasting gains: Acharya et al. (2023) show that an estimated two-asset HANK model does not improve consumption forecasts relative to the representative-agent benchmark of Smets and Wouters (2007), suggesting that the modelling environment in which heterogeneity is embedded matters as much as heterogeneity itself. No forecasting framework to date embeds microfounded consumption heterogeneity in an environment that also features out-of-equilibrium adjustment, decentralised markets, and stock–flow consistent accounting.

We combine these features in a Dutch ABM and find 40.5–54.2% lower twelve-quarter aggregate household-consumption RMSFE relative to matched univariate benchmarks, with statistical uncertainty discussed below; Figure 7 and Table 9 present the central evidence.

Agent-based models (ABMs) offer a complementary source of structural richness. In an ABM, aggregate outcomes emerge from interactions among heterogeneous, boundedly rational agents operating within explicit institutional settings (Axtell and Farmer, 2025; Dawid and Delli Gatti, 2018). Rather than enforcing market clearing and solving for equilibrium, ABMs specify micro-level decision rules and interaction protocols, including search-and-matching in goods, labour, and credit markets, production networks, and credit networks, and simulate the economy forward under stochastic shocks. This makes them well suited to study non-linear amplification, path dependence, and the joint propagation of real and financial shocks. Recent large-scale ABMs calibrated to national accounts have demonstrated competitive or better forecasting performance relative to standard benchmarks (Poledna et al., 2023; Hommes et al., 2025; Wiese et al., 2024). Yet a common limitation persists across these models: household consumption is governed by simple heuristics, typically a constant marginal propensity to consume, that cannot capture the forward-looking, portfolio-dependent behaviour the HANK literature identifies as essential.¹

This paper asks whether replacing heuristic consumption rules with microfounded, optimising household behaviour improves ABM forecasting performance. We develop an optimal-consumption ABM (OC-ABM) of the Dutch economy, chosen for its high-quality administrative microdata (Statistics Netherlands), well-documented national accounts (Eurostat), and comparability to the Austrian ABM of Poledna et al. (2023), in which households make forward-looking consumption–saving decisions over liquid and illiquid assets in the spirit of Kaplan et al. (2018). Households operate under imperfect market knowledge. They are internally rational in the sense of Adam and Marcet (2011), seeking to solve their optimisation problem given their beliefs using approximate neural-network policies. However, departing from the Bayesian updating in Adam and Marcet (2011), and motivated by the growing recognition that rational expectations place implausible computational demands on agents in

¹Some ABM frameworks include richer consumption specifications with liquidity-constrained households or rule-of-thumb heterogeneity (Dawid and Delli Gatti, 2018), but none embeds the microfounded two-asset intertemporal optimisation that Kaplan and Violante (2022) identify as necessary to match the empirical MPC hierarchy.

heterogeneous-agent settings (Moll, 2025), they form expectations using OLS-estimated AR(1) rules in the tradition of adaptive learning (Evans and Honkapohja, 2001). Expectations are parsimonious in the spirit of the behavioral learning equilibria of Hommes and Zhu (2014): households condition on a small number of aggregates each period rather than the full state of the economy. Recent work has begun to explore this intersection from the HANK side: Pfäuti and Seyrich (2022) embed cognitive discounting in a HANK framework. Our approach differs by situating optimising households in a fully decentralised ABM environment with network interactions and stock–flow consistent accounting. This bridges two literatures: from HANK, we retain a household structure rooted in the incomplete-markets tradition (Bewley, 1977; Huggett, 1993; Aiyagari, 1994) and distributional transmission channels; from ABMs, we preserve decentralised dynamics, network propagation, and explicit stock–flow consistency across sectors.

Three contributions support this synthesis. First, the OC-ABM embeds HANK-style two-asset households in a stock–flow consistent agent-based model with decentralised markets, augmented with a simple equity-fund market that pays firm and bank dividends. This provides a structural environment in which distributional dynamics and out-of-equilibrium adjustment interact with forward-looking household behaviour. Second, we compute household policy functions using an amortised neural-network method adapted from Maliar et al. (2021), trained via Euler-equation residual minimisation and generalised to a continuous parameter space. This allows preference and behavioural parameters to vary across calibration periods without re-solving the household problem from scratch, enabling efficient, data-driven calibration to quarterly data. Third, we calibrate household behaviour using anonymised administrative microdata from Statistics Netherlands (CBS), matching the joint distribution of income and wealth rather than aggregated moments alone. The calibration targets a windfall income MPC of 0.33 (Drescher et al., 2020), capital and deposit MPCs of 0.047 and 0.04, and an average propensity to consume from national accounts. The policy conditions on beliefs and preferences; network weights remain fixed during forecasting while households update their AR(1) beliefs.

We evaluate forecasting performance using rolling out-of-sample exercises over 2010Q1–2019Q4, a pre-COVID period of relative macroeconomic stability. We compare the OC-ABM against the base ABM of Poledna et al. (2023), ten heuristic extensions spanning static, habit-formation, and buffer-stock consumption rules (H1–H7) and capital-return and portfolio variants (H8–H10), with borrowing-constraint differences reported explicitly, and four benchmark time-series models: AR(1), ARX(1), VAR(1), and VARX(1). Our headline finding is that the OC-ABM substantially lowers the RMSFE of household consumption forecasts at the 12-quarter horizon, as measured by root mean squared forecast error (RMSFE). Relative to the corresponding univariate benchmark, the OC-ABM achieves consumption RMSFE reductions of 40.5–54.2% across all four expectation mechanisms, although corrected Diebold–Mariano tests do not reject equal accuracy ($p = 0.455$ – 0.489 ; Diebold and Mariano, 1995). With 28 overlapping origins these tests have little power: even an error-free forecast would give $p = 0.21$ – 0.31 . The gain is concentrated in the 2013–14 consumption trough, and the OC-ABM is the only specification that both captures it and stays within 10.2% of the benchmark over 2015–19 (Table 8). Investment RMSFE falls by 14.5–15.5%, and these gains are statistically significant ($p < 0.01$) and remain significant at 5% after a Holm correction across the twelve headline twelve-quarter tests. The largest gains arise under mechanisms without exogenous predictors (49.7% under AR, 54.2% under VAR); smaller point-estimate gains obtain when exogenous variables are included (42.6% under ARX, 40.5% under VARX). Against multivariate benchmarks, consumption point-estimate improvements reach 57.2%. The base ABM, by contrast, achieves a statistically insignificant 5.9% ($p = 0.807$) at twelve quarters under AR

expectations against AR(1). These gains are concentrated at horizons beyond four quarters; at 1–4 quarter horizons, the OC-ABM’s consumption forecasts underperform matched univariate benchmarks, consistent with the latter’s advantage in capturing short-run serial correlation. Results are also variable-specific: GDP improvements of 31.0–40.1% are directionally positive across all mechanisms but not statistically significant, inflation forecasts show a small, statistically insignificant improvement under AR expectations, and government consumption forecasts are poor at 8–12 quarters.

MPC heterogeneity alone does not ensure forecast gains. H2 raises twelve-quarter household-consumption RMSFE by 307.9% under AR expectations against AR(1) ($p = 0.019$). The OC-ABM’s positive point estimates are consistent with a role for intertemporal consumption smoothing, and the heuristic comparisons point to dynamic household behaviour and state-dependent portfolio choice as sources of the gain. Section 4 reports the sample, benchmarks and full comparisons.

The remainder of the paper proceeds as follows. Section 2 introduces the agent-based model and the extended household sector. Section 3 details the calibration strategy, including the neural-network solution method and microdata matching. Section 4 presents the forecast comparison. Section 5 assesses internal validity through auto- and cross-correlation analysis. Section 6 discusses limitations and concludes.

2 Model

This section describes the model, which builds on the macroeconomic agent-based model of Poledna et al. (2023). We make two principal extensions. First, we replace the constant marginal propensity to consume heuristic with a HANK-style optimal consumption block inspired by the two-asset framework of Kaplan et al. (2018), allowing consumption to depend on liquid and illiquid wealth, asset returns, and inflation in addition to income. Second, we introduce an equity-fund market through which households hold claims on firm and bank profits, earning dividend income. We also compare the optimal consumption model against a suite of increasingly flexible heuristic consumption rules (Section 2.4) and a baseline constant-consumption heuristic (Section 2.5).

2.1 Overview

Figure 1 shows the overall structure of the model. The economy consists of six sectors: households, firms, a commercial bank, a central bank, the government, and the rest of the world.

- **Households** sell labour to firms in return for wages and invest in the equity fund to claim a share of profits. They purchase consumption goods from firms, deposit money in the bank or borrow from it, and receive dividends from the equity fund.
- **Firms** produce goods that serve as consumption goods, investment goods, intermediate goods, or material inputs within an input–output network. Firms borrow from the bank, deposit cash reserves, and pay dividends to equity-fund holders.
- **The bank** takes deposits and extends loans to firms and households, subject to capital requirements and firm-level risk assessments. Bank profits are paid as dividends to

equity-fund holders.

- **The government** levies taxes and social contributions from households, provides subsidies and social benefits, and purchases government consumption goods from firms.
- **The central bank** provides liquidity to the commercial bank through advances or accepts reserve deposits, paying or receiving interest accordingly. It sets the policy interest rate according to a Taylor (1993) rule.
- **The rest of the world** imports and exports goods on the goods market.

The model represents heterogeneous agents aligned with European System of Accounts (ESA) classifications and is calibrated to Eurostat national accounts and CBS microdata. Markets are fully decentralised: all transactions occur through search-and-matching processes. The remainder of the model not described in this section, including firm production, pricing, the banking sector, and government fiscal rules, follows Poledna et al. (2023) and is detailed in Appendix A.

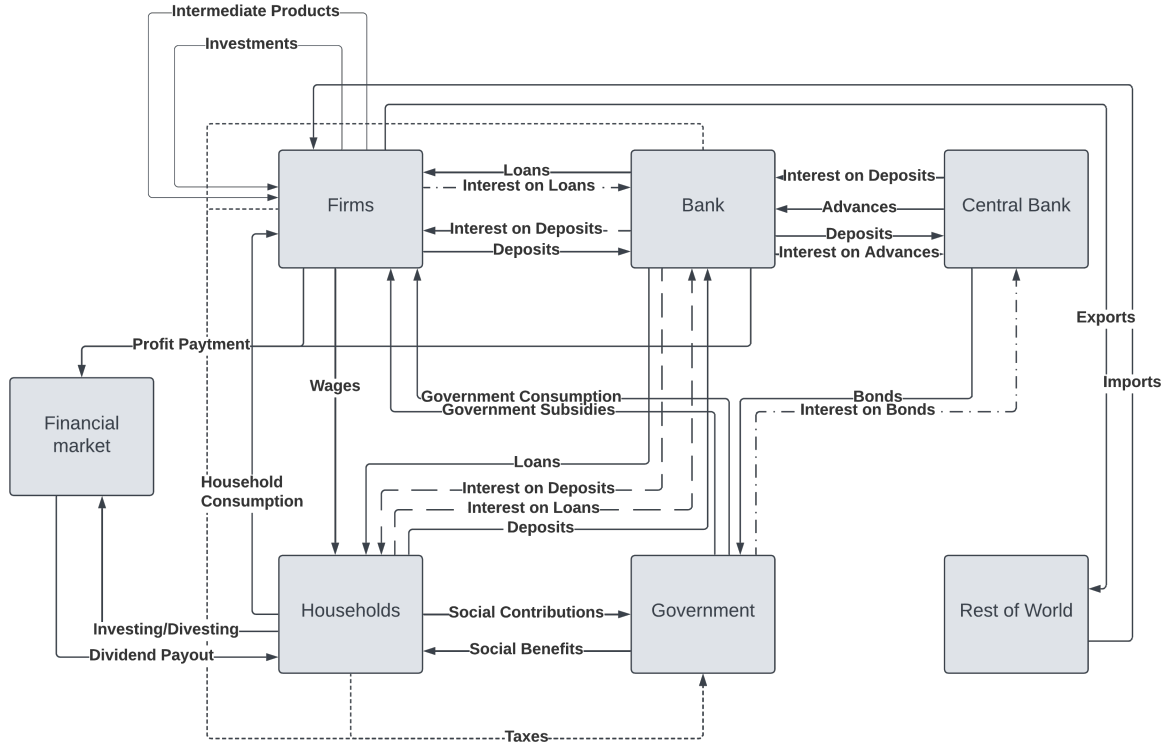


Figure 1: Flow diagram of the model. Arrow direction indicates flow direction.

2.2 Households

As Statistics Netherlands (CBS) registers wealth at the household level, we model the household sector accordingly. The sector consists of H households, each of which receives the sum of the incomes of all individuals in the household.

2.2.1 Labour Income and Search

Household income depends on activity status. If household h is employed by firm i in period t , it receives the wage $w_{h,t} = w_{i,t}$. If unemployed and economically active, the household searches for work through the search-and-matching mechanism on the labour market: it visits firms with open vacancies in random order and accepts the first available position. There are no hiring or firing costs; fired employees begin searching in the same period. If no vacancy is found, the household remains unemployed and retains its previous wage as a reference:

$$w_{h,t} = \begin{cases} w_{i,t} & \text{if employed by firm } i, \\ w_{h,t-1} & \text{if unemployed.} \end{cases} \quad (1)$$

An economically inactive household receives benefits sb_t^{inact} and does not search for work:

$$sb_t^{\text{inact}} = sb_{t-1}^{\text{inact}}(1 + \gamma_t^e), \quad (2)$$

where γ_t^e is the expected aggregate growth rate. Each household additionally receives other social transfers (related to family, children, etc.), assumed uniform across households:

$$sb_t^{\text{other}} = sb_{t-1}^{\text{other}}(1 + \gamma_t^e). \quad (3)$$

Disposable income from labour and social benefits is:

$$Y_{h,t} = \begin{cases} (w_{h,t}(1 - \tau^{\text{SIW}} - \tau^{\text{INC}}(1 - \tau^{\text{SIW}})) + sb_t^{\text{other}}) \bar{P}_{t-1}^{\text{HH}} & \text{if employed,} \\ (\theta^{\text{UB}} w_{h,t} + sb_t^{\text{other}}) \bar{P}_{t-1}^{\text{HH}} & \text{if unemployed,} \\ (sb_t^{\text{inact}} + sb_t^{\text{other}}) \bar{P}_{t-1}^{\text{HH}} & \text{if not economically active,} \end{cases} \quad (4)$$

where τ^{INC} is the income tax rate, τ^{SIW} is the rate of social insurance contributions paid by the employee, and θ^{UB} is the unemployment benefit replacement rate. We denote deflated disposable income by $y_{h,t} = Y_{h,t} / \bar{P}_{t-1}^{\text{HH}}$, which enters the household budget constraint below.²

2.2.2 Household Optimisation Problem

Having described household income, we now turn to the consumption–saving decision. Households also receive interest on liquid assets and a return on illiquid capital (described in Section 2.2.3). We adopt the two-asset formulation of Kaplan et al. (2018). Kaplan and Violante (2022) show that a two-asset structure, with sufficiently different returns on liquid and illiquid assets, is necessary for theoretical MPCs to match their empirical counterparts.³

The household block approximates the consumption–saving problem of Kaplan et al. (2018), with labour supply determined outside the household policy. Households have imperfect market knowledge: they are internally rational in the sense of Adam and Marcet (2011), acting given parsimonious perceived laws of motion rather than conditioning on the full economy. The household problem uses constant Stone–Geary subsistence and a shifted bond-convenience wedge in its Euler restrictions. The wedge is a calibrated portfolio restriction, rather than additive liquid- and illiquid-asset utility terms.

²We deflate by the lagged price index $\bar{P}_{t-1}^{\text{HH}}$ rather than the current level because households make their consumption–saving decisions before observing the current-period price realisation.

³A necessary condition is that returns on the liquid and illiquid assets differ substantially. Kaplan and Violante (2022) argue that both theory and data provide sufficient evidence that this holds.

The intertemporal benchmark (in real terms) is:

$$\max_{\{c_{h,t}, d_{h,t}, b_{h,t+1}\}_{t \in \mathbb{N}}} \mathbb{E}_0^* \sum_{t=0}^{\infty} \beta^t u(c_{h,t}), \quad (5)$$

subject to

$$\begin{aligned} (1 + \tau^{\text{VAT}})c_{h,t} &= y_{h,t} + (1 + r_t^b + \mathbb{I}_{\{b_{h,t+1} < 0\}} r_{cc})b_{h,t} - d_{h,t} - \chi(d_{h,t}, k_{h,t}) - b_{h,t+1}, \\ k_{h,t+1} &= (1 + r_t^k - \tau^K)k_{h,t} + d_{h,t}, \\ b_{h,t+1} &\geq b_{h,t}^{\min} = \max(-\varphi y_{h,t}, -\underline{b}), \quad k_{h,t+1} \geq 0, \end{aligned} \quad (6)$$

with adjustment cost

$$\chi(d_{h,t}, k_{h,t}) = \chi_0^k |d_{h,t}| + \chi_1^k \left(\frac{|d_{h,t}|}{k_{h,t} + 1} \right)^{\chi_2^k} (k_{h,t} + 1). \quad (7)$$

Here $\beta \in (0, 1)$ is the discount factor, $c_{h,t}$ is consumption, $b_{h,t}$ denotes liquid assets, $k_{h,t}$ denotes illiquid asset holdings, and $d_{h,t}$ is net deposits into the illiquid asset. The independent choice variables are $(c_{h,t}, d_{h,t}, b_{h,t+1})$, with capital determined by its accumulation equation. The remaining budget symbols are the credit surcharge r_{cc} on negative balances, value-added tax τ^{VAT} and capital tax τ^K . The policy uses an income-scaled liquid floor with $\varphi = 0.6$ and hard bound $\underline{b} = 15$ in normalised household units, rather than a common flat limit. Its transaction-cost coefficients are $\chi_0^k = 0.02$, $\chi_1^k = 0.1$ and $\chi_2^k = 1.5$; the numerical routine smooths $|d|$ as $\sqrt{d^2 + 10^{-6}}$. The budget equations describe the economic benchmark and ABM accounting; the implemented approximate Euler restrictions are distinguished below.

The utility function takes the Stone–Geary form:

$$u(c_{h,t}) = \frac{(c_{h,t} - \bar{c})^{1-\sigma}}{1-\sigma}, \quad (8)$$

where $\sigma > 0$ is relative risk aversion (denoted γ in the solver) and $\bar{c} = c_{\text{int}}$ is a constant subsistence intercept. The five calibrated policy parameters are $\Gamma = (\beta, \sigma, c_{\text{int}}, \chi_0^b, \chi_1^b)$. The bond-convenience wedge is

$$q_b(b'; y) = \chi_0^b [\max\{b' - b^{\min}(y) + 1, 0.1\}]^{-\chi_1^b}.$$

It enters the bond Euler gap directly, with a VAT factor, rather than as the marginal utility of a separable additive bond-utility term divided by $u'(c)$. In particular, the restriction omits the consumption-dependent scaling that such an additive-utility interpretation would require. We therefore describe the household block as approximately optimising under implemented Euler/KKT restrictions, rather than an exact solution of the benchmark maximisation problem. Global policy accuracy remains unverified.

Each period, agents update their perceived laws of motion as observations arrive and evaluate the fixed policy network with the revised belief inputs. Return and inflation beliefs enter the continuation calculation; the solver uses a fixed household-income persistence and volatility process. The perceived and actual laws of motion cannot exactly coincide, since parsimonious AR(1) rules cannot capture the full ABM. We describe these household-level beliefs in Section 2.2.5 and the aggregate expectation mechanisms in Section 2.6.

2.2.3 Capital Market

Households hold capital $k_{h,t}$ representing equity stakes in the productive sector, which comprises all firms and the commercial bank. Total household capital is $K_t = \sum_{h=1}^H k_{h,t}$. Holdings are initially allocated in proportion to household income and subsequently evolve through investment decisions:

$$k_{h,t+1} = (1 + r_t^k - \tau^K)k_{h,t} + d_{h,t}, \quad (9)$$

where $d_{h,t}$ is net deposits into the illiquid asset (positive for purchases, negative for sales), consistent with the budget constraint in Section 2.2.2.

Capital earns a dividend return from profits distributed by firms and the bank. Both pay out a fraction θ^{DIV} of their after-tax profits as dividends:

$$D_t = \underbrace{\sum_{i=1}^I \theta^{\text{DIV}} (1 - \tau^{\text{INC}}) (1 - \tau^{\text{FIRM}}) \max(0, \Pi_{i,t})}_{\text{Firm dividends}} + \underbrace{\theta^{\text{DIV}} (1 - \tau^{\text{INC}}) (1 - \tau^{\text{FIRM}}) \max(0, \Pi_t^{\text{bank}})}_{\text{Bank dividends}}, \quad (10)$$

where τ^{FIRM} is the corporate tax rate, τ^{INC} is the income tax rate on dividends, $\Pi_{i,t}$ is the profit of firm i , and Π_t^{bank} is bank profit. The return on capital is the dividend yield:

$$r_t^k = \frac{D_t}{K_t}. \quad (11)$$

We abstract from secondary-market equity pricing: households deposit into or withdraw from the common capital stock at par, and net purchases increase K_t , diluting the dividend yield for all holders. Returns therefore adjust through quantity rather than price, and r_t^k captures dividend yield only.

2.2.4 Demanded and Realised Consumption

As in Poledna et al. (2023), households purchase goods from multiple types of firms through search-and-matching. The household calculates a demanded consumption budget for good g :

$$c_{g,t}^d = \frac{b_g^{\text{HH}} \bar{P}_{g,t}}{\bar{P}_{t-1}^{\text{HH}}} \frac{c_{h,t}^d}{1 + \tau^{\text{VAT}}}, \quad (12)$$

where b_g^{HH} is the consumption coefficient for product g , $\bar{P}_t^{\text{HH}}$ is the consumer price index, and $\bar{P}_{g,t}$ is the producer price index for good g (both defined in Section A.1.8). The household then visits firms to purchase goods. Depending on firm inventory and production capacity, demand may or may not be fully satisfied:

$$c_{h,t} \begin{cases} = \sum_g c_{g,t}^d & \text{if demand is fully met,} \\ < \sum_g c_{g,t}^d & \text{if firms visited cannot satisfy demand.} \end{cases} \quad (13)$$

Once realised consumption is determined, realised savings follow from the budget constraint:

$$b_{h,t+1} = y_{h,t} + (1 + r_t^b + \mathbb{I}_{\{b_{h,t+1} < 0\}} r_{cc}) b_{h,t} - d_{h,t} - \chi(d_{h,t}, k_{h,t}) - \bar{P}_t^{\text{HH}} (1 + \tau^{\text{VAT}}) c_{h,t}, \quad (14)$$

$$k_{h,t+1} = (1 + r_t^k - \tau^K) k_{h,t} + d_{h,t}. \quad (15)$$

2.2.5 Household-Level Expectations

The economy is too complex for households to learn the true data-generating process. Following Hommes and Zhu (2014), households use parsimonious AR(1) beliefs in the tradition of Marcet and Sargent (1989) and Evans and Honkapohja (2001). For capital returns, bond returns and inflation, the solver estimates log-gross-rate processes:

$$\log(1 + r_{t+1}^k) = \alpha_t^k + \rho_t^k \log(1 + r_t^k) + \epsilon_{t+1}^k, \quad (16)$$

$$\log(1 + r_{t+1}^b) = \alpha_t^b + \rho_t^b \log(1 + r_t^b) + \epsilon_{t+1}^b, \quad (17)$$

$$\log(1 + \pi_{t+1}) = \alpha_t^\pi + \rho_t^\pi \log(1 + \pi_t) + \epsilon_{t+1}^\pi, \quad (18)$$

$$\log y_{h,t+1} = (1 - \rho_y) \log \bar{y} + \rho_y \log y_{h,t} + \epsilon_{h,t+1}^y, \quad (19)$$

where the disturbances are zero-mean. Return and inflation intercepts, persistences and innovation volatilities are re-estimated by OLS on the expanding observed history. All households share those estimates. The income process instead has fixed persistence and volatility calibrated from a lifecycle-income approximation; it is not an additional re-estimated belief input. The network conditions on nine return/inflation belief summaries, $(\bar{R}_j, \rho_j, \sigma_j)$ for $j \in \{k, b, \pi\}$, alongside the six current states and five policy parameters. During forecasting, nominal income and asset states are deflated by the stored household price index; the inflation state is the perceived stationary mean. These household beliefs are distinct from the aggregate mechanisms used by firms, the bank and government.

2.3 Policy Function Computation

We compute approximate household policy functions using an amortised deep-learning approach adapted from Maliar et al. (2021). Neural networks are widely used for heterogeneous-agent models (see Fernández-Villaverde et al., 2024, for a survey), including deep equilibrium nets (Azinovic et al., 2022) and models with financial frictions (Fernández-Villaverde et al., 2023). The solver combines two Euler/complementarity residuals with deterministic quadrature over future shocks.

The key idea, known as amortisation, is to separate *solving* the household restrictions from *calibrating* the policy parameters. The network is trained across states, preference parameters and belief summaries within specified support:

$$(\mathbf{s}, \Gamma, \mathcal{B}) \mapsto (z_c, z_d) \mapsto (c_{h,t}, k_{h,t+1}, b_{h,t+1}).$$

The two raw heads determine a liquid-resource consumption share and a signed capital deposit; bond balances follow from the budget transformation. Euler gaps supply implicit shadow prices, rather than separate multiplier outputs. This permits moment calibration and policy evaluation under changing beliefs without re-solving the network, subject to approximation and support error.

Our approach relates to the ‘extended policy functions’ of Kase et al. (2025), who condition policies on structural parameters when estimating nonlinear HANK models. While their method targets likelihood estimation, ours targets moment matching within an ABM and includes beliefs as policy inputs. During forecasting, both the calibrated preference vector and network weights are fixed; online learning updates the belief summaries supplied to the network, rather than applying additional gradient updates to its weights.

Amortisation makes repeated household policy evaluation tractable within the ABM. We experimented with classical grid methods, projection methods and sparse adaptive grids (Brumm and Scheidegger, 2017), but found them slow for repeated quarterly calibration and Monte Carlo forecasting. We train a separate policy for each origin’s cross-section, rather than relying on sequential warm starts from the previous quarter. A fixed trained network accommodates changes in beliefs through its conditioning inputs; this does not guarantee accuracy outside the trained state, parameter or belief support.

The network is trained to reduce two Fischer–Burmeister residuals, $R_k = \text{FB}(\lambda_k, k')$ and $R_b = \text{FB}(\lambda_b, b' - b^{\min}(y))$, where $\text{FB}(a, z) = a + z - \sqrt{a^2 + z^2}$ and λ_k, λ_b are the implicit gaps of the implemented capital and bond Euler restrictions. Conditional expectations use Stroud-3 monomial quadrature: eight equally weighted nodes over the four return, inflation and income shocks. The capital gap includes the marginal adjustment cost and continuation envelope term; the bond gap includes the direct convenience wedge q_b . For each sampled state, let $Z_i = R_{k,i}^2 + R_{b,i}^2$. The training loss is

$$\Xi^n(\theta) = \frac{1}{n} \sum_{i=1}^n \frac{\bar{R} Z_i}{\bar{R} + Z_i}, \quad \bar{R} = 0.25, \quad (20)$$

where the saturating cap limits the contribution of large residuals and gradients are computed by automatic differentiation. Budget allocations and asset bounds are imposed through the output transformation, not an additional independently trained residual. The routine also smoothly bounds the log stochastic discount factor. These numerical safeguards and finite training error prevent an interpretation as exact global optimality.

We implement this separation through two stages: network training over the state–parameter–belief domain, followed by moment calibration of Γ with the network fixed. The procedure is repeated for 40 quarterly origins (2010Q1–2019Q4). Architecture, training and forecasting details are reported in Appendix C; calibration targets and results are in Section 3.4.3.

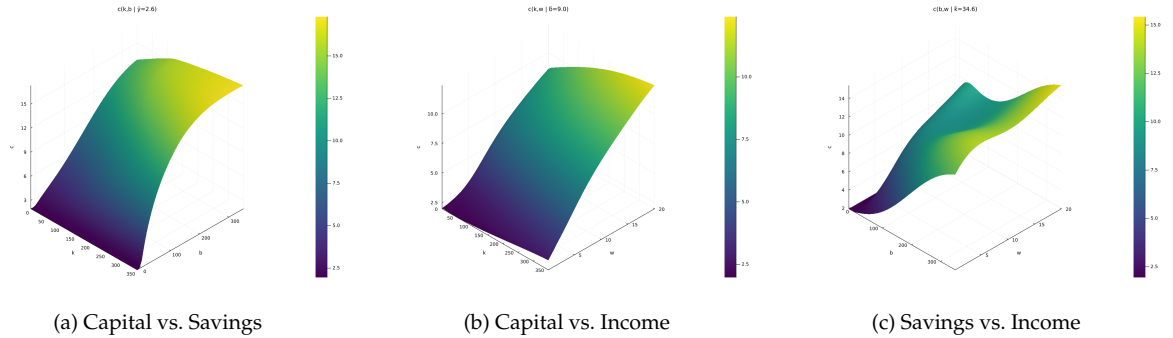


Figure 2: Policy function slices of the two-account OC model, showing consumption against pairs of asset and income states.

The consumption surfaces in Figure 2 illustrate how the policy varies with liquid balances, capital and income. The two-account transformation makes contemporaneous consumption depend on liquid resources, while capital affects portfolio adjustment and continuation incentives.

2.4 Heuristic Consumption Models

We compare the optimal consumption model against a suite of ten heuristic consumption rules, denoted H1–H10, designed to span the space of reduced-form consumption functions used in

applied macroeconomics and to vary the structural channels that distinguish reduced-form rules from the optimal policy. H1–H4 are static rules combining linear or concave income response with or without linear wealth dependence; H5–H6 add habit formation on the income component (Abel, 1990; Campbell, 1999); H7 implements the buffer-stock rule of Deaton (1991) and Carroll (1997), in which consumption is a smooth function of distance from a target wealth level. The remaining three variants vary the additional structural channels identified in Table 2: H8 partitions the income aggregate to allow a separate marginal propensity to consume out of capital returns; H9 replaces the fixed liquid/illiquid savings split with a state-contingent Merton (1969) portfolio rule; H10 combines both. The progression is not motivated by nesting — H5–H7 are not strict extensions of H1–H4 — but by spanning the families of reduced-form behaviour (income response, habit, target-wealth) and by comparing selected structural dimensions separating the heuristic class from the OC-ABM.

Before stating the heuristic equations, we define the income variable used by all heuristic models. Unlike the optimal model, where capital returns enter through a separate portfolio channel, heuristic households fold capital returns into income. This means heuristic households respond to asset returns only through the income–consumption relationship, whereas optimal households respond through both intertemporal and portfolio channels, a structural difference that matters for interpreting the forecasting comparison. Expected income is:

$$Y_{h,t}^e = \begin{cases} (w_{h,t}(1 - \tau^{\text{SIW}} - \tau^{\text{INC}}(1 - \tau^{\text{SIW}})) + sb_t^{\text{other}}) \bar{p}_{t-1}^{\text{HH}}(1 + \pi_t^e) + r_t^k k_{h,t} & \text{if employed,} \\ (\theta^{\text{UB}} w_{h,t} + sb_t^{\text{other}}) \bar{p}_{t-1}^{\text{HH}}(1 + \pi_t^e) + r_t^k k_{h,t} & \text{if unemployed,} \\ (sb_t^{\text{inact}} + sb_t^{\text{other}}) \bar{p}_{t-1}^{\text{HH}}(1 + \pi_t^e) + r_t^k k_{h,t} & \text{if not economically active.} \end{cases} \quad (21)$$

We denote expected income by $y_{h,t}^e$, total wealth by $W_{h,t} = k_{h,t} + b_{h,t}$, and use κ for the intercept, $\hat{\gamma}$ for the linear MPC out of income, $\hat{\delta}$ for the linear MPC out of wealth, $\hat{\alpha}$ and $\hat{\beta}$ for the concave income parameters, $\hat{\lambda}$ for the habit-persistence coefficient, $\hat{\phi}^{\text{bs}}$ for the buffer-stock adjustment speed, and $\bar{b}$ for the target liquid wealth level.⁴ Let $a_{h,t} = y_{h,t} + \max(0, b_{h,t} + \bar{b})$ denote available resources — realised income plus liquid dissaving capacity down to the borrowing limit. The core seven heuristics (H1–H7) are:

$$\begin{aligned} \text{H1: } c_{h,t} &= \frac{\min(\kappa + \hat{\gamma} y_{h,t}^e, a_{h,t})}{1 + \tau^{\text{VAT}}} & \text{H5: } c_{h,t} &= \frac{\min(\hat{\lambda} \bar{c}_{h,t-1} + (1 - \hat{\lambda})(\kappa + \hat{\alpha} y_{h,t}^e \hat{\beta}), a_{h,t})}{1 + \tau^{\text{VAT}}} \\ \text{H2: } c_{h,t} &= \frac{\min(\kappa + \hat{\alpha} y_{h,t}^e \hat{\beta}, a_{h,t})}{1 + \tau^{\text{VAT}}} & \text{H6: } c_{h,t} &= \frac{\min(\hat{\lambda} \bar{c}_{h,t-1}^y + (1 - \hat{\lambda})(\kappa + \hat{\alpha} y_{h,t}^e \hat{\beta}) + \hat{\delta} W_{h,t}, a_{h,t})}{1 + \tau^{\text{VAT}}} \\ \text{H3: } c_{h,t} &= \frac{\min(\kappa + \hat{\gamma} y_{h,t}^e + \hat{\delta} W_{h,t}, a_{h,t})}{1 + \tau^{\text{VAT}}} & \text{H7: } c_{h,t} &= \frac{\min(\kappa + \hat{\alpha} y_{h,t}^e \hat{\beta} + \hat{\phi}^{\text{bs}}(b_{h,t} - \bar{b}), a_{h,t})}{1 + \tau^{\text{VAT}}} \\ \text{H4: } c_{h,t} &= \frac{\min(\kappa + \hat{\alpha} y_{h,t}^e \hat{\beta} + \hat{\delta} W_{h,t}, a_{h,t})}{1 + \tau^{\text{VAT}}} \end{aligned}$$

where $\bar{c}_{h,t-1}$ is realised consumption in the previous quarter and $\bar{c}_{h,t-1}^y$ is its income component (consumption net of the additive wealth contribution). The heuristic ladder caps consumption at $a_{h,t}$, permitting liquid dissaving down to its flat limit $\bar{b}$. The OC policy instead uses the income-scaled floor $b^{\min}(y)$. The comparison therefore does not equalise borrowing capacity between heuristic and OC variants; portfolio rules, costs, calibration and numerical approximation also differ.

⁴We use hatted symbols for heuristic parameters to distinguish them from the discount factor β , growth rate γ_t^e , and AR coefficients ρ_t^j used elsewhere.

The remaining three variants build on H7 by varying the additional structural channels distinguishing the heuristic class from the OC-ABM (Table 2). They share the H7 functional form and differ only in the treatment of capital-return income and portfolio composition.

H8: Capital-return MPC asymmetry. To vary capital-return sensitivity, we partition the income aggregate in Equation (21) into labour-and-transfer income $y_{h,t}^w$ and capital-return income $r_t^k k_{h,t}$, attenuating the latter by a Christelis factor $\alpha_{\text{cap}} = 0.5$:

$$y_{h,t}^{\text{e,H8}} = y_{h,t}^w + \alpha_{\text{cap}} \cdot r_t^k k_{h,t}. \quad (22)$$

Consumption then follows the H7 rule with $y_{h,t}^e$ replaced by $y_{h,t}^{\text{e,H8}}$. The factor α_{cap} scales the contribution of capital returns to the income aggregate so that the implied marginal propensity to consume out of capital returns is half of that out of labour income. This ratio is a modelling assumption rather than an estimated moment.

H9: Merton portfolio rule. H7 splits new savings between the liquid and illiquid asset in the proportion observed in the calibration quarter. H9 replaces this rule with a state-contingent target. Following Merton (1969), the target portfolio share is

$$\omega_{h,t} = \text{clip} \left(\frac{\mu_t^k - r_t^b}{\hat{\gamma}_M (\sigma_t^k)^2}, 0.3, 0.85 \right), \quad (23)$$

where μ_t^k and σ_t^k are perceived expected return and volatility on capital, and the clipping bounds avoid pathological allocations during transitions. The Merton risk-aversion coefficient $\hat{\gamma}_M$ is inverted at each forecast origin so that the unconstrained share equals the empirical aggregate liquid-illiquid ratio at the prevailing risk-free rate r_0^b . The target illiquid stock is $K_{h,t}^{\text{target}} = \text{clip}(\omega_{h,t} W_{h,t}, 0, W_{h,t} - \underline{b})$, and the household closes a fraction of the gap each period:

$$d_{h,t} = 0.1 \cdot (K_{h,t}^{\text{target}} - k_{h,t}). \quad (24)$$

The smoothing rate 0.1 is H9's gradual-adjustment choice, rather than a matched parameter of the neural-network policy. The bond balance is then determined by the household budget constraint exactly as in H7. To preserve comparability with the OC-ABM treatment of equity, deposits adjust $k_{h,t}$ at par without entering aggregate investment, matching the OC-ABM convention.

H10: Combined. H10 combines the capital-return MPC asymmetry of H8 with the Merton portfolio rule of H9, applied jointly to the H7 buffer-stock specification. H10 provides a joint capital-return and portfolio comparison.

Heuristic calibration. We pin the structural MPC-shape parameters $(\hat{\gamma}, \hat{\alpha}, \hat{\beta}, \hat{\delta}, \hat{\varphi}^{\text{bs}})$ to match empirical MPC targets from the DNB Household Survey — $\text{MPC}_y = 0.20$ for income (Christelis et al., 2019a) and $\text{MPC}_W = 0.03$ for wealth (Christelis et al., 2019b) — and then solve numerically for the intercept κ by bisection so that aggregate consumption equals the average propensity to consume from national accounts. The habit coefficient $\hat{\lambda} = 0.7$ matches the consumption-persistence estimate of Christiano et al. (2005), and the buffer-stock target $\bar{b}$ is set to the cross-sectional median liquid wealth at each forecast origin. The capital-return scaling factor $\alpha_{\text{cap}} = 0.5$ (H8, H10) is fixed at the Christelis asymmetry value and not iterated.

The Merton risk-aversion coefficient $\hat{\gamma}_M$ (H9, H10) is inverted at each forecast origin so that the unconstrained portfolio share $\omega = (\mu^k - r^b)/(\hat{\gamma}_M(\sigma^k)^2)$ equals the empirical aggregate liquid–illiquid ratio at the prevailing risk-free rate; the perceived first two moments μ^k and σ^k are estimated by OLS on the dividend–yield series available at the forecast origin. Because the capped consumption rule is non-linear in the structural parameters, we iterate this two-step calibration until the effective cross-sectional mean MPCs (measured by numerical perturbation of y and W through the capped rule) match their targets to within 5×10^{-3} . Calibration is performed at each forecast origin; the OC policy and its parameters are calibrated separately, and both are fixed within each forecast path.

Table 1 summarises each specification.

Table 1: Heuristic Consumption Model Specifications

Model	Income response	Wealth response	Dynamics / Channel extension	Free params
H1	Linear ($\hat{\gamma}$)	—	Static	2
H2	Concave ($\hat{\alpha}, \hat{\beta}$)	—	Static	3
H3	Linear	Linear ($\hat{\delta}$)	Static	3
H4	Concave	Linear	Static	4
H5	Concave	—	Habit ($\hat{\lambda}$)	4
H6	Concave (habit-smoothed)	Linear (additive)	Habit on income only	5
H7	Concave	Target deviation ($\hat{\phi}^{bs}$)	Buffer-stock	4
H8	Concave (capital MPC scaled α_{cap})	Target deviation	Buffer-stock + Christelis asymmetry	4
H9	Concave	Target deviation	Buffer-stock + Merton portfolio ($\hat{\gamma}_M$)	5
H10	Concave (capital MPC scaled)	Target deviation	Buffer-stock + Christelis asymmetry + Merton portfolio	5

Note: All ten heuristics share the consumption cap $c_{h,t} \leq a_{h,t}/(1 + \tau^{VAT})$ where $a_{h,t} = y_{h,t} + \max(0, b_{h,t} + \underline{b})$; this flat-floor cap differs from the OC income-scaled liquid limit. Free parameter counts include the intercept κ , which is common to all specifications. H5 and H6 introduce habit through $\hat{\lambda} \in [0, 1]$ applied to the income component only; the wealth term in H6 enters additively. H7 follows Deaton (1991), with $\hat{\phi}^{bs}$ governing the speed of adjustment toward the target liquid wealth $\bar{b}$. H8 fixes $\alpha_{cap} = 0.5$ by assumption and is not counted as a free parameter; H9’s $\hat{\gamma}_M$ is inverted at calibration to match the empirical aggregate portfolio share. H10 combines H8 and H9 with no additional free parameters beyond those of H9.

Table 2: Structural channels: OC-ABM versus heuristic ladder

Channel	OC-ABM	H1–H7	H8	H9	H10
Borrowing constraint	Income-scaled floor $b^{\min}(y)$	Flat floor	Flat floor	Flat floor	Flat floor
Capital-return MPC	Separate continuation-value channel	Folded into y	Split (α_{cap})	Folded into y	Split (α_{cap})
Portfolio choice	Endogenous (NN policy on $d_{h,t}$)	Fixed split	Fixed split	Merton target	Merton target
Optimisation / Euler	Approximate Euler/FB restrictions	Reduced form	Reduced form	Reduced form	Reduced form

Note: $a_{h,t} = y_{h,t} + \max(0, b_{h,t} + \underline{b})$ is the heuristics’ consumption cap; it is not the OC income-scaled borrowing rule. H8 partitions income with capital-return scaling; H9 uses a Merton portfolio target; H10 combines both. The OC policy is trained on approximate Euler/FB restrictions with a bond-convenience wedge.

2.5 Baseline Heuristic

The baseline consumption heuristic of Poledna et al. (2023) sets consumption as a fixed fraction of income: $c_{h,t} = \phi^C y_{h,t}$, where ϕ^C is calibrated from national accounts as the ratio of household consumption to disposable income. This model features no MPC heterogeneity and does not account for wealth differences. It uses the same income process as the heuristic models above. The remainder of the model is unchanged from Poledna et al. (2023) and is described in Appendix A.

2.6 Aggregate Expectation Formation Mechanisms

The household-level expectations described in Section 2.2.5 govern the optimal consumption problem. All other agents in the model, namely firms, the bank, and the government, form expectations about aggregate output growth and inflation using one of four mechanisms, which we also use to generate the aggregate forecasts evaluated in Section 4. For the heuristic ABM variants, all agents (including households) share the same aggregate expectation mechanism. For the optimal-consumption ABM, households retain their own return and inflation beliefs while all other agents use the aggregate mechanism. The separation allows those household beliefs to enter the fixed amortised policy directly; it does not require retraining the network each period.

Throughout, we express output growth in log-differences for stationarity. The expected discrete growth rate and expected inflation are recovered as:

$$\gamma_t^e = \exp\left(\mathbb{E}_t^* \left[\log\left(\frac{Y_t}{Y_{t-1}}\right) \right]\right) - 1, \quad (25)$$

$$\pi_t^e = \mathbb{E}_t^*(1 + \pi_t) - 1. \quad (26)$$

These recovery formulae apply identically across all four specifications below.⁵

2.6.1 AR(1) Expectations

Following Poledna et al. (2023), the simplest specification models output growth and inflation as independent AR(1) processes. This serves as the parsimony benchmark: a minimal adaptive learning model that is progressively relaxed in the specifications that follow. Output growth expectations are:

$$\log\left(\frac{Y_t}{Y_{t-1}}\right) = \rho_t^Y \log\left(\frac{Y_{t-1}}{Y_{t-2}}\right) + \alpha_t^Y + \epsilon_t^Y, \quad (27)$$

and inflation perceived law of motion is:

$$(1 + \pi_t) = \rho_t^\pi (1 + \pi_{t-1}) + \alpha_t^\pi + \epsilon_t^\pi, \quad (28)$$

where all coefficients are re-estimated each period by OLS on observations $t' \in \{-T', \dots, t-1\}$. Expected growth and inflation are recovered via equations (25)–(26).

⁵The transformation $\gamma_t^e = \exp(\mathbb{E}_t^*[\log(Y_t/Y_{t-1})]) - 1$ recovers the geometric rather than arithmetic expected growth rate. By Jensen's inequality, this systematically understates arithmetic expected growth for symmetric log-growth shocks. The bias is negligible for the magnitude of quarterly growth rates in our sample.

2.6.2 VAR Expectations

The VAR specification models output growth and inflation jointly, capturing their interdependencies:

$$\begin{bmatrix} \log\left(\frac{Y_t}{Y_{t-1}}\right) \\ 1 + \pi_t \end{bmatrix} = \begin{bmatrix} \rho_t^{YY} & \rho_t^{Y\pi} \\ \rho_t^{\pi Y} & \rho_t^{\pi\pi} \end{bmatrix} \begin{bmatrix} \log\left(\frac{Y_{t-1}}{Y_{t-2}}\right) \\ 1 + \pi_{t-1} \end{bmatrix} + \begin{bmatrix} \alpha_t^Y \\ \alpha_t^\pi \end{bmatrix} + \begin{bmatrix} \epsilon_t^Y \\ \epsilon_t^\pi \end{bmatrix}, \quad (29)$$

with all coefficients re-estimated each period by OLS. Expected growth and inflation are recovered via equations (25)–(26).

2.6.3 ARX Expectations

Following Poledna et al. (2023), we incorporate predetermined paths for imports (M_t), exports (X_t), and government consumption (G_t) as exogenous predictors, consistent with a small open economy framework. Output growth expectations are:

$$\log\left(\frac{Y_t}{Y_{t-1}}\right) = \rho_t^Y \log\left(\frac{Y_{t-1}}{Y_{t-2}}\right) + \phi_t^M \Delta \log M_{t-1} + \phi_t^G \Delta \log G_{t-1} + \phi_t^X \Delta \log X_{t-1} + \alpha_t^Y + \epsilon_t^Y, \quad (30)$$

and inflation perceived law of motion is:

$$(1 + \pi_t) = \rho_t^\pi (1 + \pi_{t-1}) + \phi_t^M \Delta \log M_{t-1} + \phi_t^G \Delta \log G_{t-1} + \phi_t^X \Delta \log X_{t-1} + \alpha_t^\pi + \epsilon_t^\pi, \quad (31)$$

where $\Delta \log X_t = \log X_t - \log X_{t-1}$. All coefficients are re-estimated each period. Expected growth and inflation follow from equations (25)–(26).

2.6.4 VARX Expectations

The VARX specification combines the VAR structure with exogenous predictors:

$$\begin{bmatrix} \log\left(\frac{Y_t}{Y_{t-1}}\right) \\ 1 + \pi_t \end{bmatrix} = \begin{bmatrix} \rho_t^{YY} & \rho_t^{Y\pi} \\ \rho_t^{\pi Y} & \rho_t^{\pi\pi} \end{bmatrix} \begin{bmatrix} \log\left(\frac{Y_{t-1}}{Y_{t-2}}\right) \\ 1 + \pi_{t-1} \end{bmatrix} + \begin{bmatrix} \phi_t^{YM} & \phi_t^{YG} & \phi_t^{YX} \\ \phi_t^{\pi M} & \phi_t^{\pi G} & \phi_t^{\pi X} \end{bmatrix} \begin{bmatrix} \Delta \log M_{t-1} \\ \Delta \log G_{t-1} \\ \Delta \log X_{t-1} \end{bmatrix} + \begin{bmatrix} \alpha_t^Y \\ \alpha_t^\pi \end{bmatrix} + \begin{bmatrix} \epsilon_t^Y \\ \epsilon_t^\pi \end{bmatrix}, \quad (32)$$

with all coefficients re-estimated each period. Expected growth and inflation follow from equations (25)–(26).

3 Calibration

This section describes the calibration of the agent-based model. The calibration strategy follows the approach of Poledna et al. (2023) for the macroeconomic structure and extends it with microdata-based calibration of the household sector. We proceed in four steps. Section 3.1 describes the data sources. Section 3.2 explains how macroeconomic parameters are calibrated from national accounts, input–output tables, and institutional guidelines. Section 3.3 sets out the initial conditions for all sectors. Section 3.4 presents the microdata-based calibration of the household sector, including the empirical wealth–income distribution, the neural-network solution method, and the calibration results.

3.1 Data Sources

We draw on two primary data sources: Eurostat national accounts and Statistics Netherlands (CBS) microdata. The model is calibrated at quarterly frequency, with each agent representing a natural or legal entity (household, firm, government body, or other institution) in the Netherlands. The Netherlands is a small open economy with approximately 17 million inhabitants.⁶ Government expenditures amount to 44.5% of GDP, exports to 51% and imports to 45%, and the labour income share is 77.3%. Contrary to Poledna et al. (2023), we scale the model to 1:100 due to computational and data privacy constraints, yielding 172,699 individuals and 13,814 firms.

Table 3 reports the Eurostat datasets used for macroeconomic calibration. For the household sector, we use CBS Microdata (Table 4), which provides individual-level information on personal income, household income, and household wealth, enabling calibration of the joint income–wealth distribution that drives MPC heterogeneity in the model.

Table 3: Eurostat datasets used for model calibration

Name	Code
Population by current activity status, NACE Rev. 2 activity and NUTS 2 region	cens_11an_r2
Business demography by legal form (from 2004 onwards, NACE Rev. 2)	bd_9ac_1_form_r2
Symmetric input–output table at basic prices (product by product)	naio_10_cp1700
Cross-classification of fixed assets by industry and by asset (stocks)	nama_10_nfa_st
Government revenue, expenditure and main aggregates	gov_10a_main
General government expenditure by function (COFOG)	gov_10a_exp
Quarterly non-financial accounts for general government	gov_10q_ggnfa
Quarterly government debt	gov_10q_ggdebt
Financial balance sheets (annual)	nasa_10_f_bs
Financial balance sheets (quarterly)	nasq_10_f_bs
Non-financial transactions (annual)	nasa_10_nf_tr
Non-financial transactions (quarterly)	nasq_10_nf_tr
GDP and main components (output, expenditure and income)	namq_10_gdp
Money market interest rates (quarterly)	irt_st_q

Table 4: CBS Microdata tables for household sector calibration

Name	Code
Income of persons (annual, from tax declarations)	INPATAB
Income of households (annual, from tax declarations)	INHATAB
Wealth of households (annual, from tax declarations)	VEHTAB

INPATAB contains income data for all individuals in the Dutch population (available from 2011 onwards), INHATAB contains income data at the household level (available from 2011 onwards), and VEHTAB contains wealth data at the household level (available from 2006 onwards).

3.2 Macroeconomic Parameters

3.2.1 Census and Demography

The number of agents is calibrated from census and business demography data. We use Eurostat table cens_11an_r2 to set the number of economically active persons H^{act} to the 2011

⁶Data retrieved from Statistics Netherlands, <https://opendata.cbs.nl/#/CBS/en/>, accessed 22 March 2023.

value. The classification of industries follows the Statistical Classification of Economic Activities in the European Community (NACE Rev. 2). Eurostat compiles tables, including input–output tables, demographic data, and cross-classification tables, at a breakdown of 64 activities. We exclude sectors T (“Services of households as employers”) and U (“Services provided by extraterritorial organisations”), both of which have zero output in the Netherlands, giving $S = G = 62$ industries and products. The number of firms per industry I_s is set using business demography data (bd_9ac_1_form_r2). Following Poledna et al. (2023), we set the number of foreign firms importing domestic goods to 50% and the number of government entities to 25%, corresponding approximately to the shares of exports and government consumption in total value added.

3.2.2 Input–Output Tables

Parameters related to productivity, technology, capital formation, and consumption are calculated from input–output tables and updated annually. To calibrate the technology, consumption, and capital formation coefficients ($a_{sg}, b_g^{CF}, b_g^{HH}, b_g^{CFH}, c_g^G, c_g^E, c_g^I$) and the productivity coefficient of intermediate inputs and net tax rates ($\beta_i^M, \tau_i^Y, \tau_i^{PROD}$), we use the symmetric input–output table at basic prices (naio_10_cp1700). Parameters are computed by normalising the table columns. Figure 3 illustrates the Dutch input–output network aggregated to 19 sectors for readability; the model operates at the full 62-sector NACE Rev. 2 disaggregation.

Some parameters require both input–output tables and cross-classification data. The productivity coefficients for labour and capital ($\bar{a}_i, \kappa_i$), the depreciation rate (δ_i), and the average wage rate ($\bar{w}_i$) are calibrated by combining these sources.

3.2.3 Tax Rates and Sector Accounts

Tax rates are calculated from national accounting identities to match financial flows in the input–output tables, government statistics, and sector accounts. An average tax rate for an institutional sector (firms, households, etc.) is defined as the aggregate tax flow divided by the aggregate monetary flow constituting the tax base. Tax rates are computed per calendar year and applied uniformly across agents within each sector.⁷

The corporate profit tax rate τ^{FIRM} equals total corporate tax flows divided by total operating surplus and mixed income, sourced from sector accounts (nasa_10_nf_tr) and input–output tables respectively. Social security contribution rates for employers (τ^{SIF}) and employees (τ^{SIW}) are calibrated similarly. Value-added tax rates ($\tau^{VAT}, \tau^{CF}, \tau^G, \tau^{EXPORT}$) are obtained from input–output tables.

The dividend payout ratio θ^{DIV} equals interest and dividend receipts plus mixed income received by the household sector (nasa_10_nf_tr) divided by total net operating surplus and mixed income from input–output tables. The risk premium μ on firms’ outstanding debt is calculated as the difference between the 3-month Euribor rate (irt_st_q) and the ratio of observed interest payments to total liabilities of non-financial corporations (nasq_10_f_bs). The interest rate on government debt r^G is calibrated as interest due per quarter (gov_10q_ggnfa) divided by total government debt (gov_10q_ggdebt).

⁷The Netherlands has a progressive marginal tax system, which we abstract from for model parsimony.

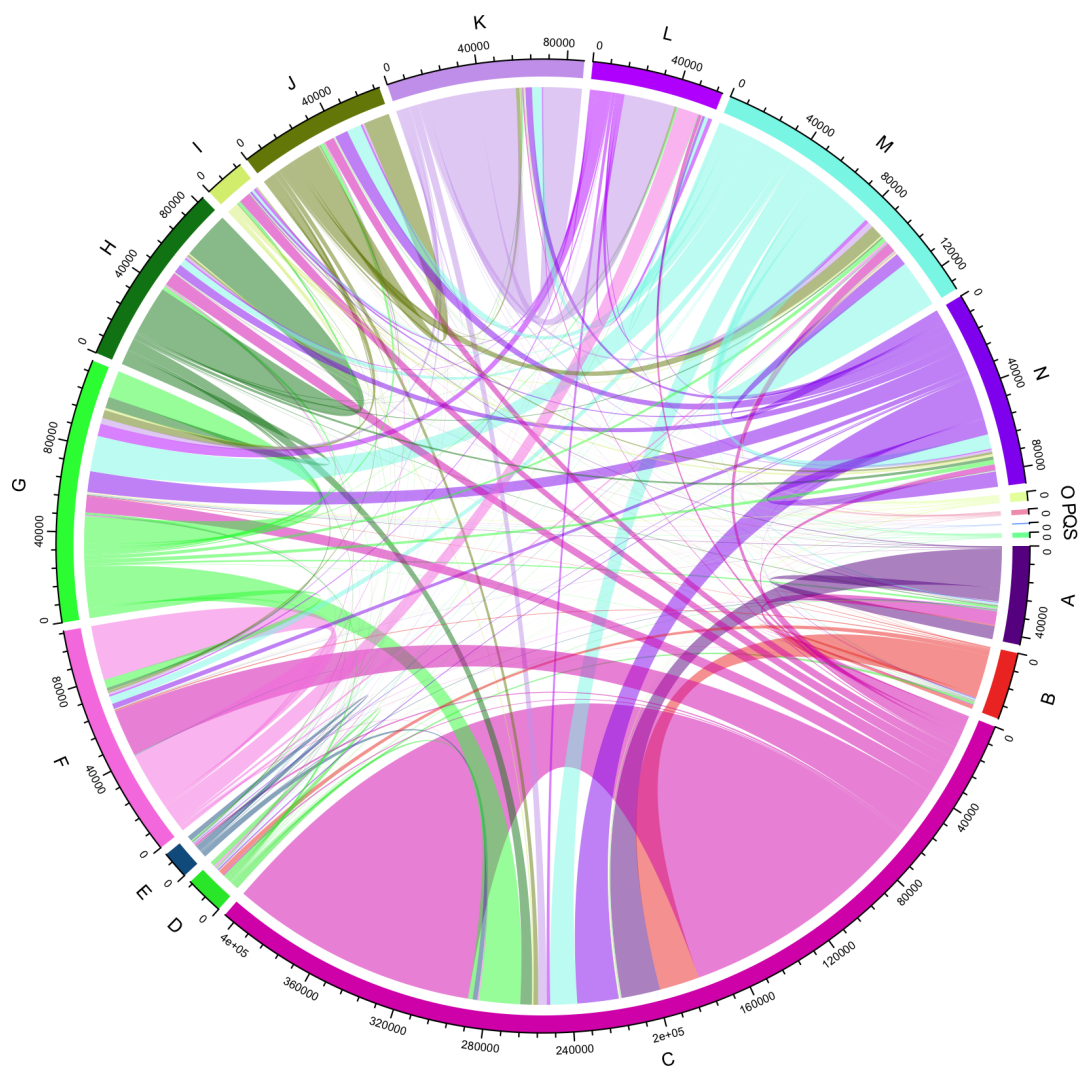


Figure 3: Intermediate consumption between 19 industries derived from Eurostat input-output tables, aggregated from the 62-sector NACE Rev. 2 classification used in the model.

A	Agriculture, forestry and fishing	H	Transportation and storage	O	Public administration and defence
B	Mining and quarrying	I	Accommodation and food service activities	P	Education
C	Manufacturing	J	Information and communication	Q	Human health and social work activities
D	Electricity, gas, steam and air conditioning supply	K	Financial and insurance activities	R	Arts, entertainment and recreation
E	Water supply	L	Real estate activities	S	Other service activities
F	Construction	M	Professional, scientific and technical activities		
G	Wholesale and retail trade	N	Administrative activities		

3.2.4 Institutional Guidelines and Banking Practices

Several parameters are set according to statutory guidelines and financial regulation. The capital ratio ζ follows Basel III requirements. The central bank inflation target π^* is 2%, per ECB statutes. The rate of debt instalment θ is 5% quarterly. The maximum loan-to-value ratio ζ^{LTV} is 60%, and the initial loan-to-value ratio for replacement firms ζ^b is 50%.

3.2.5 Exogenous Processes

Exogenous processes, including imports, exports, government consumption, euro area inflation, and euro area GDP growth, are estimated from national accounts (namq_10_gdp) and money market interest rates (irt_st_q) using data from 1997Q1 through the calibration quarter.

3.3 Initial Conditions

This section describes the initial conditions for all sectors. Table 6 reports reference values for 2010Q1; Table 7 reports sector-level aggregates.

3.3.1 Firms

The size distribution of firms in industrialised economies is highly skewed, with many small firms and few large ones (Axtell, 2001). Initial employment $N_{i,0}$ for firm i in industry s is sampled from a power-law distribution with exponent -2 (subject to $\sum_{i \in I_s} N_{i,0} = N_s$ and $N_{i,0} > 0$), following the parameterisation of Poledna et al. (2023).⁸

Initial production is determined by labour productivity:

$$Y_{i,0} = Q_{i,0}^d = \bar{\alpha}_i N_{i,0}. \quad (33)$$

The initial capital stock, where $K_{i,0}$ denotes the physical capital stock of firm i (distinct from household equity holdings $k_{h,t}$), is set to provide the firm's target reserve capacity:

$$K_{i,0} = \frac{Y_{i,0}}{\kappa_i \omega}. \quad (34)$$

Initial intermediate inputs are sized to meet expected usage plus a buffer stock:

$$M_{i,0} = \frac{Y_{i,0}}{\omega \beta_i^M}. \quad (35)$$

Cross-classification tables for financial assets by industry are not available at the NACE 64-sector level. We therefore allocate initial firm debt $L_{i,0}$ in proportion to capital:

$$L_{i,0} = L^I \frac{K_{i,0}}{\sum_{j=1}^I K_{j,0}}, \quad (36)$$

⁸As we currently lack access to data on the firm-size distribution in the Netherlands, we follow Poledna et al. (2023), who calibrate to Austrian data. A sensitivity analysis using alternative distributional assumptions is left for future work.

Table 5: Model parameters

Parameter	Description	Value	Source
G/S	Number of products/industries	62	census data, business demography data
H^{act}	Number of economically active persons	7860391	
H^{inact}	Number of economically inactive persons	3921200	
J	Number of government entities	152820	
L	Number of foreign consumers	305639	
I	Number of firms	1536974	Internal calibra- tion
β	Household discount rate	0.94	
$1/\sigma$	Intertemporal elasticity of substitution	0.7	
x_0	Size of transaction cost of investment	0.1	
x_1	Convexity of transaction cost of investment	1.5	
$\bar{\alpha}_i$	Average productivity of labour of the i^{th} firm	parameters are firm/sector specific; see table 12	input-output tables
κ_i	Productivity of capital of the i^{th} firm		
β_i	Productivity of intermediate consumption of the i^{th} firm		
δ_i	Depreciation rate for capital of the i^{th} firm		
$\bar{w}_i$	Average wage rate of firm i		
a_{sg}	Technology coefficient of the g^{th} product in the s^{th} industry		
$b_{g^{\text{CF}}}$	Capital formation coefficient of the g^{th} product (firm investment)		
$b_{g^{\text{CFH}}}$	Household investment coefficient of the g^{th} product		
$b_{g^{\text{HH}}}$	Consumption coefficient of the g^{th} product of households		
$c_{g^{\text{G}}}$	Consumption of the g^{th} product of the government in mln. Euro		
$c_{g^{\text{E}}}$	Exports of the g^{th} product in mln. Euro		
$c_{g^{\text{I}}}$	Imports of the g^{th} product in mln. Euro		
τ_i^{Y}	Net tax rate on products of the i^{th} firm		
τ_i^{K}	Net tax rate on production of the i^{th} firm		
τ^{INC}	Income tax rate	0.1715	government statistics, sector accounts
τ^{FIRM}	Corporate tax rate	0.0805	
τ^{VAT}	Value-added tax rate	0.1381	
τ^{SIF}	Social insurance rate (employers' contributions)	0.2922	
τ^{SIW}	Social insurance rate (employees' contributions)	0.1103	
τ^{EXPORT}	Export tax rate	0.0024	
τ^{CF}	Tax rate on capital formation	0.0969	
τ^{G}	Tax rate on government consumption	0.0019	
r^{G}	Interest rate on government bonds	0.0057	
μ	Risk premium on policy rate	0.0243	
ψ	Fraction of income devoted to consumption	0.8487	
ψ^{H}	Fraction of income devoted to investment in housing	0.0936	
θ^{DIV}	Dividend payout ratio	0.5354	
θ^{UB}	Unemployment benefit replacement rate	0.4054	Basel III, ECB statutes, banking practices, literature
θ	Rate of instalment on debt	0.05	
ζ	Banks' capital ratio	0.03	
ζ^{LTV}	Loan-to-value (LTV) ratio	0.6	
ζ^{b}	Loan-to-capital ratio for new firms after bankruptcy	0.5	
π^*	Inflation target of the monetary authority	0.005	national accounts (exogenously estimated)
α^{G}	Autoregressive coefficient for government consumption	0.9821	
β^{G}	Scalar constant for government consumption	0.1943	
σ^{G}	Standard deviation of government consumption	0.0095	
α^{E}	Autoregressive coefficient for exports	0.9747	
β^{E}	Scalar constant for exports	0.3029	
α^{I}	Autoregressive coefficient for imports	0.9664	
β^{I}	Scalar constant for imports	0.3963	
$\alpha^{\text{Y}^{\text{EA}}}$	Autoregressive coefficient for euro area GDP	0.9650	
$\beta^{\text{Y}^{\text{EA}}}$	Scalar constant for euro area GDP	0.5152	
$\alpha^{\pi^{\text{EA}}}$	Autoregressive coefficient for euro area inflation	0.3933	
$\beta^{\pi^{\text{EA}}}$	Scalar constant for euro area inflation	0.0024	
$\sigma^{\pi^{\text{EA}}}$	Standard deviation of euro area inflation	0.0023	
ρ	Adjustment coefficient of the policy rate	0.9287	
r^*	Real equilibrium interest rate	-0.0035	
ζ^{π}	Weight of the inflation target	0.2854	
ζ^{γ}	Weight of economic growth	1.3048	
C	Covariance matrix of euro area GDP and imports and exports		

Note: Model parameters for the reference quarter 2014:Q1. Exogenous autoregressive coefficients and parameters of the Taylor rule are estimated over the sample 1997:Q1 to 2014:Q1. Note that the number of agents are not scaled here.

Table 6: Initial conditions (reference values, 2010Q1)

Initial condition	Description	Value
$P_{i,0}$	Initial price of the i^{th} firm	1.00
$Y_{i,0}/Q_{i,0}^d$	Initial production/demand of the i^{th} firm (mln. Euro)	57,413.9
$K_{i,0}$	Initial capital of the i^{th} firm (mln. Euro)	6,849.5
$M_{i,0}$	Initial intermediate inputs of the i^{th} firm (mln. Euro)	1,094.0
$S_{i,0}$	Initial finished goods inventory of the i^{th} firm (mln. Euro)	0.00
$N_{i,0}$	Initial number of employees of the i^{th} firm	4.59
$D_{i,0}$	Initial deposits of the i^{th} firm (mln. Euro)	176,303.0
$L_{i,0}$	Initial debt of the i^{th} firm (mln. Euro)	782,191.0
$\Pi_{i,0}$	Initial profit of the i^{th} firm (mln. Euro)	67.21
$b_{h,0}$	Initial liquid assets (deposits) of the h^{th} household (mln. Euro)	367,679.0
$k_{h,0}$	Initial illiquid capital of the h^{th} household (mln. Euro)	925,403.0
$w_{h,0}$	Initial wage of the h^{th} household (mln. Euro)	29.77
sb_0^{inact}	Initial pension/social benefits (mln. Euro)	12.69
sb_0^{other}	Initial other social benefits (mln. Euro)	3.57
L_0^G	Initial government debt (mln. Euro)	359,255.0
Π_0^{bank}	Initial bank profit (mln. Euro)	26,733.0
E_0^{bank}	Initial bank equity (mln. Euro)	105,485.0
E_0^{CB}	Initial central bank equity (mln. Euro)	491,979.0
D_0^{RoW}	Initial net position with rest of world (mln. Euro)	0.00

Reference values for 2010Q1. The deposit and firm-debt entries reproduce the sector aggregates in Table 7 and cannot be interpreted as per-agent means.

Table 7: Initial conditions for institutional sectors (2010Q1)

Symbol	Description	Value
D^I	Firm sector deposits (mln. Euro)	176,303
L^I	Firm sector debt (mln. Euro)	782,191
ω	Desired capacity utilisation rate	0.85
D^H	Household sector liquid assets (mln. Euro)	367,679
K^H	Household sector capital (mln. Euro)	503,735

Initial conditions for 2010Q1.

where L^I is total firm debt from financial balance sheets (nasa_10_f_bs, loans F.4, non-financial corporations S.11, non-consolidated liabilities). Initial deposits D^I are also from financial balance sheets (nasa_10_f_bs, deposits F.2, S.11) and are distributed according to each firm's share of operating surplus:

$$D_{i,0} = D^I \frac{\max(\bar{\pi}_i Y_{i,0}, 0)}{\sum_{j=1}^I \max(\bar{\pi}_j Y_{j,0}, 0)}, \quad (37)$$

where the operating margin is $\bar{\pi}_i = 1 - (1 + \tau^{\text{SIF}})\bar{w}_i/\bar{\alpha}_i - \delta_i/\kappa_i - 1/\beta_i^M - \tau_i^{\text{PROD}} - \tau_i^Y$.⁹ Initial profits are:

$$\Pi_{i,0} = \bar{\pi}_i Y_{i,0} - \bar{r}_0 L_{i,0} + r_0 D_{i,0}, \quad (38)$$

where r_0 is the initial policy rate and $\bar{r}_0 = r_0 + \mu$ is the initial lending rate including the risk premium. Initial inventories of finished goods $S_{i,0}$ are set to zero (no reliable data available) and initial prices $P_{i,0}$ are normalised to one.

⁹Here τ_i^{PROD} is the net tax rate on production for industry i , obtained from input-output tables, distinct from the capital tax rate τ^K on illiquid asset returns in the household budget constraint (Section 2.2.2).

3.3.2 Households

We calibrate household initial conditions in two steps. First, following Poledna et al. (2023), we set aggregate positions from national accounts and disaggregate to the household level using income shares as a proxy for wealth. Second, we resample household wealth positions from the CBS microdata-based empirical distribution (Section 3.4.2).

Initial liquid assets $b_{h,0}$ are sourced from financial balance sheets (nasa_10_f_bs, deposits F.2, household and NPISH sector S14_S15) and disaggregated by income share:

$$b_{h,0} = D^H \frac{Y_{h,0}}{\sum_{j=1}^H Y_{j,0}}, \quad (39)$$

where $Y_{h,0}$ follows equation (4). Initial household capital $k_{h,0}$ is set to the value of dwellings (N111N) from balance sheets for non-financial assets (nama_10_nfa_st), disaggregated analogously:

$$k_{h,0} = K^H \frac{Y_{h,0}}{\sum_{j=1}^H Y_{j,0}}. \quad (40)$$

Initial wages are:

$$w_{h,0} = \begin{cases} \bar{w}_i & \text{if employed by firm } i, \\ w^{\text{UB}} / \theta^{\text{UB}} & \text{if unemployed,} \end{cases} \quad (41)$$

where θ^{UB} is the unemployment benefit replacement rate (Table 5). Initial unemployment benefits w^{UB} are computed as total unemployment payments (GF.1005, gov_10a_exp) divided by the number of unemployed persons (cens_11an_r2).

Government transfers to households in the form of social benefits (D.62) are allocated to household types based on employment status using COFOG-classified government expenditure data (gov_10a_exp). All social benefits sb_0^{inact} and sb_0^{other} are distributed in equal proportion across household types, ensuring individual flows sum to total macroeconomic flows. Net transfers other than consumption, savings, taxes, and subsidies, comprising property and interest income (D.4), other current transfers (D.7), adjustments for changes in pension entitlements (D.8), and capital transfers other than capital taxes (D.9 – D.91), are treated as a net transfer from the government to the household sector.

3.3.3 Government, Bank, and Central Bank

Initial government debt L_0^G equals consolidated gross debt (GD) of the Dutch government (S.13) from the government deficit/surplus dataset (gov_10dd_edpt1).

Initial bank equity E_0^{bank} is sourced from financial balance sheets (nasa_10_f_bs, equity F.5 and financial net worth BF.90, monetary financial institutions excl. the central bank, S122_S123). Initial bank profit is:

$$\Pi_0^{\text{bank}} = \bar{r}_0 \sum_{j=1}^I L_{j,0} - r_0 \left(\sum_{j=1}^I D_{j,0} + \sum_{j=1}^H b_{j,0} \right), \quad (42)$$

where initial advances from the central bank D_0^{bank} are determined according to equation (97).

Initial central bank equity E_0^{CB} is the residual on the central bank's balance sheet: assets (government debt L_0^G) minus liabilities (bank reserves D_0^{bank} and the net position with the rest of the world D_0^{RoW}), computed according to equation (105). The initial balance of trade with the rest of the world is assumed to be zero.

3.4 Household Sector Calibration

The national-accounts-based disaggregation described above assigns wealth in proportion to income, which cannot capture the rich joint distribution of income, liquid wealth, and illiquid wealth that Kaplan et al. (2014) and Fagereng et al. (2021) show is critical for realistic MPC heterogeneity. This section describes how we use CBS microdata to overcome this limitation.

3.4.1 Liquid and Illiquid Asset Classification

We map the diverse household balance sheets in the CBS microdata to the two asset categories of the model. Following Statistics Netherlands conventions, we classify net liquid assets $b_{h,t}$ as all deposits in checking and savings accounts (VEHW1111BANH). Illiquid assets $k_{h,t}$ are defined as the difference between net wealth (VEHW1000VERH) and liquid assets, comprising real estate wealth net of mortgage debt, financial assets including government bonds, corporate and private equity, and remaining properties.

3.4.2 Empirical Distribution

We estimate the empirical joint density of household income, liquid wealth, and illiquid wealth using CBS microdata. These three dimensions correspond directly to the state variables in the household optimisation problem: wages $w_{h,t}$, deposits $b_{h,t}$, and capital $k_{h,t}$. The empirical distribution serves two purposes: initialising the model so that the simulated agent distribution matches observed data, and providing the sampling ranges for neural network training (Section 2.3).

We combine three datasets by linking them using personal identification numbers: personal income (INPATAB), household income (INHATAB), and household wealth (VEHTAB), for the years 2011–2019; for 2010, we use the 2011 distribution as earlier data are unavailable. Household income $Y_{h,t}$ is constructed from personal income data and aggregated to the household level. Due to data privacy regulations, we apply a cutoff to the upper tail to prevent inference about the highest incomes when extracting data from the CBS servers.

We define bin edges X_j for $j \in \{1, \dots, 51\}$, yielding 50 bins per dimension and $50^3 = 125,000$ three-dimensional bins. With approximately 170,000 model households, many bins are sparsely populated or empty; we treat empty bins as having zero probability, so households are never sampled into unobserved wealth–income combinations. Increasing the number of bins would exacerbate sparsity without improving density estimation. We compute the three-dimensional histogram and normalise it to obtain the empirical joint density $f(w, k, b)$.

Conditional Sampling Procedure. The labour market module inherited from Poledna et al. (2023) assigns wages based on sectoral affiliation, which precludes substantial within-sector wage heterogeneity. To reconcile this with the empirical wealth distribution, we employ a two-step conditional sampling procedure:

1. **Wage assignment:** Household h receives wage $w_{h,0}$ from the sectoral wage structure of Poledna et al. (2023): employed households receive the firm-specific wage $\bar{w}_i$; unemployed households receive unemployment benefits.
2. **Conditional wealth draw:** Given $w_{h,0}$, we draw capital and deposit holdings from the conditional distribution:

$$(k_{h,0}, b_{h,0}) \sim f(k, b \mid w = w_{h,0}), \quad (43)$$

where the conditional density is computed from the empirical joint histogram by summing over the k and b bins for the wage bin containing $w_{h,0}$:

$$f(k, b \mid w) = \frac{f(w, k, b)}{\sum_{k'} \sum_{b'} f(w, k', b')}. \quad (44)$$

This preserves the empirical correlation between income and wealth: high-wage households are more likely to hold larger capital and deposit positions, consistent with the positive income–wealth correlation in the microdata. In practice, we identify the wage bin containing $w_{h,0}$ and sample $(k_{h,0}, b_{h,0})$ from the corresponding two-dimensional slice of the histogram. If a wage falls outside the observed range, we use the nearest boundary bin. The procedure is applied separately for each quarterly period using the corresponding year’s microdata.

Generalising this approach to allow within-sector wage heterogeneity, sampling from the full joint distribution $f(w, k, b)$ rather than conditioning on pre-assigned wages, would require modifications to the labour market module, which is beyond the scope of this paper.

3.4.3 Calibration of the Household Policy Functions

The neural network solution method described in Section 2.3 produces household policy functions parameterised by the preference vector Γ . Estimation uses a two-stage procedure: approximate Euler-policy training followed by preference calibration with the policy network fixed. The figures below report two supplementary calibration experiments (No χ /With χ); they are not the forecast calibration.

Figure 5 presents calibrated parameters across the 40 quarterly periods (2010Q1–2019Q4) for two supplementary experiments: four parameters with fixed deposit-policy coefficients (No χ), and six parameters with those coefficients estimated (With χ). The panels use the experiment’s notation $\gamma, \beta, \psi, c_i, \chi_b^0$ and χ_b^1 : γ is relative risk aversion (σ in Section 2.2.2), ψ a solver input that does not enter the CRRA preferences, c_i the subsistence intercept c_{int} , and χ_b^0, χ_b^1 the bond-convenience coefficients χ_0^b, χ_1^b .

The forecast calibration targets a windfall income MPC of 0.33, capital and deposit MPCs of 0.047 and 0.04, and an APC of 0.8958; quarter-specific APCs from national accounts lie at approximately 0.89–0.92. These targets differ from those of the supplementary experiments. The 2016Q1 policy has $\beta = 0.959$ and risk aversion $\sigma = 2.277$; these are values for one quarter, not estimated quarterly medians.

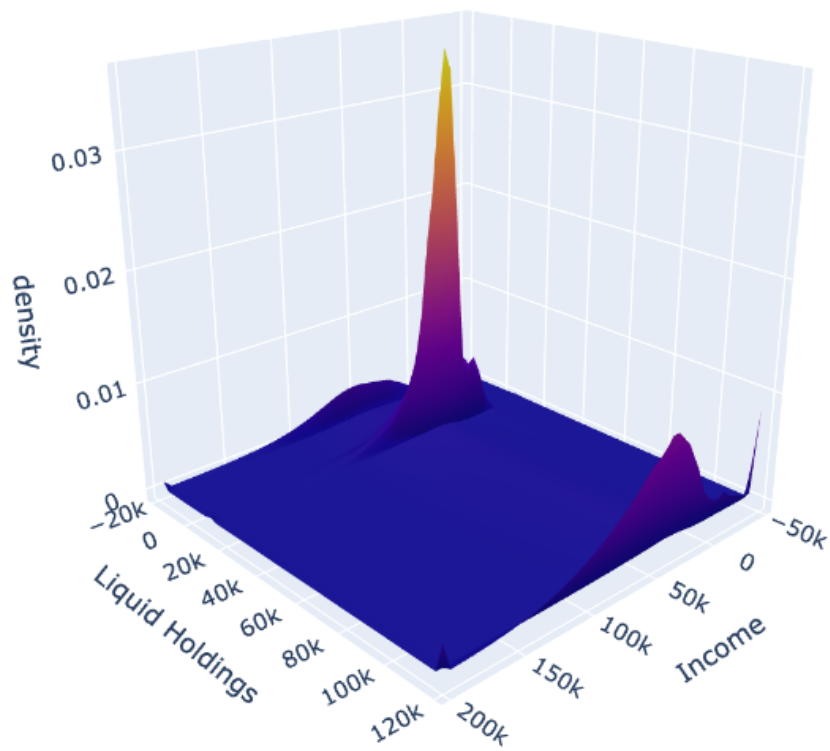


Figure 4: Empirical joint distribution of household income (w), liquid wealth (b), and illiquid wealth (k), constructed from CBS microdata for 2011–2019. A cutoff is applied to the upper tail to comply with data privacy regulations. Conditional slices (fixing w) are used to sample household wealth positions given assigned wages.

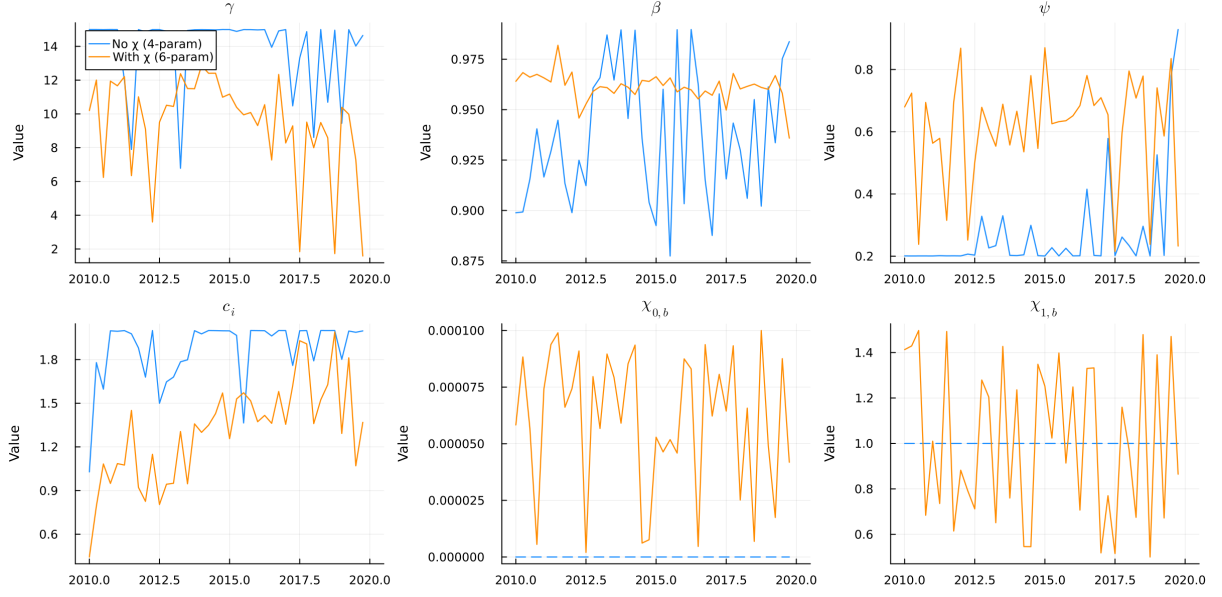


Figure 5: Supplementary two-stage calibration parameters across quarters (2010Q1–2019Q4): four-parameter No χ (blue) and six-parameter With χ (orange). Panels show γ , β , ψ , c_i , χ_b^0 and χ_b^1 in the experiment's notation. These are separate diagnostics, not the forecast calibration.

The No χ experiment fixes the deposit-policy coefficients at $\chi_0^b = 0$ and $\chi_1^b = 1$, whereas With χ estimates them jointly with the other parameters.

Figure 6 displays achieved moments for the two supplementary specifications. Dashed lines indicate targets: $MPC_y = 0.20$, $MPC_k = MPC_b = 0.02$, and quarter-specific APC and capital-to-deposits ratios. The fit varies over time and differs between specifications, particularly for APC.

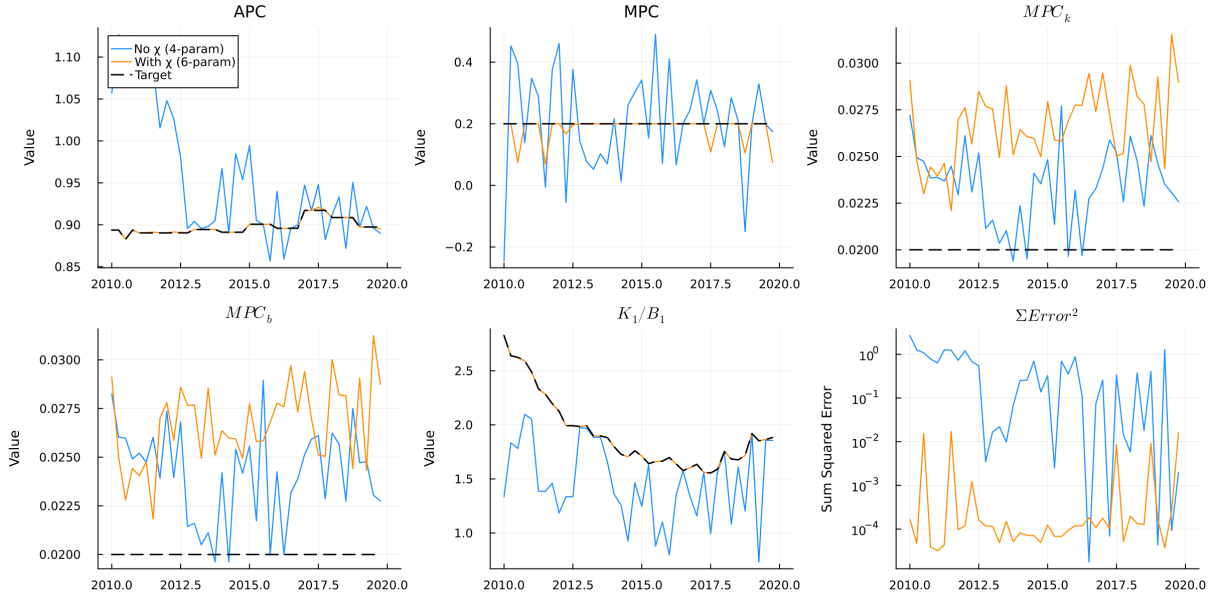


Figure 6: Moment achievement across quarters for the supplementary four-parameter No χ and six-parameter With χ experiments. Dashed lines indicate empirical targets; coloured lines show model-implied values. Panels display average propensity to consume (APC), marginal propensity to consume out of income (MPC), marginal propensities with respect to capital (MPC_k) and bonds (MPC_b), the capital-to-bond ratio (K_1/B_1), and the sum of squared moment errors on a logarithmic scale.

The bottom-right panel of Figure 6 reports squared moment errors on a logarithmic scale. The six-parameter experiment generally has lower loss than the four-parameter experiment. This comparison concerns the supplementary calibrations, not the forecasting policy described in Section 2.3.

The forecasting exercises in Section 4 use the two-account Euler policy. The network is held fixed during rollout while household beliefs are updated.

4 Comparison of Forecast Results

Forecasting performance provides an external validity test for agent-based models: if a structurally richer model cannot outpredict parsimonious benchmarks, its additional complexity is not justified by the data. Conversely, forecast gains that concentrate in specific variables or horizons can motivate hypotheses about which structural features carry empirical content. We therefore evaluate whether the optimal-consumption household block introduced in Section 2.2.2 improves out-of-sample prediction, and at which horizons and for which variables the gains materialise.

We compare the OC-ABM, the base ABM of Poledna et al. (2023), and ten heuristic extensions (H1-ABM to H10-ABM) against four time-series benchmarks: AR(1), ARX(1), VAR(1), and VARX(1). Each ABM variant is combined with all four aggregate expectation mechanisms (Section 2.6), yielding twelve model $\times$ four mechanism combinations evaluated against the corresponding univariate and multivariate benchmarks. The heuristics allow liquid dissaving to a flat floor; the OC-ABM uses an income-dependent floor (Section 2.4); H8–H10 additionally vary capital-return MPC scaling and portfolio choice, to show which household features carry predictive content (Section 4.3).

We forecast real GDP, household consumption, investment, government consumption, exports, imports, Euro area real GDP and inflation, and the Euribor rate. GDP, household consumption, investment, government consumption, exports, imports, and Euro area GDP are entered as log levels. Inflation for the Netherlands and the Euro area is entered as the first difference of the log GDP deflator. The Euribor rate is entered as the quarterly rate. All time-series benchmarks are initially estimated over 1997Q1–2010Q1 and re-estimated each quarter through 2019Q4, so that the forecast origin advances with the data. Each ABM is calibrated to the corresponding reference quarter. In the ARX and VARX specifications, the 12-quarter-ahead paths of exogenous variables (imports, exports, government consumption, Euro area GDP growth, Euro area inflation, and the Euribor rate) are constructed as iterated forecasts from models estimated at the forecast origin, using information dated at the origin within a retrospective-data exercise; results are similar when treating these paths as known, though a systematic comparison is beyond the scope of this paper. We restrict the evaluation sample to the pre-COVID period 2010Q1–2019Q4 (40 candidate reference quarters). Targets beyond 2019Q4 are excluded, leaving 39, 38, 36, 32 and 28 eligible origins at horizons 1, 2, 4, 8 and 12 quarters respectively. The OC forecasts hold network weights fixed while household beliefs update. All models are scored against the same actuals and benchmark forecasts at identical evaluation dates and targets; calibration, random draws and borrowing constraints differ across models. We select the AR(1), ARX(1), VAR(1), and VARX(1) specifications because they minimise both the Akaike and Bayesian information criteria over the initial estimation sample.

Because ABM simulations are stochastic, we average over 100 Monte Carlo draws per reference

quarter to obtain the point forecast. The shading in the time-series figures depicts simulation-path dispersion; its nominal coverage is unverified and it is not a confidence interval for the ensemble mean. We measure accuracy by the root mean squared forecast error (RMSFE),

$$\text{RMSFE} = \sqrt{\frac{1}{T} \sum_{t=1}^T (\hat{x}_t - x_t)^2}, \quad (45)$$

where $\hat{x}_t$ is the forecast and x_t the realisation. We report percentage improvements in RMSFE relative to the benchmark,

$$\Delta\text{RMSFE} = \frac{\text{RMSFE}_{\text{benchmark}} - \text{RMSFE}_{\text{ABM}}}{\text{RMSFE}_{\text{benchmark}}} \times 100, \quad (46)$$

so that positive values indicate the ABM variant is more accurate. To test whether forecast accuracy differs significantly, we apply the modified Diebold–Mariano test of Harvey et al. (1997), which incorporates a small-sample correction. The test statistic is computed on the loss differential (difference between squared forecast errors) using Bartlett Newey–West standard errors through lag $h - 1$ to account for serial correlation in overlapping multi-period forecasts (Diebold and Mariano, 1995). Because the ABM and time-series benchmarks belong to different model classes, they are non-nested and the standard Diebold–Mariano test is appropriate without the Clark–West (2007) size correction. Two-sided p -values use the Harvey–Leybourne–Newbold correction and Student- t critical values with $n_h - 1$ degrees of freedom. Corrected tests do not reject equal twelve-quarter consumption accuracy against the matched univariate benchmarks. Apart from the Holm-corrected twelve-quarter tests for GDP, consumption and investment, the remaining tests are exploratory nominal comparisons. Each test compares one ABM with its benchmark, not ABM variants with each other.

Figure 7 summarises the OC-ABM’s twelve-quarter RMSFE improvements across all four expectation mechanisms against matched univariate benchmarks. Six patterns emerge. First, consumption gains range from 40.5% to 54.2%, but corrected tests do not reject equal accuracy ($p = 0.455\text{--}0.489$). Second, GDP gains of 31.0–40.1% are directionally positive and imprecisely estimated. Third, investment gains of 14.5–15.5% are significant ($p \leq 0.0014$) and remain significant at 5% after a Holm correction across the twelve twelve-quarter tests for GDP, consumption and investment. Fourth, inflation and Euribor show small, mixed point estimates against the univariate benchmarks. Fifth, under AR expectations the OC-ABM has larger consumption and GDP point estimates than the heuristic alternatives, without a direct model-difference test. Sixth, the consumption gains are larger under AR and VAR than under ARX and VARX. The per-mechanism results appear in Section 4.1, Section 4.2 and Appendix F.

Euribor	0.20	-1.9%	2.1%	-2.6%	2.3%
Investment	13.27	14.9%	14.6%	15.5%	14.5%
Consumption	3.68	49.7%	42.6%	54.2%	40.5%
Inflation	0.60	0.2%	-1.7%	1.6%	-1.8%
GDP	3.47	38.3%	34.0%	40.1%	31.0%
	AR(1) RMSFE	OC-ABM AR / AR(1)	OC-ABM ARX / ARX(1)	OC-ABM VAR / AR(1)	OC-ABM VARX / ARX(1)

Figure 7: Twelve-quarter OC-ABM RMSFE reductions relative to matched univariate benchmarks: AR(1) for AR and VAR expectations, ARX(1) for ARX and VARX. Grey column: AR(1) RMSFE multiplied by 100; coloured columns: percentage improvements (green) or losses (red). Evaluation uses 28 origins (2010Q1–2016Q4), targets through 2019Q4, and 100 paths per origin. Consumption gains are point estimates; corrected tests do not reject equal accuracy.

Twelve-quarter tests have low power. Consecutive forecast errors share eleven realised quarters, and the consumption loss differentials have first-order autocorrelations of 0.61–0.84, so the 28 overlapping origins carry roughly five to eight independent observations (the ratio of the sample variance to the Bartlett long-run variance used in the test, times 28). Had the OC-ABM forecast consumption without error at every origin, the corrected test against the matched benchmark would still give $p = 0.21$ – 0.31 . Non-rejection is therefore weak evidence of equal accuracy.

Table 8 splits the same errors by target period. Targets in 2013–2014, the trough of Dutch household consumption after the sovereign-debt crisis, account for most of the consumption gain: the OC-ABM reduces RMSFE by 75.8–83.3%, and the habit heuristics H5 and H6 reach 71.4–78.0%. For targets in 2015–2019 the OC-ABM is within 10.2% of the benchmark, whereas every other ABM specification loses at least 30%. The OC-ABM is thus the only specification that captures the trough without a large penalty in the subsequent recovery. The split was chosen after evaluation and is descriptive. With a single downturn in the sample, it does not establish that the OC-ABM forecasts downturns more accurately in general.

Table 8: Twelve-quarter household-consumption RMSFE by target period, relative to matched univariate benchmarks

Targets	AR vs. AR(1)		ARX vs. ARX(1)		VAR vs. AR(1)		VARX vs. ARX(1)	
	2013–14	2015–19	2013–14	2015–19	2013–14	2015–19	2013–14	2015–19
Base ABM	15.9	-30.0	9.6	-42.0	18.6	-35.0	13.7	-44.4
H1	-62.5	-755.0	-74.7	-634.0	-48.6	-720.7	-75.5	-639.7
H2	-70.7	-787.9	-86.3	-666.2	-53.3	-751.7	-87.6	-664.6
H3	39.2	-166.3	36.8	-133.6	46.8	-152.8	36.1	-136.3
H4	34.7	-190.7	32.3	-149.3	44.1	-167.7	30.9	-150.2
H5	78.0	-194.9	74.5	-173.4	75.0	-184.3	75.1	-173.0
H6	76.2	-52.7	71.7	-52.0	74.5	-48.3	71.4	-50.5
H7	34.6	-47.8	17.7	-36.9	27.6	-45.7	19.9	-38.6
H8	37.9	-57.4	20.9	-38.4	31.2	-50.2	20.8	-39.9
H9	65.1	-58.9	53.0	-45.8	59.7	-53.2	56.6	-45.7
H10	66.5	-71.0	52.1	-47.9	58.3	-53.1	58.0	-44.6
OC-ABM	79.6	-10.2	75.8	-0.6	83.3	-1.7	76.3	-5.0

Percentage RMSFE improvements (+) or losses (–) relative to the matched benchmark. Origins 2010Q1–2011Q4 (8) target 2013–2014; origins 2012Q1–2016Q4 (20) target 2015–2019. Same forecasts as Figure 7; the split by target year was chosen after evaluation. No significance tests are reported for the subsamples.

4.1 AR expectations

Under AR expectations, aggregate variables follow univariate AR(1) processes updated each period. This is the simplest expectation mechanism and provides a parsimonious comparison of whether the extended household block, without multivariate or exogenous information, improves forecasts.

Figure 8 displays the 12-quarter relative RMSFE for the nine specifications in the core panel (base ABM, H1–H7 and OC-ABM) under AR expectations. The OC-ABM achieves a 49.7% ($p = 0.481$) consumption improvement and a 38.3% ($p = 0.577$) GDP improvement. These are the largest consumption and GDP point estimates in this panel, but neither rejects equal accuracy against AR(1). Among heuristic models, H6 produces the largest consumption point estimate (+31.6%, $p = 0.662$), while H7 gains 13.7% ($p = 0.756$). Static H1–H4 show consumption losses ranging from –25.9% to –307.9%. The OC policy and the heuristics differ in their borrowing constraints, calibration and policy structure.

Euribor	-0.5%	-5.5%	-2.7%	-3.4%	-2.8%	-2.4%	-1.5%	-3.2%	-1.9%
Investment	4.6%	-14.0%	-14.8%	6.5%	5.6%	4.2%	8.2%	6.9%	14.9%
Consumption	5.9%	-292.2%	-307.9%	-25.9%	-37.0%	-27.0%	31.6%	13.7%	49.7%
Inflation	0.3%	-2.4%	0.8%	-3.4%	-0.7%	1.4%	0.7%	-1.4%	0.2%
GDP	5.8%	-91.9%	-96.9%	6.2%	-0.4%	-4.0%	17.1%	11.2%	38.3%
	Base	H1	H2	H3	H4	H5	H6	H7	OC-ABM

Figure 8: Twelve-quarter relative RMSFE of the base ABM, core heuristics H1–H7 and OC-ABM under AR expectations, relative to AR(1). Evaluation uses 28 eligible origins (2010Q1–2016Q4) and 100 paths per origin; positive values indicate lower RMSFE. Dashed outlines mark H6 (black) and OC-ABM (red).

Table 9 compares the ABMs against the univariate AR(1). The OC-ABM underperforms in household consumption at 1–4 quarters and improves at longer horizons. At 12 quarters it reduces household-consumption RMSFE by 49.7% ($p = 0.481$) and investment RMSFE by 14.9% ($p < 0.001$). The GDP gain of 38.3% ($p = 0.577$) is directionally positive but imprecisely estimated. Investment gains emerge earlier, reaching 16.2% ($p < 0.001$) at eight quarters. The base ABM gains 5.9% ($p = 0.807$) in consumption at twelve quarters.

Table 9: Forecast performance under AR expectations, relative to AR(1)

	GDP	Inflation	Household cons.	Investment	Euribor
AR(1)	<i>RMSFE for different forecast horizons</i>				
1q	0.41	0.57	0.56	3.3	0.03
2q	0.67	0.57	0.82	4.48	0.06
4q	1.32	0.56	1.47	6.21	0.11
8q	2.59	0.58	2.72	9.61	0.16
12q	3.47	0.6	3.68	13.27	0.2
ABM	<i>Percentage improvements (+) or losses (-) relative to AR(1) model</i>				
1q	-2.1 (0.811)	-1.4 (0.671)	5.2 (0.374)	8.8 (0.263)	-80.9*** (< 0.001)
2q	-10.2 (0.516)	1.4 (0.498)	-0.9 (0.916)	0.8 (0.853)	-37.1** (0.021)
4q	-27.7 (0.385)	-3.3*** (0.003)	-1.2 (0.960)	-5.1 (0.522)	-14.3 (0.409)
8q	7.1 (0.860)	0.9 (0.694)	8.7 (0.754)	2.8 (0.546)	-7.9 (0.771)
12q	5.8 (0.899)	0.3 (0.902)	5.9 (0.807)	4.6* (0.086)	-0.5 (0.988)
H6-ABM	<i>Percentage improvements (+) or losses (-) relative to AR(1) model</i>				
1q	-2.0 (0.818)	-1.4 (0.671)	-2.9 (0.711)	8.8 (0.263)	-80.9*** (< 0.001)
2q	-5.8 (0.712)	-1.0 (0.625)	10.1* (0.077)	1.4 (0.741)	-39.1*** (0.010)
4q	-22.4 (0.472)	-1.5 (0.357)	10.9 (0.617)	-4.8 (0.517)	-17.4 (0.274)
8q	14.3 (0.749)	-1.2 (0.469)	20.0 (0.645)	7.0* (0.090)	-8.4 (0.748)
12q	17.1 (0.798)	0.7 (0.748)	31.6 (0.662)	8.2** (0.011)	-1.5 (0.965)
OC-ABM	<i>Percentage improvements (+) or losses (-) relative to AR(1) model</i>				
1q	-2.8 (0.749)	-0.9 (0.789)	-93.5*** (0.001)	8.9 (0.264)	-82.2*** (< 0.001)
2q	-14.3 (0.475)	0.8 (0.541)	-129.0*** (0.008)	1.3 (0.757)	-40.1*** (0.006)
4q	-23.6 (0.464)	-0.8 (0.577)	-33.7* (0.067)	-0.3 (0.978)	-19.4 (0.192)
8q	43.3 (0.379)	-0.3 (0.792)	20.3 (0.614)	16.2*** (< 0.001)	-9.5 (0.718)
12q	38.3 (0.577)	0.2 (0.898)	49.7 (0.481)	14.9*** (< 0.001)	-1.9 (0.958)

ABMs under AR expectations vs. AR(1). See Section 4 for estimation details. Diebold–Mariano p -values in parentheses; *, **, ***: 10%, 5%, 1% significance.

Figures 9 and 10 show quarterly OC-ABM forecasts under AR expectations from two origins: one during the Eurocrisis (2012Q1, through 2015Q1) and one during the recovery (2015Q1, through 2018Q1). These are separate 12-quarter forecasts, not a partition of the evaluation sample.

From the 2012Q1 origin (Figure 9), the OC-ABM forecasts broadly flat household consumption, close to the realised stagnation of 2012–2014, whereas the AR(1) extrapolates the earlier trend and overpredicts consumption by about €3 billion per quarter by 2015. The OC-ABM also tracks GDP closely, while the AR(1) overpredicts it. Neither model captures the 2013 investment dip, and the OC-ABM underpredicts the growth of exports and imports.

From the 2015Q1 origin (Figure 10), the OC-ABM starts about €2 billion below realised GDP and €1 billion below household consumption, which illustrates its weaker short-horizon accuracy. Its paths then converge towards the data, and its consumption forecast matches realised consumption from 2017, while the AR(1) tracks both series closely throughout. Neither model anticipates the one-quarter investment and import spike in 2015Q2.

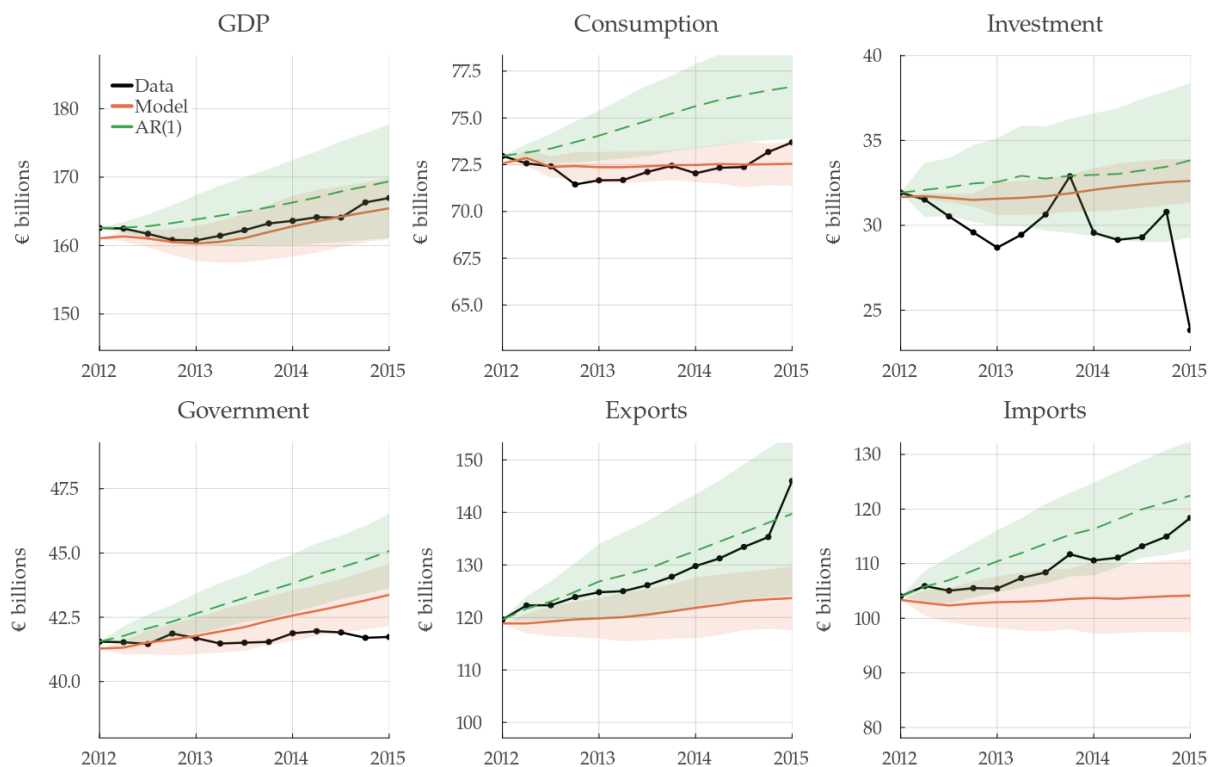


Figure 9: Quarterly forecasts from 2012Q1 to 2015Q1 (Eurocrisis period) under AR expectations: OC-ABM (red), AR(1) (green dashed) and realised Eurostat data (black). Real levels in € billions. Lines show means and shaded areas ± 1 standard deviation across 100 simulations; nominal coverage is unverified.

4.2 Robustness across expectation mechanisms

The household-consumption point-estimate gain holds under each of the three remaining expectation mechanisms. At twelve quarters the OC-ABM achieves reductions of 42.6% ($p = 0.465$) under ARX, 54.2% ($p = 0.455$) under VAR, and 40.5% ($p = 0.489$) under VARX, relative to matched univariate benchmarks. Against multivariate benchmarks, the reductions reach 53.8% under ARX, 57.2% under VAR and 52.2% under VARX. The ARX/VARX comparisons with VARX(1) are nominally significant ($p < 0.001$), whereas the VAR comparison with VAR(1) is not ($p = 0.145$). These secondary comparisons remain exploratory. Investment gains range from 14.5% to 15.5% and are significant ($p \leq 0.0014$); GDP gains of 31.0–40.1% are positive but do not reject equal accuracy. Appendix F reports full tables and mechanism heatmaps.

The consumption point estimates are larger under mechanisms without exogenous predictors (49.7% under AR and 54.2% under VAR) than under ARX and VARX (42.6% and 40.5%). Across the heuristic ladder, H6 produces the largest consumption gains (+15.4% under ARX, +31.6% under AR, +32.9% under VAR and +16.1% under VARX), below the OC-ABM in each comparison. H7 gains under AR and VAR but has small losses under ARX and VARX. Static and habit H1–H5 lose between 18% and 338% across these matched univariate comparisons. The OC-ABM has positive point estimates under all four mechanisms, but its corrected benchmark tests do not reject equal consumption accuracy.

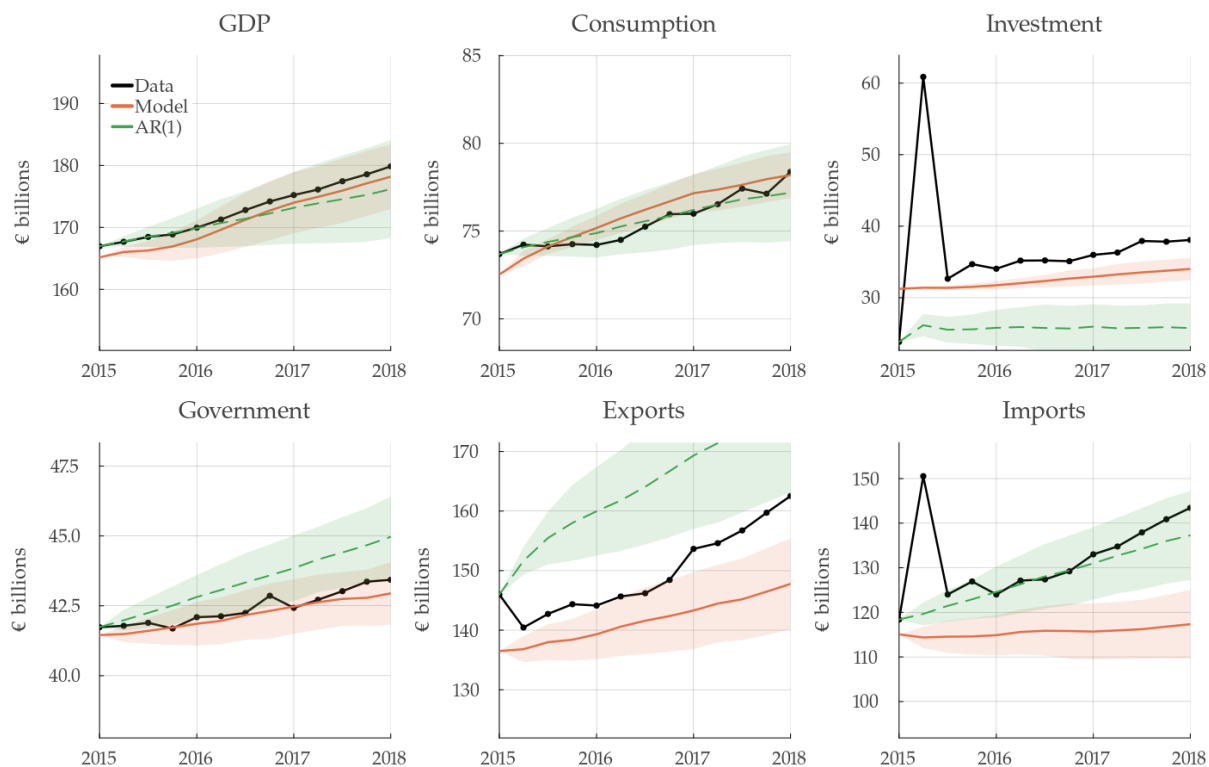


Figure 10: Quarterly forecasts from 2015Q1 to 2018Q1 (recovery period) under AR expectations: OC-ABM (red), AR(1) (green dashed) and realised Eurostat data (black). Real levels in € billions. Lines show means and shaded areas ± 1 standard deviation across 100 simulations; nominal coverage is unverified.

4.3 Channel comparisons

The H1–H7 ladder allows liquid dissaving down to a flat floor, whereas the OC-ABM uses an income-dependent floor. Other differences include capital-return sensitivity, portfolio choice, calibration, adjustment costs and the approximate Euler-policy framework (Section 2.4, Table 2). H8 and H9 vary capital-return scaling and portfolio choice within the heuristic class, and H10 combines them.

Table 10 reports the 12-quarter consumption RMSFE for the channel-decomposition heuristics, the H7 baseline, and the OC-ABM relative to the AR(1) benchmark. Three findings emerge. First, capital-return MPC scaling changes the consumption point estimate little: H8 produces +12.6% versus H7's +13.7%, a difference of 1.1 pp; no direct equivalence test is reported. This is consistent with the empirical evidence that capital-return income is small relative to labour income for the median household and varies little within the 2010–2019 evaluation sample. Second, adding a Merton portfolio target raises the consumption point estimate: H9 reaches +25.4%, an 11.7 pp gain over H7 that remains below the OC-ABM's +49.7% improvement. State-contingent portfolio rebalancing toward a Merton target, rather than holding the liquid/illiquid split fixed at the calibration ratio, is therefore a relevant specification difference at the point-estimate level. Third, the combined variant H10 (+21.2%) lies between H8 and H9 rather than exceeding both, suggesting that the two changes interact in this specification; their separate causal contributions are not identified.

Table 10: Channel comparisons: 12-quarter consumption RMSFE under AR expectations vs. AR(1)

Model	Specification change	Δ RMSFE (%)	DM p -value
H7 (Deaton buffer-stock)	—	+13.7	0.756
H8 (cap-split)	Capital-return MPC scaling	+12.6	0.795
H9 (Merton)	Merton portfolio target	+25.4	0.712
H10 (combined)	Both extensions	+21.2	0.764
OC-ABM (Euler)	Optimising policy approximation	+49.7	0.481

Note: 12-quarter household consumption RMSFE relative to AR(1) under AR expectations, evaluated at 28 eligible origins (2010Q1–2016Q4), with targets through 2019Q4 and 100 Monte Carlo paths per origin. All heuristics share the H7 flat borrowing floor; the OC-ABM has a different income-dependent floor. H8 partitions the income aggregate by Equation (22) with $\alpha_{\text{cap}} = 0.5$. H9 implements the Merton portfolio rule of Equations (23)–(24). H10 combines both. Corrected two-sided Diebold–Mariano p -values use Bartlett HAC covariances and the correction of Harvey et al. (1997). These tests compare each model with AR(1), not with another ABM variant.

The remaining gap between H9 (25.4%, $p = 0.712$) and the OC-ABM (49.7%, $p = 0.481$) is consistent with a contribution from the Euler restrictions; a controlled comparison with matched constraints and calibration would test it directly.

Taken together, the channel comparisons suggest a role for dynamic household rules and portfolio choice in the point estimates: H9 gains +11.7 pp over H7, capital-return scaling alone changes the gain little, and H10 does not exceed H9.

4.4 Sectoral forecasts

The ABM’s multi-sector structure enables forecasting at a level of granularity unavailable to aggregate time-series models. We exploit this to test whether ABM gains concentrate in specific sectors, which can shed light on the structural channels driving aggregate improvements. We decompose the model into ten sectors following the statistical classification of economic activities (NACE Rev. 2) and forecast log levels of nominal sectoral gross value added (GVA).

We benchmark against sector-specific AR(1) models, selected by information criteria, estimated from 1997Q1 to 2010Q1 and re-estimated quarterly through 2019Q4. Under AR expectations, we compare the base ABM, H6-ABM (the best-performing heuristic for aggregate consumption), and OC-ABM.

Table 11: Sectoral GVA forecast performance under AR expectations, relative to AR(1)

	A	B-E	F	G-I	J	K	L	M-N	O-Q	R-S
AR(1)	<i>RMSFE for different forecast horizons</i>									
1q	1.2	0.68	0.79	0.98	1.28	1.12	1.15	1.12	1.01	1.22
2q	0.97	1.14	1.52	1.91	2.64	2.17	1.88	2.26	2.08	2.14
4q	1.36	2.23	2.94	3.8	5.34	4.22	3.11	4.52	4.24	4.11
8q	2.49	4.26	5.54	7.59	10.75	8.15	5.72	9.01	8.5	7.89
12q	3.92	6.11	8.21	11.41	16.13	11.68	8.8	13.54	12.6	11.48
ABM	<i>Percentage improvements (+) or losses (-) relative to AR(1) model</i>									
1q	-358.7*** (< 0.001)	-231.9*** (< 0.001)	-286.2*** (< 0.001)	12.4 (0.156)	-2.9 (0.851)	-131.7*** (< 0.001)	-131.6*** (0.001)	8.6 (0.389)	24.2*** (0.002)	33.3*** (< 0.001)
2q	-719.2*** (< 0.001)	-154.4*** (0.003)	-182.6*** (0.002)	14.6 (0.123)	37.3*** (< 0.001)	-58.9** (0.011)	-166.0*** (0.001)	32.2*** (< 0.001)	51.6*** (< 0.001)	22.7** (0.028)
4q	-563.5*** (< 0.001)	-75.3* (0.056)	-122.3** (0.015)	31.2*** (< 0.001)	51.2*** (< 0.001)	-9.3 (0.477)	-175.7*** (0.004)	40.5*** (< 0.001)	60.4*** (< 0.001)	35.1*** (0.004)
8q	-312.2*** (< 0.001)	-53.1 (0.254)	-118.0 (0.176)	58.1*** (< 0.001)	54.9*** (< 0.001)	-2.1 (0.955)	-109.8*** (< 0.001)	47.4*** (< 0.001)	59.9*** (< 0.001)	53.3*** (< 0.001)
12q	-99.2*** (0.009)	-68.8 (0.334)	-102.9 (0.374)	66.7*** (< 0.001)	57.3*** (< 0.001)	-17.4 (0.744)	-51.9** (0.024)	53.8*** (< 0.001)	58.1*** (< 0.001)	51.8*** (< 0.001)
H6-ABM	<i>Percentage improvements (+) or losses (-) relative to AR(1) model</i>									
1q	-358.7*** (< 0.001)	-231.9*** (< 0.001)	-286.2*** (< 0.001)	12.4 (0.156)	-2.9 (0.851)	-131.7*** (< 0.001)	-131.6*** (0.001)	8.6 (0.389)	24.2*** (0.002)	33.3*** (< 0.001)
2q	-716.5*** (< 0.001)	-156.4*** (0.002)	-182.1*** (0.002)	20.9** (0.017)	38.9*** (< 0.001)	-58.5** (0.012)	-162.2*** (0.001)	33.2*** (< 0.001)	51.3*** (< 0.001)	27.4*** (0.004)
4q	-555.7*** (< 0.001)	-77.8* (0.058)	-118.6** (0.019)	36.7*** (< 0.001)	54.7*** (< 0.001)	-10.5 (0.464)	-171.6*** (0.005)	43.3*** (< 0.001)	61.8*** (< 0.001)	37.9*** (< 0.001)
8q	-300.0*** (< 0.001)	-57.7 (0.205)	-111.5 (0.179)	61.2*** (< 0.001)	59.6*** (< 0.001)	-4.4 (0.907)	-104.1*** (< 0.001)	51.5*** (< 0.001)	60.1*** (< 0.001)	59.1*** (< 0.001)
12q	-90.4*** (0.006)	-64.3 (0.334)	-92.1 (0.370)	66.8*** (< 0.001)	63.4*** (< 0.001)	-14.4 (0.797)	-50.2* (0.076)	57.8*** (< 0.001)	59.7*** (< 0.001)	63.9*** (< 0.001)
OC-ABM	<i>Percentage improvements (+) or losses (-) relative to AR(1) model</i>									
1q	-358.8*** (< 0.001)	-232.4*** (< 0.001)	-286.6*** (< 0.001)	12.6 (0.147)	-3.0 (0.843)	-132.2*** (< 0.001)	-131.5*** (0.001)	8.5 (0.398)	23.7*** (0.003)	32.7*** (< 0.001)
2q	-719.4*** (< 0.001)	-155.9*** (0.002)	-181.6*** (0.002)	13.6 (0.186)	38.9*** (< 0.001)	-59.1** (0.011)	-167.1*** (0.001)	34.7*** (< 0.001)	52.2*** (< 0.001)	11.5 (0.200)
4q	-549.5*** (< 0.001)	-86.2** (0.027)	-107.1** (0.017)	33.4*** (< 0.001)	58.6*** (< 0.001)	-27.2 (0.164)	-147.1*** (0.007)	44.3*** (< 0.001)	64.3*** (< 0.001)	37.0*** (< 0.001)
8q	-316.9*** (< 0.001)	-70.1 (0.161)	-100.4 (0.224)	70.0*** (< 0.001)	66.3*** (< 0.001)	-25.3 (0.554)	-79.7*** (0.008)	59.8*** (< 0.001)	60.4*** (< 0.001)	72.2*** (< 0.001)
12q	-101.4*** (0.003)	-66.6 (0.314)	-86.2 (0.403)	71.8*** (< 0.001)	67.8*** (< 0.001)	-25.3 (0.682)	-36.9* (0.083)	62.2*** (< 0.001)	60.9*** (< 0.001)	71.9*** (< 0.001)

Sectors: Agriculture, forestry and fishing (A); Industry except construction (B, C, D and E); Construction (F); Wholesale and retail trade, transport, accommodation and food service activities (G, H and I); Information and communication (J); Financial and insurance activities (K); Real estate activities (L); Professional, scientific and technical activities, administrative and support service activities (M and N); Public administration, defence, education, human health and social work activities (O, P and Q); Arts, entertainment, recreation, other service activities (R and S). ABMs under AR expectations vs. sectoral AR(1). See Section 4 for estimation details. Diebold–Mariano p -values in parentheses; *, **, ***: 10%, 5%, 1% significance.

Table 11 reveals a broad pattern, with exceptions in K and L: the largest positive sectoral point estimates occur where the AR(1) struggles. Sectors with high baseline RMSFE, such as wholesale, retail and transport (G, H, I), professional services (M, N), and public administration (O, P, Q), show substantial ABM improvements, with OC point estimates of approximately 61–72% at the 12-quarter horizon. These are sectors characterised by heterogeneous firm populations, complex demand linkages through the input–output network, and labour market dynamics that the ABM explicitly models. Conversely, sectors where the AR(1) already forecasts well, such as agriculture (A), industry (B, C, D, E), and construction (F), see ABM losses, suggesting that the ABM’s stochastic firm-level dynamics introduce noise where aggregate regularities suffice. This pattern holds for both heuristic and optimal-consumption variants, suggesting

that the sectoral gains derive primarily from the ABM's production-side structure (firm heterogeneity, IO linkages, search-and-matching) rather than from the household optimisation block, though we cannot rule out indirect demand-side effects from the household block.

4.5 *National accounting decompositions*

A distinguishing feature of the ABM framework is its stock-flow consistency: every flow is an outflow for one agent and an inflow for another, following double-entry bookkeeping in accordance with ESA national accounting conventions. This property enables internally coherent decomposition of aggregate forecasts along multiple dimensions. Figure 11 illustrates this with annual nominal GDP forecasts for 2014–2017 from a 2014Q4 origin, using the production approach (panel a: sectoral GVA contributions), the income approach (panel b: wages, social contributions, gross operating surplus, taxes), and the expenditure approach (panel c: household consumption, government consumption, capital formation, net exports). The accounting identities hold by construction in the model.¹⁰

This decomposition capability is not a forecasting result per se but an internal validity property of the modelling framework. It becomes practically useful when policymakers require not only an aggregate forecast but also a structural narrative, for instance whether a GDP revision is driven by a consumption shortfall or an investment downturn.

¹⁰We display a single representative forecast origin (2014Q4) to keep the figure legible; the stock-flow identity holds by construction at every reference quarter.

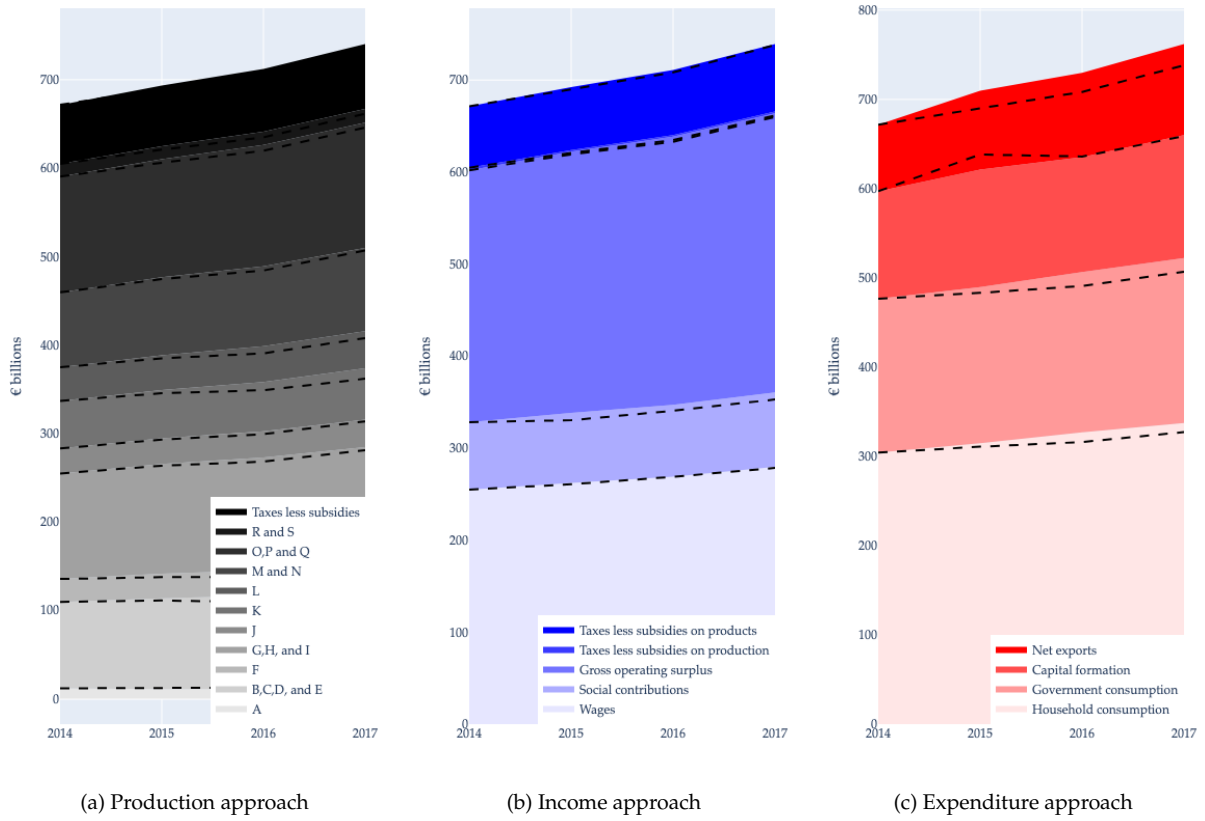


Figure 11: Accounting illustration: annual nominal GDP forecasts for 2014–2017 from a 2014Q4 origin, decomposed by production (a), income (b), and expenditure (c) approaches. Dashed lines: realised data. Shaded areas: mean OC-ABM forecast under AR expectations across 100 simulations. All panels in € billions.

5 Internal Validity

The correlation figures below use a bond-liquidity variant of the household block, not the two-account Euler policy used for forecasting. They diagnose the shared ABM framework; a multi-origin internal-validity exercise for the forecasting policy is not reported here.

Having presented the forecasting results in Section 4, we review whether the bond-liquidity variant of the household block generates plausible macroeconomic dynamics. A model that forecasts well but produces implausible internal behaviour may be exploiting artefacts of the evaluation sample rather than capturing genuine economic mechanisms. We examine two diagnostic dimensions: persistence (auto-correlations) and comovement (cross-correlations), following the validation protocol of Caiani et al. (2016). Specifically, we adopt their approach of comparing HP-filtered cyclical components across the same set of variables (GDP, investment, consumption, wages, operating surplus, and the GDP deflator).

We focus on the bond-liquidity variant under AR expectations, the simplest expectation mechanism, as a diagnostic of the household block. All diagnostics are computed from a single calibration origin (2012Q1), which sits near the trough of the Eurocrisis. Results from this origin may therefore not be representative of the model's typical behaviour; robustness across origins is left to future work. Appendix D presents the corresponding analysis under ARX, VAR, and VARX expectations, where the GDP deflator dynamics improve substantially.

5.1 Auto-correlations

Figure 12 displays the sample auto-correlation functions (ACFs) of the HP-filtered cyclical components for six variables: GDP, capital formation, household consumption, wages, operating surplus, and the GDP deflator.¹¹ ACFs are computed from 100 Monte Carlo simulations launched from the 2012Q1 calibration origin over a 20-quarter horizon.¹² The shaded band shows one standard deviation across simulations; the orange line shows the empirical ACF over 1997Q1–2019Q4.

The model matches the data well for GDP and operating surplus, reproducing the characteristic decay from strong positive auto-correlation at short lags to near-zero by lag 12–15. Capital formation shows a similar decay rate, though the model generates slightly more negative auto-correlations at longer lags. However, two discrepancies stand out. First, wages and household consumption decay more slowly in the model than in the data. For wages, this likely reflects insufficient labour-market frictions: wages adjust immediately to production changes via overtime payments, producing too much persistence, though the adaptive AR(1) expectation mechanism may also contribute. Because households’ expected future income tracks this persistent wage process, the excess persistence feeds through to consumption via the income channel. Introducing search frictions or time-to-fill for vacancies would directly address wage persistence; the consumption effect should diminish as a consequence. Second, the GDP deflator shows excessive persistence, indicating that the price-setting or expectation-formation mechanisms may be too sluggish.

¹¹We apply the Hodrick–Prescott filter with the standard quarterly smoothing parameter $\lambda = 1,600$. Cyclical components are computed as percentage deviations from the HP trend in log levels for GDP, investment, and household consumption, and in levels for the GDP deflator growth rate.

¹²We use the biased (Box–Jenkins) auto-correlation estimator, $r_k = \frac{\frac{1}{T} \sum_{t=1}^{T-k} (y_t - \bar{y})(y_{t+k} - \bar{y})}{\frac{1}{T} \sum_{t=1}^T (y_t - \bar{y})^2}$, which divides both numerator and denominator by T rather than $T - k$. This is the standard convention in the time-series literature and ensures positive semi-definiteness of the implied autocovariance matrix. With a simulation horizon of $T = 20$, the bias correction difference between dividing by T and $T - k$ is non-trivial at longer lags; this may partly account for differences between model ACFs (computed over $T = 20$) and empirical ACFs (computed over $T \approx 90$).

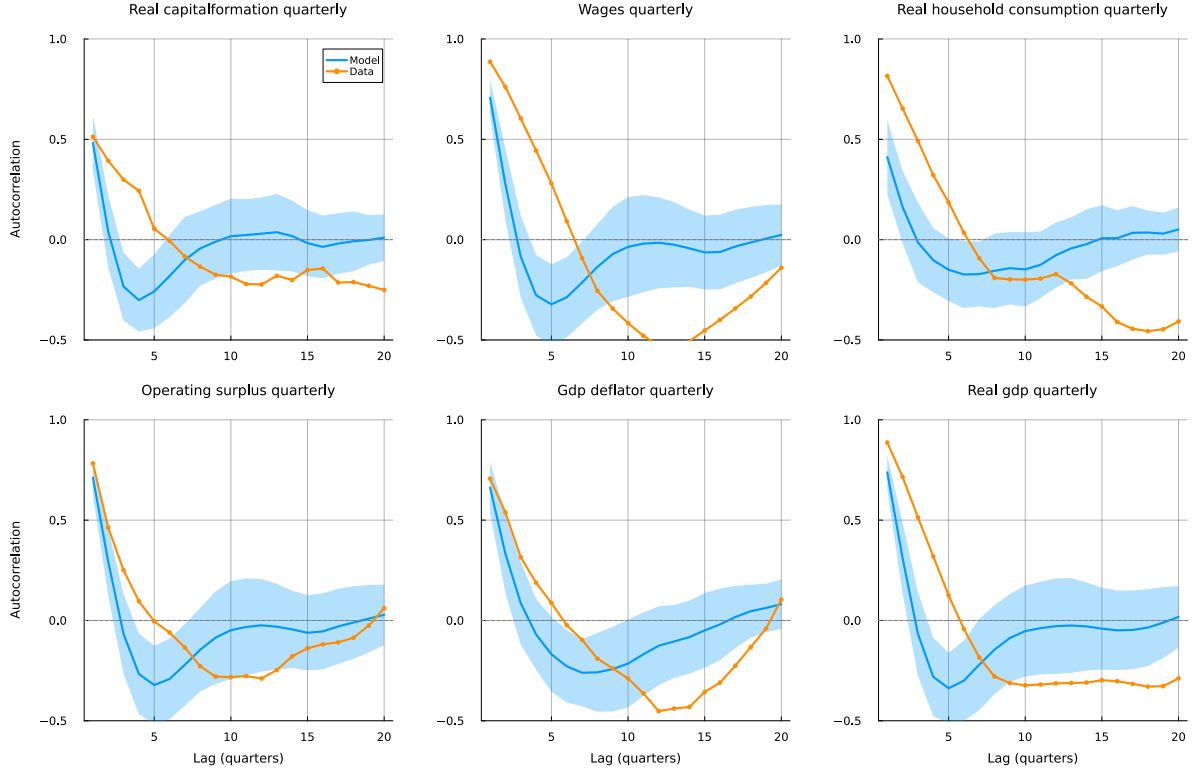


Figure 12: Bond-liquidity variant: auto-correlations of HP-filtered ($\lambda = 1,600$) cyclical components. Blue line: mean across 100 Monte Carlo simulations from origin 2012Q1 (20-quarter horizon). Shaded area: ± 1 standard deviation. Orange line: empirical ACF (1997Q1–2019Q4). The model matches GDP, operating surplus, and capital formation well but shows slower decay for wages, household consumption, and the GDP deflator.

5.2 Cross-correlations

Figure 13 shows the cross-correlation between the HP-filtered cyclical component of real GDP at time t and other variables at time $t - k$, where negative lags indicate the variable leads GDP (i.e., the variable at $t - k$ is correlated with GDP at t , so the variable precedes GDP by k quarters).¹³ Simulation settings match Section 5.1.

Capital formation and household consumption match the data well: both peak at lag zero in the model and in the data, indicating coincident cyclical behaviour. Operating surplus shows the correct shape but with a flatter profile in the model.

Wages present a notable discrepancy. In the data, wages are pro-cyclical and leading, that is, positively correlated with GDP and peaking before it (around lag -5). In the model, wages are coincident with GDP, peaking at lag zero. This arises because wages adjust immediately when production rises through overtime payments, eliminating the lead that hiring frictions generate in practice.

The GDP deflator cross-correlations provide the weakest match. The data show a negative cross-correlation at negative lags transitioning to positive at positive lags, indicating that deflator movements lag GDP. The model reproduces this sign pattern but generates a much flatter

¹³We compute the sample cross-correlation as $\hat{\rho}_{xy}(k) = \hat{R}_{xy}(k) / [\hat{R}_{xx}(0) \hat{R}_{yy}(0)]^{1/2}$, where $\hat{R}_{xy}(k) = \frac{1}{T} \sum_{t=0}^{T-k-1} x_{t+k} y_t$ for $k \geq 0$ and $\hat{R}_{xy}(k) = \hat{R}_{yx}(-k)$ for $k < 0$. This is the standard Pearson-style normalisation ensuring $\hat{\rho}_{xy}(k) \in [-1, 1]$.

profile, with cross-correlations near zero across all lags rather than exhibiting the pronounced swing seen in the data. The GDP auto-correlation panel confirms that the model’s cyclical GDP dynamics are internally consistent, peaking at unity at lag zero as expected. Under ARX expectations (Appendix D), the deflator cross-correlations improve markedly: conditioning on exogenous variables disciplines the price-setting mechanism, aligning the model’s deflator dynamics more closely with the empirical pattern.

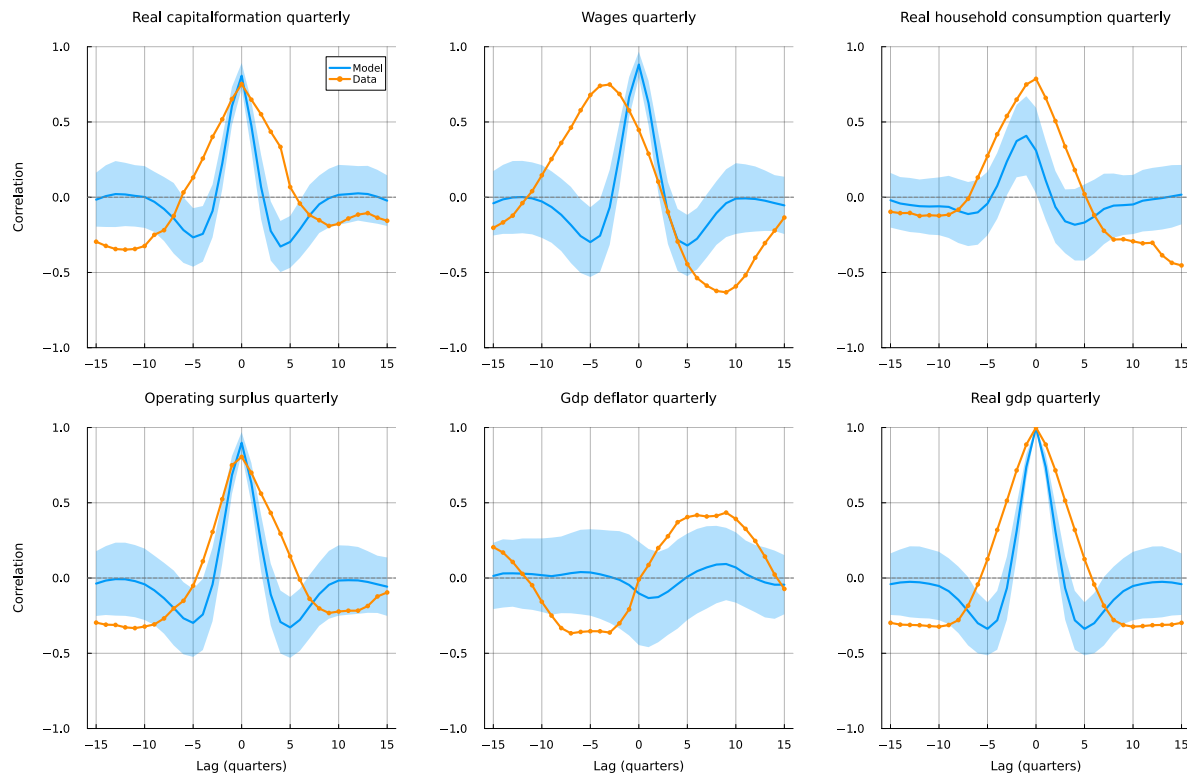


Figure 13: Bond-liquidity variant: cross-correlations between HP-filtered ($\lambda = 1,600$) cyclical GDP and other variables. Positive lags: variable lags GDP. Negative lags: variable leads GDP. Blue line: mean across 100 Monte Carlo simulations from origin 2012Q1 (20-quarter horizon). Shaded area: ± 1 standard deviation. Orange line: empirical cross-correlation (1997Q1–2019Q4). Capital formation and consumption match well; wages peak at lag zero rather than leading as in the data.

6 Discussion

This paper asked whether replacing heuristic consumption rules with optimising households improves the forecasts of an agent-based model. For household consumption at medium horizons, the evidence points in that direction. At twelve quarters, the OC-ABM reduces consumption RMSFE by 40.5–54.2% against matched univariate benchmarks under all four expectation mechanisms (Figure 7), whereas the base ABM, with its constant marginal propensity to consume, gains 5.9% under AR expectations. Investment RMSFE falls by 14.5–15.5%, a statistically significant improvement. The consumption gains are not statistically significant: with 28 overlapping origins, the tests could not reject equal accuracy even for an error-free forecast. At 1–4 quarters the autoregressive benchmarks remain more accurate, and GDP gains of 31.0–40.1% are imprecisely estimated.

These results bear on the observation by Acharya et al. (2023) that household heterogeneity in an estimated HANK model does not improve consumption forecasts. Embedding two-asset

households in a decentralised, stock–flow consistent environment yields large point gains, consistent with the view in the Introduction that the environment in which heterogeneity is placed matters as much as the heterogeneity itself. The gains are concentrated in the 2013–14 trough of Dutch household consumption. Habit rules H5 and H6 also capture the trough but lose at least 48% against the benchmark over 2015–19, while the OC-ABM stays within 10.2% (Table 8). The OC-ABM is thus the only specification that tracks the downturn without a large penalty in the recovery.

The heuristic comparisons indicate which household features carry this predictive content (Section 4.3). Static rules lose accuracy. Under AR expectations, the habit rule H6 and the buffer-stock rule H7 gain 31.6% and 13.7%, and a state-dependent portfolio choice adds to these gains: a Merton portfolio target (Merton, 1969) raises the buffer-stock heuristic’s twelve-quarter consumption gain from 13.7% to 25.4%, against 49.7% for the OC-ABM. This ordering is consistent with the argument of Kaplan and Violante (2022) that two-asset intertemporal optimisation is needed to reproduce how households respond to income and wealth. The heuristics and the OC-ABM also differ in borrowing constraints and calibration, so the ordering identifies relevant features rather than a precise decomposition.

Methodologically, the paper shows that internally rational households in the sense of Adam and Marcet (2011) can be embedded in a large ABM. Conditioning the neural policy on preference and belief parameters (Kase et al., 2025) lets households update their AR(1) beliefs each quarter while the network weights stay fixed, so learning requires no re-resolution of the household problem. Households need not know the full state of the economy, which responds to the computational objection of Moll (2025) to rational expectations in heterogeneous-agent models.

The main limitation is statistical power. Forecasts from consecutive origins share eleven realised quarters, so the 28 twelve-quarter origins carry roughly five to eight independent observations, and the sample contains a single downturn. Power should be raised by adding forecast origins at a fixed horizon rather than lengthening the horizon, which increases overlap: origins from 2017Q1–2019Q4 can be scored once actuals through 2022Q4 are available, with the treatment of COVID-19 targets fixed in advance, and origins before 2010 would add the 2008–2009 recession. Applying the same protocol to other countries, with country-specific calibration and pooled inference that allows for common shocks, would test whether the gains generalise beyond the Netherlands. The primary test, samples and countries should be fixed before these forecasts are scored. Beyond power, the exercise uses retrospective data, the global accuracy of the approximate policy and its robustness across training seeds require further validation, and the correlation diagnostics (Section 5) use a bond-liquidity variant of the household block. On the model side, a financial accelerator could help capture the 2013 investment dip (Section 4.1), labour-market search frictions the wage-timing discrepancy, and heterogeneous expectation rules (Brock and Hommes, 1997) would relax the assumption of common beliefs, extending the behavioural learning approach of Hommes and Zhu (2014).

The Introduction began from the observation that no single modelling tradition captures what drives household consumption: representative-agent models impose discipline but abstract from distribution, time-series models fit the short run but lack structure, and agent-based models capture heterogeneity and institutions but rely on ad hoc household rules. This paper shows that these strengths can be combined. Households that optimise over liquid and illiquid wealth, calibrated to administrative microdata and learning from the data they observe, can be embedded in a large stock–flow consistent economy. The resulting model forecasts the 2013–14 Dutch consumption slump that the time-series benchmarks miss, without the loss of

accuracy in the recovery that the heuristic rules suffer. For central banks and fiscal councils, it offers forecasts that can be traced through production, income and expenditure (Section 4.5), and a household block that can evaluate distributional policies, such as targeted versus universal transfers, that representative-agent and reduced-form models cannot. Agent-based models need not choose between institutional realism and optimising behaviour.

References

- A. B. Abel. Asset prices under habit formation and catching up with the joneses. *American Economic Review*, 80(2):38–42, 1990.
- S. Acharya, W. Chen, M. Del Negro, K. Dogra, A. Gleich, S. Goyal, D. Lee, E. Matlin, R. Sarfati, and S. Sengupta. Estimating HANK for central banks. Staff Reports 1071, Federal Reserve Bank of New York, 2023.
- K. Adam and A. Marcet. Internal rationality, imperfect market knowledge and asset prices. *Journal of Economic Theory*, 146(3):1224–1252, May 2011.
- S. R. Aiyagari. Uninsured idiosyncratic risk and aggregate saving. *Quarterly Journal of Economics*, 109(3):659, Aug. 1994. Publisher: Oxford University Press / USA.
- R. L. Axtell. Zipf distribution of US firm sizes. *Science*, 293(5536):1818–1820, 2001.
- R. L. Axtell and J. D. Farmer. Agent-Based Modeling in Economics and Finance: Past, Present, and Future. *Journal of Economic Literature*, 63(1):197–287, Mar. 2025.
- M. Azinovic, L. Gaegauf, and S. Scheidegger. Deep equilibrium nets. *International Economic Review*, 63(4):1471–1525, 2022.
- T. Bewley. The Permanent Income Hypothesis: A Theoretical Formulation. *Journal of Economic Theory*, 16:252–292, 1977.
- T. S. Blattner and E. Margaritov. Towards a Robust Monetary Policy Rule for the Euro Area. *SSRN Electronic Journal*, 2010.
- W. A. Brock and C. H. Hommes. A Rational Route to Randomness. *Econometrica*, 65(5):1059–1095, 1997. Publisher: Wiley, Econometric Society.
- J. Brumm and S. Scheidegger. Using Adaptive Sparse Grids to Solve High-Dimensional Dynamic Models. *Econometrica*, 85(5):1575–1612, 2017.
- A. Caiani, A. Godin, E. Caverzasi, M. Gallegati, S. Kinsella, and J. E. Stiglitz. Agent based-stock flow consistent macroeconomics: Towards a benchmark model. *Journal of Economic Dynamics and Control*, 69:375–408, Aug. 2016.
- J. Y. Campbell. Asset prices, consumption, and the business cycle. In J. B. Taylor and M. Woodford, editors, *Handbook of Macroeconomics*, volume 1, Part C, pages 1231–1303. Elsevier, 1999.
- C. D. Carroll. Buffer-stock saving and the life cycle/permanent income hypothesis. *Quarterly Journal of Economics*, 112(1):1–55, 1997.
- D. Christelis, D. Georgarakos, T. Jappelli, L. Pistaferri, and M. van Rooij. Asymmetric consumption effects of transitory income shocks. *The Economic Journal*, 129(622):2322–2341, 2019a.

- D. Christelis, D. Georgarakos, T. Jappelli, L. Pistaferri, and M. van Rooij. Wealth shocks and MPC heterogeneity. DNB Working Paper 645, De Nederlandsche Bank, 2019b.
- L. J. Christiano, M. Eichenbaum, and C. L. Evans. Nominal rigidities and the dynamic effects of a shock to monetary policy. *Journal of Political Economy*, 113(1):1–45, 2005.
- T. E. Clark and K. D. West. Approximately normal tests for equal predictive accuracy in nested models. *Journal of Econometrics*, 138(1):291–311, 2007.
- H. Dawid and D. Delli Gatti. Agent-Based Macroeconomics. In *Handbook of Computational Economics*, volume 4, pages 63–156. Elsevier, 2018.
- A. Deaton. Saving and liquidity constraints. *Econometrica*, 59(5):1221–1248, 1991.
- F. X. Diebold and R. S. Mariano. Comparing Predictive Accuracy. *Journal of Business & Economic Statistics*, 13(3):253–263, 1995.
- K. Drescher, P. Fessler, and P. Lindner. Helicopter money in Europe: New evidence on the marginal propensity to consume across European households. *Economics Letters*, 195, Oct. 2020.
- G. W. Evans and S. Honkapohja. *Learning and Expectations in Macroeconomics*. Princeton University Press, Princeton, NJ, 2001.
- A. Fagereng, M. B. Holm, and G. J. Natvik. MPC Heterogeneity and Household Balance Sheets. *American Economic Journal: Macroeconomics*, 13(4):1–54, Oct. 2021.
- J. Fernández-Villaverde, S. Hurtado, and G. Nuño. Financial frictions and the wealth distribution. *Econometrica*, 91(3):869–901, 2023.
- J. Fernández-Villaverde, G. Nuño, and J. Perla. Taming the curse of dimensionality: Quantitative economics with deep learning. Working Paper 33117, National Bureau of Economic Research, 2024.
- D. Harvey, S. Leybourne, and P. Newbold. Testing the equality of prediction mean squared errors. *International Journal of Forecasting*, 13(2):281–291, June 1997.
- C. Hommes and M. Zhu. Behavioral learning equilibria. *Journal of Economic Theory*, 150:778–814, Mar. 2014.
- C. Hommes, M. He, S. Poledna, M. Siqueira, and Y. Zhang. CANVAS: A Canadian behavioral agent-based model for monetary policy. *Journal of Economic Dynamics and Control*, 172:104986, Mar. 2025.
- M. Huggett. The risk-free rate in heterogeneous-agent incomplete-insurance economies. *Journal of Economic Dynamics and Control*, 17(5-6):953–969, Sept. 1993.
- G. Kaplan and G. L. Violante. The Marginal Propensity to Consume in Heterogeneous Agent Models. *Annual Review of Economics*, 14(Volume 14, 2022):747–775, Aug. 2022. Publisher: Annual Reviews.
- G. Kaplan, G. Violante, and J. Weidner. The Wealthy Hand-to-Mouth. Technical Report w20073, National Bureau of Economic Research, Cambridge, MA, Apr. 2014.
- G. Kaplan, B. Moll, and G. L. Violante. Monetary Policy According to HANK. *American Economic Review*, 108(3):697–743, Mar. 2018.

- H. Kase, L. Melosi, and M. Rottner. Estimating nonlinear heterogeneous agent models with neural networks. Working paper, European Central Bank, European University Institute, and Bank for International Settlements, 2025.
- L. Maliar, S. Maliar, and P. Winant. Deep learning for solving dynamic economic models. *Journal of Monetary Economics*, 122:76–101, Sept. 2021.
- A. Marcet and T. J. Sargent. Convergence of least squares learning mechanisms in self-referential linear stochastic models. *Journal of Economic Theory*, 48(2):337–368, 1989.
- R. C. Merton. Lifetime portfolio selection under uncertainty: The continuous-time case. *Review of Economics and Statistics*, 51(3):247–257, 1969.
- B. Moll. The trouble with rational expectations in heterogeneous agent models: A challenge for macroeconomics. *The Economic Journal*, 2025. Originally delivered as the 2024 EJ Lecture.
- O. Pfäuti and F. Seyrich. A behavioral heterogeneous agent New Keynesian model. CRC TR 224 Discussion Paper No. 334, revised 2024, 2022.
- S. Poledna, M. G. Miess, C. Hommes, and K. Rabitsch. Economic forecasting with an agent-based model. *European Economic Review*, 151:104306, Jan. 2023.
- F. Smets and R. Wouters. Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach. *American Economic Review*, 97(3):586–606, June 2007.
- J. B. Taylor. Discretion versus policy rules in practice. *Carnegie-Rochester Conference Series on Public Policy*, 39:195–214, Dec. 1993.
- S. Wiese, J. Kaszowska-Mojša, J. Dyer, J. Moran, M. Pangallo, F. Lafond, J. Muellbauer, A. Calinescu, and J. D. Farmer. Forecasting Macroeconomic Dynamics using a Calibrated Data-Driven Agent-based Model, 2024.

A Model details

This appendix provides the full specification of the model components not described in the main text. The household sector, including the optimisation problem, capital market, and expectation formation, is presented in Section 2. Here we detail the firm sector (production, pricing, investment, and finance), the government sector (fiscal rules, taxation, and debt management), the banking sector (loan provision and capital requirements), the central bank (monetary policy and balance sheet), and the trade sector (imports and exports). All equations follow Poledna et al. (2023) unless otherwise noted. Parameter values and their sources are reported in Table 5 and the sector parameter tables (Table 12).

A.1 Firms

We follow Poledna et al. (2023) for the firm sector. The sector consists of heterogeneous firms across $s \in \{1, \dots, S\}$ industries, each containing I_s firms for a total of $I = \sum_{s=1}^S I_s$ firms. Each firm $i \in \{1, \dots, I\}$ produces a principal product $g \in \{1, \dots, G\}$ using labour, capital, and intermediate inputs from other firms. Demand for firm i 's products is the sum of final consumption, capital goods, material inputs, and intermediate goods demanded.

A.1.1 Sales

Realised demand $Q_{i,t}^d$ is determined after the firm sets its price and production $Y_{i,t}$. Firms face demand from households, government entities, and other firms seeking capital or intermediate goods.

$$Q_{i,t}^d \begin{cases} < Y_{i,t} + S_{i,t-1} & \text{if demand from consumers is smaller than supply from firm } i, \text{ and} \\ = Y_{i,t} + S_{i,t-1} & \text{if demand from consumers exactly matches supply from firm } i, \text{ and} \\ > Y_{i,t} + S_{i,t-1} & \text{if demand from consumers is larger than supply from firm } i, \end{cases} \quad (47)$$

where $S_{i,t-1}$ is the firm's inventory of finished goods. Which firm receives demand is determined by a search-and-matching mechanism that shapes the consumption and supply networks each period. Each period, a consumer visits a number of randomly chosen foreign or domestic firms selling good g . The probability that a consumer selects firm i depends on both the firm's price and its size. Two probabilities, one based on price competitiveness and one on firm size, are computed from exponential distributions and averaged to obtain the selection probability:

$$\begin{aligned} pr_{i,t}^{\text{price}} &= \frac{e^{-2P_{i,t}}}{\sum_{i \in I_{s=g}} e^{-2P_{i,t}}} \\ pr_{i,t}^{\text{size}} &= \frac{Y_{i,t}}{\sum_{i \in I_{s=g}} Y_{i,t}} \\ pr_{i,t}^{\text{cum}} &= \frac{pr_{i,t}^{\text{price}} + pr_{i,t}^{\text{size}}}{2} \end{aligned} \quad (48)$$

Here $pr_{i,t}^{\text{price}}$ is the probability firm i is selected by a consumer due to its offering price. $pr_{i,t}^{\text{size}}$ is the probability firm i is selected by a consumer due to its size. $pr_{i,t}^{\text{cum}}$ is the average probability firm i is selected by a consumer due to its size and its offering price. If the most preferred

firm runs out of stock before the consumer has satisfied its demands, the consumer goes to the other firms. If a consumer cannot satisfy its demands for a product g it saves involuntarily. Consequently, actual sales is both determined on demand and supply available and is the minimum of the two quantities:

$$Q_{i,t} = \min\{Y_{i,t} + S_{i,t-1}, Q_{i,t}^d\} \quad (49)$$

Excess supply is the difference between production and sales:

$$\Delta S_{i,t} = Y_{i,t} - Q_{i,t}. \quad (50)$$

This reflects the firm's expectation error concerning demand. Excess supply is stored as inventory:

$$S_{i,t} = S_{i,t-1} + \Delta S_{i,t}. \quad (51)$$

In the next period these goods are available again for sale at the same firm together with the newly produced goods. We assume there is no depreciation of goods.

A.1.2 Supply

The supply choice of the firm is determined by multiplying the expected growth rate by the previous period's demand for its product:

$$Q_{i,t}^s = Q_{i,t-1}^d (1 + \gamma_t^e). \quad (52)$$

Prices reflect the previous price, expected inflation, and cost-push inflation arising from the firm's cost structure:

$$P_{i,t} = P_{i,t-1} \cdot \underbrace{(1 + \pi_{i,t}^c)}_{\text{Cost-Push Inflation}} \cdot \underbrace{(1 + \pi_t^e)}_{\text{Built-In Inflation}}, \quad (53)$$

where

$$\begin{aligned} \pi_{i,t}^c = & \underbrace{\frac{(1 + \tau^{\text{SIF}}) \bar{w}_i}{\bar{\alpha}_i} \left(\frac{\bar{P}_t^{\text{HH}}}{P_{i,t}} - 1 \right)}_{\text{Increase of unit labour costs}} + \underbrace{\frac{1}{\beta_i^M} \left(\frac{\sum_g a_{sg} \bar{P}_{g,t-1}}{P_{i,t}} - 1 \right)}_{\text{Increase of unit material costs}} \\ & + \underbrace{\frac{\delta_i}{\kappa_i} \left(\frac{\bar{P}_t^{\text{CF}}}{P_{i,t}} - 1 \right)}_{\text{Increase of unit capital costs}} \quad \forall i \in I_S. \end{aligned} \quad (54)$$

$\bar{\alpha}_i$ denotes the average productivity of labour. $\bar{w}_i$ are average gross wages indexed by the consumer price index $\bar{P}_t^{\text{HH}}$, and including employers' contribution to social insurance charged with a rate τ^{SIF} . $\frac{1}{\beta_i^M} \sum_g a_{sg}$ are unit expenditures (in real terms) on intermediate input by industry s on good g weighted by the average product price index for good g ($\bar{P}_{g,t}$). δ_i/κ_i are unit capital costs due to depreciation. δ_i is the firm's capital depreciation rate and κ_i the productivity coefficient for capital. $\bar{P}_t^{\text{CF}}$ is the average price of capital goods. Inflation rate is the log difference of the consumer price index (CPI):

$$\pi_t = \log \left(\frac{\bar{P}_t}{\bar{P}_{t-1}} \right) \quad (55)$$

where the producer price index is defined as

$$\bar{p}_t = \frac{\sum_i P_{i,t} Q_{i,t} + \sum_m P_{m,t} Q_{m,t}}{\sum_i Q_{i,t} + \sum_m Q_{m,t}}. \quad (56)$$

$P_{m,t}$ and $Q_{m,t}$ are price and sales from foreign producers m respectively. By incorporating expectations about future costs, inflation, and profits alongside current costs, firms reduce the probability of bankruptcy due to irrational pricing behaviour. Under adaptive learning, the expectation gap gradually narrows toward the actual state of the economy.

A.1.3 Production

In every period t each firm i produces output $Y_{i,t}$ in the form of principal product g using labour $N_{i,t}$, intermediate goods and raw materials $M_{i,t}$, and capital $K_{i,t}$. The firms produce by means of a Leontief production function which is given by:

$$Y_{i,t} = \min \left(Q_{i,t}^S, \beta_i^M M_{i,t}, \alpha_{i,t} N_{i,t}, \kappa_i K_{i,t-1} \right), \quad (57)$$

where $\alpha_{i,t}$ is the firm i 's labour productivity, β_i^M is the firm's intermediate input productivity coefficient and κ_i is the firm's capital productivity. Production may be lower than desired production if it cannot obtain enough resources for production.

A.1.4 Investment

Every firm i makes an investment decision each period which adjusts next period real capital stock $K_{i,t}$. As today's investment is available to use for production tomorrow capital is durable and sticky. The desired investment in capital stock is given by:

$$I_{i,t}^d = \frac{\delta_i}{\kappa_i} \min(Q_{i,t}^S, \kappa_i K_{i,t}). \quad (58)$$

δ_i is the firm's capital depreciation rate. Capital stock is homogeneous for all firms. Each firm demands $b_g^{CF} I_{i,t}^d$ from firms producing good g . Hence, firm i 's demand for capital investment in good g is

$$I_{ig,t}^d = b_g^{CF} I_{i,t}^d. \quad (59)$$

It is possible that firm i cannot realize its capital demand. This is dependent on the search-and-matching process. We have that realized capital investment is given by:

$$I_{i,t} \begin{cases} = \sum_g I_{ig,t}^d & \text{if the firm successfully realized the investment plan, and} \\ < \sum_g I_{ig,t}^d & \text{if all firms visited could not satisfy its demand} \end{cases} \quad (60)$$

Next period capital stock is determined by realized investment, current capital stock and depreciation due to capital use:

$$K_{i,t} = K_{i,t-1} - \frac{\delta_i}{\kappa_i} Y_{i,t} + I_{i,t}. \quad (61)$$

A.1.5 Intermediate Inputs

Intermediate inputs are used by firms for production. Each firm i holds a stock of input goods $M_{i,t}$ in real terms for each good g . The firm ensures a positive supply to prevent impeding production. Each period firm i demands intermediate goods such that it can produce its production plan. The desired amount of intermediate goods and raw materials $\Delta M_{i,t}^d$ is given by:

$$\Delta M_{i,t}^d = \frac{\min\{Q_{i,t}^s, \kappa_i K_{i,t-1}\}}{\beta_i^M} \quad (62)$$

Moreover, firm i belongs to industry s and consumes intermediate input g according to sector-specific technology coefficients a_{sg} which gives

$$\Delta M_{ig,t}^d = a_{sg} \Delta M_{i,t}^d, \forall i \in I_s. \quad (63)$$

The intermediate inputs also depend on a search-and-matching process which gives:

$$\Delta M_{i,t} \begin{cases} = \sum_g \Delta M_{ig,t}^d & \text{if the firm successfully realized its plan, and} \\ < \sum_g \Delta M_{ig,t}^d & \text{if all firms visited could not satisfy its demand} \end{cases} \quad (64)$$

Failure in realizing the firm's production plan results in its production being limited. The evolution of the stock of good g of firm i depends on the usage of the good, the purchasing of the good and the stock of the good of the previous period. The law of motion is:

$$M_{i,t} = M_{i,t-1} - \frac{Y_{i,t}}{\beta_i^M} + \Delta M_{i,t}. \quad (65)$$

We assume no depreciation of raw materials, as inventories are continuously replenished.

A.1.6 Employment

Labour $N_{i,t}$ is used as a production input by firm i measured in number of persons employed. The firm demands labour based on its according to desired scale of activity $Q_{i,t}^s$ and average labour productivity $\bar{\alpha}_i$:

$$N_{i,t}^d = \max \left\{ 1, \text{round} \left(\frac{\min\{Q_{i,t}^s, \kappa_i K_{i,t-1}\}}{\bar{\alpha}_i} \right) \right\}. \quad (66)$$

If a firm demands less than a half-time position, then its demand is rounded down. If it demands more than a half-time position, then demand is rounded up and a new employee is hired. If the operating workforce is higher than is needed, the firm fires $N_{i,t} - N_{i,t}^d$ random employees. If the demand for labour is larger than the current work force, the firm posts labour vacancies:

$$V_{i,t} = N_{i,t}^d - N_{i,t-1}. \quad (67)$$

Vacancies are filled by means of the labour market search-and-matching mechanism.

$$N_{i,t} \begin{cases} = N_{i,t}^d & \text{if the firm successfully fills all vacancies, and} \\ < N_{i,t}^d & \text{if there are unfilled vacancies.} \end{cases} \quad (68)$$

Employees can work part-time, full-time, or overtime. This is reflected in the actual productivity of labour $\alpha_{i,t}$. Productivity of firm i is

$$\alpha_{i,t} = \bar{\alpha}_i \min \left(1.5, \frac{\min \left(Q_{i,t}^S, \beta_i^M M_{i,t-1}, \kappa_i K_{i,t-1} \right)}{N_{i,t} \bar{\alpha}_i} \right). \quad (69)$$

The maximum work effort is set to 150 percent of full time employment. Wages are increased or decreased to pay for work efforts relative to normal working hours, giving

$$w_{i,t} = \bar{w}_i \frac{\min \left(Q_{i,t}^S, \beta_i^M M_{i,t-1}, \kappa_i K_{i,t-1} \right)}{N_{i,t} \bar{\alpha}_i}. \quad (70)$$

Here, $w_{i,t}$ is the real wage paid by firm i . Nominal wages are increased according to inflation.

A.1.7 External Finance

Firms may need to finance current or future expenditures by borrowing. Each firm forecasts its future cash flow $\Delta D_{i,t}^e$, equal to the expected change in deposits $D_{i,t}$:

$$\Delta D_{i,t}^e = \underbrace{\Pi_{i,t}^e}_{\text{Exp. profit}} - \underbrace{\theta L_{i,t-1}}_{\text{Debt instalment}} - \underbrace{\tau^{\text{FIRM}} \max(0, \Pi_{i,t}^e)}_{\text{Corporate taxes}} - \underbrace{\theta^{\text{DIV}} (1 - \tau^{\text{FIRM}}) \max(0, \Pi_{i,t}^e)}_{\text{Dividend payout}}, \quad (71)$$

where

$$\Pi_{i,t}^e = \Pi_{i,t-1} (1 + \gamma_t^e) (1 + \pi_t^e), \quad (72)$$

is expected profit of firm i which is forecasted using previous period profits. θ is the rate of debt instalments on firm i 's outstanding loans $L_{i,t-1}$. τ^{FIRM} is the corporate tax rate. θ^{DIV} is the dividend payout ratio. We assume that the dividends are paid out proportionally to the illiquid asset holdings of the households. If a firm cannot use internal finance to pay its expenditure, it will turn to a bank for a loan to cover remaining expected future expenditures:

$$\Delta L_{i,t}^d = \max(0, -\Delta D_{i,t}^e - D_{i,t-1}) \quad (73)$$

Whether a firm is granted a loan depends on the bank's capitalisation and the number of firms requesting loans. If a firm cannot obtain a loan, it may become insolvent.

A.1.8 Accounting

Firm profit $\Pi_{i,t}$ is an accounting measure, defined as revenues from sales plus changes in inventories minus expenditures on labour, material, depreciation, interest payments and taxes

$$\begin{aligned} \Pi_{i,t} = & \underbrace{P_{i,t} Q_{i,t}}_{\text{Sales}} + \underbrace{P_{i,t} \Delta S_{i,t}}_{\text{Inventory change}} - \underbrace{(1 + \tau^{\text{SIF}}) w_{i,t} N_{i,t} \bar{P}_t^{\text{HH}}}_{\text{Labour costs}} \\ & - \underbrace{\frac{1}{\beta_i^M} \bar{P}_{i,t} Y_{i,t}}_{\text{Material costs}} - \underbrace{\frac{\delta_i}{\kappa_i} P_{i,t}^{\text{CF}} Y_{i,t}}_{\text{Depreciation}} - \underbrace{\tau_i^Y P_{i,t} Y_{i,t} - \tau_i^{\text{PROD}} P_{i,t} Y_{i,t}}_{\text{Net taxes/subsidies on products/production}} \\ & - \underbrace{r_t (L_{i,t-1} + \max(0, -D_{i,t-1}))}_{\text{Interest payments}} + \underbrace{\bar{r}_t \max(0, D_{i,t-1})}_{\text{Interest received}}, \end{aligned} \quad (74)$$

where r_t is the interest rate paid on outstanding loans. The actual prices paid by firm i for intermediate goods and investment in capital goods are $\bar{P}_{i,t}$ and $P_{i,t}^{\text{CF}}$. These prices are an outcome of the search-and-matching process. Finally, $\bar{P}_t^{\text{HH}}$ is the consumer price index (CPI) :

$$\bar{P}_t^{\text{HH}} = \sum_g b_g^{\text{HH}} \bar{P}_{g,t}. \quad (75)$$

The parameter b_g^{HH} is the household consumption coefficient for product g , and $\bar{P}_{g,t}$ is the producer price index for good g :

$$\bar{P}_{g,t} = \frac{\sum_{i \in I_{s=g}} P_{i,t} Q_{i,t} + P_{m=g,t} Q_{m=g,t}}{\sum_{i \in I_{s=g}} Q_{i,t} + Q_{m=g,t}}. \quad (76)$$

Firm net cash flow is a measure how much liquidity is available for firms to use and is equal to changes in the deposit account:

$$\begin{aligned} \Delta D_{i,t} = & \underbrace{P_{i,t} Q_{i,t}}_{\text{Sales}} - \underbrace{\left(1 + \tau^{\text{SIF}}\right) w_{i,t} N_{i,t} \bar{P}_t^{\text{HH}}}_{\text{Labor costs}} - \underbrace{\bar{P}_{i,t} \Delta M_{i,t}}_{\text{Material costs}} \\ & - \underbrace{\tau_i^Y P_{i,t} Y_{i,t} - \tau_i^{\text{PROD}} P_{i,t} Y_{i,t}}_{\text{Net taxes/subsidies on products and production}} - \underbrace{\tau^{\text{FIRM}} \max(0, \Pi_{i,t})}_{\text{Corporate tax payments}} \\ & - \underbrace{\theta^{\text{DIV}} \left(1 - \tau^{\text{FIRM}}\right) \max(0, \Pi_{i,t})}_{\text{Dividend payments}} - \underbrace{r (L_{i,t-1} + \max(0, -D_{i,t-1}))}_{\text{Interest payments}} \\ & + \underbrace{\bar{r}_t \max(0, D_{i,t-1})}_{\text{Interest received}} - \underbrace{P_{i,t}^{\text{CF}} I_{i,t}}_{\text{Investment costs}} + \underbrace{\Delta L_{i,t}}_{\text{New credit}} - \underbrace{\theta L_{i,t-1}}_{\text{Debt instalment}}. \end{aligned} \quad (77)$$

Firms have to pay interest on loans and overdrafts (in case $D_{i,t} < 0$) at rate r_t , which includes the bank's markup rate. When firms have a positive balance on the bank account, i.e. $D_{i,t} > 0$, the interest rate received is lower and is equal to the rate set by the central bank. Firm deposits are equal to deposits plus net cash flow:

$$D_{i,t} = D_{i,t-1} + \Delta D_{i,t} \quad (78)$$

Similarly, debt follows the following law of motion:

$$L_{i,t} = (1 - \theta) L_{i,t-1} + \Delta L_{i,t} \quad (79)$$

Firm equity $E_{i,t}$ is computed as a balancing item on the firm's balance sheet taking into account deposits debts, capital and input goods. All goods are accounted for market-to-market:

$$E_{i,t} = D_{i,t} + \sum_g a_{sg} \bar{P}_{g,t} M_{i,t} + P_{i,t} S_{i,t} + \bar{P}_t^{\text{CF}} K_{i,t} - L_{i,t} \quad \forall i \in I_s \quad (80)$$

$\bar{P}_t^{\text{CF}}$ is defined as the capital goods price index (CGPI) which is given by:

$$\bar{P}_t^{\text{CF}} = \sum_g b_g^{\text{CF}} \bar{P}_{g,t}, \quad (81)$$

where b_g^{CF} is the capital formation coefficient for product g .

A.1.9 Insolvency

When a firm has a negative deposit balance ($D_{i,t} < 0$) and negative equity ($E_{i,t} < 0$) simultaneously, it declares bankruptcy. The firm is then replaced by a new firm which enters the market. The real capital stock is taken over from the bankrupt firm at zero costs however the new firm has also to take on part of the liabilities of the old firm. The remaining liabilities of firm i amount to a fraction ζ^b of its real capital stock for the new firm as a part of the loans is written off. The remaining liabilities are transferred to the balance sheet of the new firm. In the next period ($t + 1$) liabilities of the new firm i are given by

$$L_{i,t+1} = \zeta^b \bar{P}_{i,t}^{\text{CF}} K_{i,t}. \quad (82)$$

The new firm starts with zero deposits:

$$D_{i,t+1} = 0. \quad (83)$$

The new firm's equity is initialised as

$$E_{i,t+1} = E_{i,t} + (L_{i,t} - D_{i,t} - \zeta^b \bar{P}_{i,t}^{\text{CF}} K_{i,t}) \quad (84)$$

A.2 Government

The Dutch government is modelled to have two functions: to act as a consumer on the retail market to purchase government consumption and as a redistributive entity that redistributes levied taxes to provide social services to its citizens. Government consumption is assumed to be exogenous.

A.2.1 Government Consumption

The government consists of governmental entities $j \in \{1, \dots, J\}$ which participate in the markets as consumers. These entities represent the state, the provincial government, the municipalities and social security funds. Governmental demand follows the following rule:

$$\log(C_t^G) = \alpha^G \log(C_{t-1}^G) + \beta^G + \epsilon_{t-1}^G \quad (85)$$

where ϵ_{t-1}^G is a random shock with zero mean and variance $(\sigma^G)^2$. The total nominal government consumption demand is then uniformly distributed to the J government entities and attributed to goods g :

$$C_{j,t}^d = \frac{C_t^G \sum_g c_g^G \bar{P}_{g,t-1} (1 + \pi_t^e)}{J} \quad (86)$$

and the consumption budget of the j -th government entity to purchase the g -th good is given by

$$C_{jg,t}^d = \frac{c_g^G \bar{P}_{g,t-1}}{\sum_g c_g^G \bar{P}_{g,t-1}} C_{j,t}^d \quad (87)$$

where c_g^G is the fraction of goods of type g demanded by the government. Realized government consumption is then determined again by the search-and-matching process on the consumption goods market:

$$C_{j,t} \begin{cases} = \sum_g C_{jg,t}^d & \text{if the government successfully realized the consumption plan, and} \\ < \sum_g C_{jg,t}^d & \text{if all firms visited could not satisfy its demand.} \end{cases}$$

The government also makes other expenditures such as interest payments, social benefits other than social transfers in kind, and subsidies. The government pays interest at rate r^G on outstanding government debt L_{t-1}^G . The government also pays social benefits for inactive households ($\sum_{h \in H^{\text{inact}}} sb_t^{\text{inact}}$), social benefits for any household h ($\sum_h sb_t^{\text{other}}$), and unemployment benefits for unemployed households ($\sum_{h \in H_t^U} w_{h,t}$). The government also pays subsidies. These are paid to firms via subsidy rates (uniform for each industry, but different across industries) on products and production. These subsidies are incorporated in the net tax rates on products (τ_i^Y) and production (τ_i^{PROD}).

A.2.2 Government Revenue

Taxes, social contributions and other transfers from all sectors form the revenue of the government:

$$\begin{aligned}
Y_t^G = & \underbrace{\left(\tau^{\text{SIF}} + \tau^{\text{SIW}} \right) \bar{P}_t^{\text{HH}} \sum_{h \in H_t^E} w_{h,t}}_{\text{Social security contributions}} + \underbrace{\tau^{\text{INC}} \left(1 - \tau^{\text{SIW}} \right) \bar{P}_t^{\text{HH}} \sum_{h \in H_t^E} w_{h,t}}_{\text{Labor income taxes}} \\
& + \underbrace{\tau_h^{\text{VAT}} \sum_h C_{h,t}}_{\text{Value added taxes}} + \underbrace{\tau^{\text{INC}} \left(1 - \tau^{\text{FIRM}} \right) \theta^{\text{DIV}} \left(\sum_i \max(0, \Pi_{i,t}) + \max(0, \Pi_{k,t}) \right)}_{\text{Capital income taxes}} \\
& + \underbrace{\tau^{\text{FIRM}} \left(\sum_i \max(0, \Pi_{i,t}) + \max(0, \Pi_{k,t}) \right)}_{\text{Corporate income taxes}} + \underbrace{\tau^{\text{CF}} \sum_h I_{h,t}}_{\text{Taxes on capital formation}} \\
& + \underbrace{\sum_i \tau_i^Y P_{i,t} Y_{i,t}}_{\text{Net taxes/subsidies on products}} + \underbrace{\sum_i \tau_i^{\text{PROD}} P_{i,t} Y_{i,t}}_{\text{Net taxes/subsidies on production}} + \underbrace{\tau_l^{\text{EXPORT}} \sum_l C_{l,t}}_{\text{Export taxes}}.
\end{aligned} \tag{88}$$

A.2.3 Government Deficit

The government deficit (or surplus) is an accounting identity consisting of expenditures minus revenues:

$$\begin{aligned}
\Pi_t^G = & \underbrace{\sum_{h \in H^{\text{inact}}} \bar{P}_t^{\text{HH}} sb_t^{\text{inact}} + \sum_{h \in H_t^U} \bar{P}_t^{\text{HH}} \theta^{\text{UB}} w_{h,t} + \sum_h \bar{P}_t^{\text{HH}} sb_t^{\text{other}}}_{\text{Social benefits and transfers}} \\
& + \underbrace{\sum_j C_{p,j,t}}_{\text{Government consumption}} + \underbrace{r^G L_{t-1}^G}_{\text{Interest payments}} - \underbrace{Y_t^G}_{\text{Government revenues}}.
\end{aligned} \tag{89}$$

A.2.4 Government Debt

The government debt is previous period government debt plus the current deficit:

$$L_t^G = L_{t-1}^G + \Pi_t^G. \tag{90}$$

We assume that the central bank buys all government debt.

A.3 Bank

For simplicity, we assume that there is a single bank that represent the entire private financial system. The representative bank takes deposits from households and firms, extends loans to firms, and receives advances from (or deposits reserves at) the central bank.

A.3.1 Provision of Loans

The bank extends loans to firms according to a risk assessment of potential borrowers and is subject to minimum capital requirements imposed by the regulator. The bank uses fractional reserve banking, thus the bank is allowed to loan up to a multiple of its equity. The bank is however uncertain about the realized values of its equity due to fundamental uncertainty and thus the bank must forecast future equity value $E_{k,t}^e$ and future outstanding loan value $\sum_{i=1}^I (L_{i,t}^e + \Delta L_{i,t})$. The bank has to adhere to a minimum capital requirement coefficient $0 < \zeta < 1$:

$$\frac{E_{k,t}^e}{\sum_{i=1}^I (L_{i,t}^e + \Delta L_{i,t})} = \frac{E_{k,t-1}}{\sum_{i=1}^I ((1 - \theta)L_{i,t-1} + \Delta L_{i,t})} \geq \zeta, \quad (91)$$

Therefore, $1/\zeta$ is the maximum allowed leverage for the bank. $\Delta L_{i,t}$ is the realized new loans to firm i in period t , which is equivalent to the new credit demanded by firms $\Delta L_{i,t}^d$ if the bank capital requirements are met and the firm borrows within the maximum LTV. When bank capital and leverage requirements are not met, no lending can take place. Furthermore, the bank forms a risk assessment of a potential default on the part of firm i before extending a loan to it. This risk assessment is based on the borrower's leverage as measured by its loan-to-value ratio, that is the amount of loans over the market value of its capital stock. Thus, the bank will grant a loan to firm i only up to the point where the borrower's leverage (or loan-to-value) ratio after the loan (including overdrafts on deposit accounts), is below a regulated level which is ζ^{LTV} . Due to fundamental uncertainty, the bank has to form expectations on the value of firm i 's capital stock $(K_{i,t}^e)$:

$$\frac{L_{i,t}^e + \Delta L_{i,t}}{K_{i,t}^e} = \frac{\overbrace{(1 - \theta)L_{i,t-1} + \Delta L_{i,t}}^{=L_{i,t}^e}}{\underbrace{\bar{P}_{t-1}^{\text{CF}} (1 + \pi_t^e) K_{i,t-1}}_{=K_{i,t}^e}} \leq \zeta^{\text{LTV}}. \quad (92)$$

Here, $K_{i,t}^e$ denotes the amount of collateral the bank expects a certain firm i to hold at the moment when the firm asks for credit, while $L_{i,t}^e$ is the amount of debt already in the books of the firm. Altogether, therefore, the amount of new credit extended to firm i by the bank ($\Delta L_{i,t}$) depends on the credit demanded by the firm, the bank's risk assessment regarding the default of its potential borrower, and the minimum capital requirements imposed by the regulator:

$$\Delta L_{i,t} \begin{cases} = \Delta L_{i,t}^d & \text{if the borrower's loan-to-value ratio and capital requirements are satisfied} \\ < \Delta L_{i,t}^d & \text{otherwise.} \end{cases} \quad (93)$$

The order of arrival of firms at the bank is random and is important for loan provision. If financially robust (low leverage) firms come late to the bank, then it may be denied credit if it arrived "too late" (i.e. after other less robust firms).

A.3.2 Accounting for Profits and Losses

The difference between interest revenues from loan provisions (including overdrafts on deposit accounts incurred by firms and households ($D_{i,h,t-1} < 0$)) and costs due to interest payments on deposits held with the bank by firms and households ($D_{i,h,t-1} > 0$) are the bank's profits. They are computed as follows:

$$\begin{aligned} \Pi_{k,t} = & r_t \underbrace{\left(\sum_{i=1}^I L_{i,t-1} + \max(0, -D_{i,t-1}) + r_t \sum_{h=1}^H \max(0, -D_{h,t-1}) + \bar{r}_t \max(0, D_{k,t-1}) \right)}_{\text{Interest received}} \\ & - \underbrace{\bar{r}_t \sum_{i=1}^I \max(0, D_{i,t-1}) - \bar{r}_t \sum_{h=1}^H \max(0, D_{h,t-1}) - \bar{r}_t \max(0, -D_{k,t-1})}_{\text{Interest payments}} \end{aligned} \quad (94)$$

The bank pays policy rate $\bar{r}_t$ on deposits. This rate is set exogenously by the central bank. The effective interest rate r_t faced for bank credit or overdrafting is determined by the policy rate $\bar{r}_t$ and a fixed markup μ :

$$r_t = \bar{r}_t + \mu \quad (95)$$

Bank equity is an accounting identity which is determined by bank profits or losses and is given by

$$\begin{aligned} E_{k,t} = & E_{k,t-1} + \Pi_{k,t} - \underbrace{\theta^{\text{DIV}} (1 - \tau^{\text{FIRM}}) \max(0, \Pi_{k,t})}_{\text{Dividend payments}} \\ & - \underbrace{\tau^{\text{FIRM}} \max(0, \Pi_{k,t})}_{\text{Corporate taxes}} - \underbrace{\sum_{i \in I'} (L_{i,t} - D_{i,t} - \zeta^b \bar{P}_{i,t}^{\text{CF}} K_{i,t})}_{\text{Write-off of bad debt}}, \end{aligned} \quad (96)$$

where I' is the set of insolvent borrowers. Moreover, the outstanding overdraft of firm i 's deposit account as well as a fraction $(1 - \zeta^b) \bar{P}_{i,t}^{\text{CF}} K_{i,t}$ of loans extended to firm i have to be written off from the bank's balance sheet when firm i is declared bankrupt. The bank's balance sheet consists of (1) loans to firms (on the asset side); (2) deposits received (on the liability side), (3) equity capital; and (4) (net) central bank reserves held, $D_{k,t}$, or advances obtained by the bank from the central bank:

$$D_{k,t} = \sum_{i=1}^I D_{i,t} + \sum_{h=1}^H D_{h,t} + E_{k,t} - \sum_{i=1}^I L_{i,t} \quad (97)$$

A.4 Central Bank

The central bank (CB) determines monetary policy by setting the policy rate $\bar{r}_t$. The central bank does so taking in consideration implicit inflation and growth targets. Its goal is to provide liquidity to the banking system, and to take deposits from the bank in the form of reserves deposited at the central bank. Finally, the central bank also purchases external assets (government bonds).

A.4.1 Determination of Interest Rates

A generalized Taylor rule (Taylor, 1993) determines the policy rate. We use the same rule as Blattner and Margaritov (2010), which includes a "growth" rule specification:

$$\bar{r}_t = \rho \bar{r}_{t-1} + (1 - \rho) \left(r^* + \pi^* + \xi^\pi \left(\pi_t^{\text{EA}} - \pi^* \right) + \xi^\gamma \gamma_t^{\text{EA}} \right) \quad (98)$$

where ρ is a measure for gradual adjustment of the policy rate, r^* is the real equilibrium interest rate, π^* is the inflation target of the central bank, ξ^π is the weight the central bank puts on inflation targeting and ξ^γ the weight placed on economic growth, respectively. Note that the output gap does not enter the equation. Inflation (π_t^{EA}) and economic growth (γ_t^{EA}) of the monetary union follow an AR(1) rule given by:

$$\log \left(1 + \pi_t^{\text{EA}} \right) = \alpha^{\pi^{\text{EA}}} \log \left(1 + \pi_{t-1}^{\text{EA}} \right) + \beta^{\pi^{\text{EA}}} + \epsilon_{t-1}^{\pi^{\text{EA}}} \quad (99)$$

and

$$\log \left(\gamma_t^{\text{EA}} \right) = \alpha^{\gamma^{\text{EA}}} \log \left(\gamma_{t-1}^{\text{EA}} \right) + \beta^{\gamma^{\text{EA}}} + \epsilon_{t-1}^{\gamma^{\text{EA}}} \quad (100)$$

where

$$\gamma_t^{\text{EA}} = \frac{\gamma_t^{\text{EA}}}{\gamma_{t-1}^{\text{EA}}} - 1 \quad (101)$$

and $\epsilon_{t-1}^{\pi^{\text{EA}}}$ and $\epsilon_{t-1}^{\gamma^{\text{EA}}}$ are random shocks with zero mean. $\epsilon_{t-1}^{\pi^{\text{EA}}}$ has variance $(\sigma^{\pi^{\text{EA}}})^2$. We assume that the small open economy is part of a monetary union and has no influence on the policy rate.

A.4.2 Accounting for Profits and Losses

The difference between revenues from interest payments on government debt, as well as revenues ($D_{k,t} < 0$) or costs ($D_{k,t} > 0$) as a result of the net position in advances or reserves of the banking system is defined as the central bank's profits Π_t^{CB} . Profits are computed by:

$$\Pi_t^{\text{CB}} = r^G L_{t-1}^G - \bar{r}_t D_{k,t-1}. \quad (102)$$

The central bank's equity E_t^{CB} is an accounting identity dependent on its profits or losses and its past equity. It is computed by:

$$E_t^{\text{CB}} = E_{t-1}^{\text{CB}} + \Pi_t^{\text{CB}}. \quad (103)$$

The following law of motion determines the net creditor/debtor position of the national economy to the rest of the world (D_t^{RoW}):

$$D_t^{\text{Row}} = D_{t-1}^{\text{Row}} - \underbrace{\left(1 + \tau^{\text{EXPORT}} \right) \sum_l C_{l,t}}_{\text{Exports}} + \underbrace{\sum_m P_{m,t} Q_{m,t}}_{\text{Imports}}. \quad (104)$$

For instance, a balance of trade surplus ($(1 + \tau^{\text{EXPORT}}) \sum_l C_{l,t} > \sum_m P_{m,t} Q_{m,t}$) enters with a negative sign. This is such as D_t^{RoW} is on the liability side of the central banks balance sheet. Thus a trade surplus would reduce national liabilities versus the RoW as it is an inflow of money into the national economy. Our financial system is closed via the accounting identity

due to inherent stock-flow consistency. This connects the change in the amount of deposits in the banking system to the government deficit (surplus) and to the balance of trade:

$$\begin{aligned} E_t^{\text{CB}} + D_t^{\text{RoW}} &= L_t^G - D_{k,t} \\ &= L_t^G - \sum_{i=1}^I D_{i,t} - \sum_{h=1}^H D_{h,t} - E_{k,t} + \sum_{i=1}^I L_{i,t}. \end{aligned} \quad (105)$$

A.5 Imports and Exports

Trade with the rest of the world (RoW) is modelled by a set of foreign agents that trade with the domestic economy. Each sector is represented by a single foreign agent which supplies goods on the domestic market for intermediate, capital, and consumption goods. Foreign consumption is also modelled by a single agent for each market. We assume a small open economy setting and hence that demand for export and supply for import is exogenous. Hence, imports are constrained by the exogenously set foreign supply. Demand for imports and supply for export is however endogenous.

A.5.1 Imports

Total supply of Imports Y_t^I in real terms follows an AR(1) rule:

$$\log(Y_t^I) = \alpha^I \log(Y_{t-1}^I) + \beta^I + \epsilon_{t-1}^I, \quad (106)$$

where ϵ_{t-1}^I is a random shock with zero mean. A representative foreign firm for each sector imports goods from the rest of the world and supplies them to domestic markets. Thus the m -th, ($m \in \{1, \dots, S\}$), foreign firm representing an industry s imports the principal product g

$$Y_{m,t} = c_{g=s}^I Y_t^I \quad (107)$$

where $c_{g=s}^I$ is the fraction of imported goods of type g as part of total imports. Import price is assumed to develop similarly as the average sectoral domestic adjusted for expected inflation.

$$P_{m,t} = \bar{P}_{g,t-1}(1 + \pi_t^e), \quad (108)$$

where m produces the principal product g . Sales of imports are equal to the realized demand which is an outcome of the search-and-matching process on the goods markets:

$$Q_{m,t} = \min(Y_{m,t}, Q_{m,t}^d) \quad (109)$$

where $Q_{m,t}^d$ is subject to the search-and-matching mechanism specifying the demand by consumers from foreign firm m :

$$Q_{m,t}^d \begin{cases} < Y_{m,t} & \text{if demand from consumers is smaller than supply from foreign firm } m, \\ = Y_{m,t} & \text{if demand from consumers exactly matches supply from foreign firm } m, \text{ and} \\ > Y_{m,t} & \text{if demand from consumers is larger than supply from foreign firm } m. \end{cases} \quad (110)$$

A.5.2 Exports

The export market consists of foreign consumers $l \in \{1, \dots, L\}$ which act in the domestic market as consumer. Total demand for exports C_t^E is assumed to be exogenous and follows an AR(1) rule:

$$\log(C_t^E) = \alpha^E \log(C_{t-1}^E) + \beta^E + \epsilon_{t-1}^E, \quad (111)$$

where ϵ_{t-1}^E is a random shock with zero mean. The total demand for exports is then uniformly distributed to the L foreign consumers and attributed to goods g :

$$C_{l,t}^d = \frac{C_t^E \sum_g c_{g,t}^E \bar{P}_{g,t-1} (1 + \pi_t^e)}{L}, \quad (112)$$

and the demand for exported goods by the l -th foreign consumer to purchase the g -th good is given by

$$C_{lg,t}^d = \frac{c_g^E \bar{P}_{g,t-1}}{\sum_g c_g^E \bar{P}_{g,t-1}} C_{l,t}^d, \quad (113)$$

where c_g^E is the fraction of exports of goods of type g . Realized consumption by foreign consumers is again determined by the search-and-matching process on goods markets:

$$C_{l,t} \begin{cases} = \sum_g C_{lg,t}^d & \text{if the foreign consumer successfully realized the consumption plan, and} \\ < \sum_g C_{lg,t}^d & \text{if all firms visited could not satisfy its demand.} \end{cases} \quad (114)$$

A.6 Macroeconomic Aggregates

Macroeconomic aggregates follow Poledna et al. (2023). GDP in the model is calculated by adding the value of all final goods and services produced and purchased by agents in the model in a given period. The nominal GDP and its components of each period t can be measured by three different approaches: (1) production; (2) expenditure based, and (3) income

based:

$$\begin{aligned}
\text{GDP}_t &= \underbrace{\sum_i \tau_i^Y P_{i,t} Y_{i,t} + \sum_h \tau^{\text{VAT}} C_{h,t} + \sum_h \tau^{\text{CF}} I_{h,t} + \sum_j \tau^G C_{j,t} + \sum_l \tau^{\text{EXPORT}} C_{l,t}}_{\text{Taxes on products}} \\
&+ \underbrace{\sum_i \left(1 - \tau_i^Y\right) P_{i,t} Y_{i,t}}_{\text{Total sales of goods and services}} - \underbrace{\sum_i \frac{1}{\beta_i^M} \bar{P}_{i,t} Y_{i,t}}_{\text{Intermediate inputs}} \quad (\text{Production Approach}) \\
&= \underbrace{\sum_h \left(1 + \tau^{\text{VAT}}\right) C_{h,t}}_{\text{Household consumption}} + \underbrace{\sum_j \left(1 + \tau^G\right) C_{j,t}}_{\text{Government consumption}} + \underbrace{\sum_h \left(1 + \tau^{\text{CF}}\right) I_{h,t} + \sum_i P_{i,t}^{\text{CF}} I_{i,t}}_{\text{Gross fixed capital formation}} \\
&+ \underbrace{\sum_i P_{i,t} (Y_{i,t} - Q_{i,t}) + \bar{P}_{i,t} \left(\Delta M_{i,t} - \frac{1}{\beta_i^M} Y_{i,t}\right)}_{\text{Changes in inventories}} \quad (\text{Expenditure Approach}) \\
&+ \underbrace{\sum_l \left(1 + \tau^{\text{EXPORT}}\right) C_{l,t}}_{\text{Exports}} - \underbrace{\sum_m P_{m,t} Q_{m,t}}_{\text{Imports}} \\
&= \underbrace{\sum_i \tau_i^Y P_{i,t} Y_{i,t} + \sum_h \tau^{\text{VAT}} C_{h,t} + \sum_h \tau^{\text{CF}} I_{h,t} + \sum_j \tau^G C_{j,t} + \sum_l \tau^{\text{EXPORT}} C_{l,t}}_{\text{Taxes on products}} \\
&+ \underbrace{\sum_i P_{i,t} Y_{i,t} - \left(1 + \tau^{\text{SIF}}\right) \bar{P}_t^{\text{HH}} N_{i,t} w_{i,t} - \frac{1}{\beta_i^M} \bar{P}_{i,t} Y_{i,t} - \tau_i^Y P_{i,t} Y_{i,t} - \tau_i^{\text{PROD}} P_{i,t} Y_{i,t}}_{\text{Gross operating surplus and mixed income}} \\
&+ \underbrace{\sum_i \left(1 + \tau^{\text{SIF}}\right) \bar{P}_t^{\text{HH}} N_{i,t} w_{i,t}}_{\text{Compensation of employees}} + \underbrace{\sum_i \tau_i^{\text{PROD}} P_{i,t} Y_{i,t}}_{\text{Net taxes on production}} \quad (\text{Income Approach})
\end{aligned} \tag{115}$$

The GDP deflator is a measure of inflation and is an economy-wide average price of all goods and services produced and sold. All individual prices and sales are determined on the agent level by the search and matching mechanism. In our model, the GDP deflator is defined as nominal GDP divided by real GDP:

$$\text{GDP deflator}_t = \frac{\text{GDP}_t}{\text{real GDP}_t}, \tag{116}$$

where

$$\begin{aligned}
\text{real GDP}_t &= \sum_i \tau_i^Y Y_{i,t} + \sum_h \tau^{\text{VAT}} \frac{C_{h,t}}{\bar{P}_{h,t}} + \sum_h \tau^{\text{CF}} \frac{I_{h,t}}{\bar{P}_{h,t}^{\text{CF}}} + \sum_j \tau^G \frac{C_{j,t}}{\bar{P}_{j,t}} \\
&+ \sum_l \tau^{\text{EXPORT}} \frac{C_{l,t}}{\bar{P}_{l,t}} + \sum_i \left(1 - \tau_i^Y\right) Y_{i,t} - \sum_i \frac{1}{\beta_i^M} Y_{i,t}.
\end{aligned} \tag{117}$$

B Sector Parameters

In this section we report the sector parameters. Parameters are shown for 2010Q1. Column headers correspond to the number of firms (I_s), employment (N_s), labour productivity (α_s), intermediate input productivity (β_s), capital productivity (κ_s), depreciation rate (δ_s), average wage (w_s), net product tax rate (τ_s^Y), net production tax rate (τ_s^{PROD}), and the capital formation (b_g^{CF}), household capital formation (b_g^{CFH}), household consumption (b_g^{HH}), government consumption (c_g^G), export (c_g^E), and import (c_g^I) coefficients.

Table 12: Sectoral parameters

	I_s	N_s	α_s	β_s	κ_s	δ_s	w_s	τ_s^Y	τ_s^{PROD}	b_g^{CF}	b_g^{CFH}	b_g^{HH}	c_g^G	c_g^E	c_g^I
A01	47	50	142.2422	1.6442	0.0697	0.0092	10.228	0.0081	-0.0198	0.0038	0	0.0116	0.0003	0.0371	0.0341
A02	1	1	62.7955	1.8045	0.325	0.0135	17.0328	0.0125	0	0	0	0	0.0006	0.0006	0.0005
A03	1	1	138.935	2.2311	0.0531	0.0083	12.2553	0	0.0038	0	0	0.0002	0	0.0015	0.0009
B	1	4	1363.5774	5.8705	0.3027	0.0238	42.0109	0.0006	0.0008	0.0051	0	0.0122	0.0001	0.0456	0.1006
C10-12	3	61	226.8615	1.2876	0.7901	0.029	18.8172	0.0058	0.004	0.0025	0	0.0692	0	0.0805	0.0602
C13-15	2	7	118.0405	1.5052	0.5931	0.0346	18.1308	0.0085	0.0003	0.002	0	0.0206	0	0.019	0.0327
C16	1	7	96.4733	1.5227	0.6919	0.0287	18.6946	0.0031	-0.0046	0.0019	0	0.001	0	0.0017	0.0062
C17	1	9	167.7744	1.3859	0.6517	0.0443	22.5258	0.0047	0.0005	0.0001	0	0.0032	0	0.0088	0.0125
C18	1	14	88.4743	1.7152	0.5085	0.0472	18.6204	0.0034	0	0.0006	0	0.0007	0	0.001	0
C19	1	3	2298.3141	1.0264	1.3098	0.0306	40.1587	0.0003	0.0003	0.0006	0	0.0124	0	0.07	0.0525
C20	1	22	469.3842	1.269	1.2584	0.0668	29.883	0.0018	0.0002	0.004	0	0.0056	0	0.0979	0.0797
C21	1	8	187.765	1.9297	0.3421	0.0467	27.5745	0.0014	0.0014	0.0014	0	0.0044	0.0145	0.0408	0.049
C22	1	15	119.6428	1.5382	0.684	0.0385	19.6085	0.0055	-0.0022	0.0039	0	0.002	0	0.0157	0.0191
C23	1	13	109.248	1.5451	0.4147	0.0228	20.1007	0.0088	0.0004	0.0014	0	0.0014	0	0.0037	0.0076
C24	2	11	190.4082	1.3076	0.8387	0.0399	22.3391	-0.0006	-0.0046	0.0007	0	0.0002	0	0.0266	0.0318
C25	4	42	105.1637	1.5537	0.6349	0.0255	19.0012	0.003	-0.0021	0.0146	0	0.0025	0	0.0117	0.0144
C26	1	14	464.8173	1.2193	0.3015	0.0141	26.1131	0.0008	-0.002	0.0502	0	0.0135	0.0045	0.1258	0.1399
C27	1	10	129.0447	1.6943	0.5589	0.0932	22.1635	0.0041	-0.0041	0.006	0	0.0041	0.0001	0.021	0.0271
C28	2	36	152.8241	1.6006	0.8951	0.0506	23.3451	0.0025	-0.0034	0.0587	0	0.0007	0	0.0579	0.0512
C29	1	10	155.0001	1.4389	0.6434	0.0463	20.0447	0.0039	-0.0037	0.0523	0	0.0134	0	0.0147	0.0323
C30	1	9	189.84	1.4251	1.5109	0.0514	21.3257	0.0018	-0.0031	0.0293	0	0.0039	0	0.0108	0.0102
C31_32	6	71	40.5554	2.0417	0.76	0.0399	13.212	0.0093	-0.0067	0.022	0	0.0104	0.0151	0.0208	0.0274
C33	2	18	114.3401	1.5387	3.119	0.1063	24.5799	0.0018	-0.0008	0.0036	0	0.0003	0	0.0025	0.0017
D	1	13	357.6926	1.6992	0.3929	0.0507	25.709	0.0007	0.0011	0.0147	0	0.018	0	0.0022	0.0019
E36	1	3	148.0054	3.1081	0.0634	0.0173	21.8796	0.0843	0.0189	0.0007	0	0.0039	0	0	0
E37-39	2	14	133.0105	1.5777	0.1107	0.0094	20.7124	0.0103	-0.0049	0.0003	0	0.0012	0.0005	0.0078	0.0088
F	74	184	124.4548	1.5484	0.6466	0.0163	21.1838	0.0053	-0.0002	0.3977	0	0.0019	0.0031	0.006	0
G45	16	57	75.3683	1.9114	0.6931	0.0391	16.4425	0.0112	-0.0022	0.0099	0	0.0251	0	0.0027	0
G46	43	219	96.3222	2.3218	0.7276	0.0364	21.374	0.0035	-0.0044	0.0015	0	0.0506	0.0055	0.0884	0.0086
G47	58	334	27.2404	2.6443	0.5602	0.042	7.856	0.0064	-0.0085	0.0028	0	0.1184	0.0099	0.0031	0
H49	9	91	74.3942	1.8315	0.2525	0.0153	17.3844	0.0303	0.0015	0.0058	0	0.0213	0.0038	0.0193	0.0099
H50	3	8	232.2778	1.4592	0.2618	0.0274	21.8882	0.0042	-0.008	0.0004	0	0.0013	0	0.0131	0.0041
H51	1	13	190.6406	1.4254	0.673	0.0623	29.3681	-0.0014	0.0056	0.0008	0	0.0061	0	0.0131	0.0042
H52	3	37	123.618	1.9797	0.0742	0.0096	23.051	0.0118	0.0034	0.0036	0	0.0027	0.0097	0.0135	0.0064
H53	3	32	40.8171	2.2236	1.616	0.0634	11.3271	0.0419	-0.0026	0.0004	0	0.0014	0	0.0032	0.0022
I	25	144	34.9064	1.929	0.4168	0.0188	7.0638	0.0226	0.0017	0.0004	0	0.0661	0.0003	0.0003	0.0098
J58	2	16	103.6125	2.0038	2.5062	0.1048	21.8103	-0.0002	0.0005	0.0041	0	0.0084	0	0.0023	0.0039
J59_60	6	10	111.2788	1.8703	0.868	0.0512	20.7718	0.0169	-0.0016	0.0013	0	0.0066	0	0.0008	0.0013
J61	1	16	281.9909	2.1403	0.2185	0.0376	27.6394	0.0015	-0.0006	0.0038	0	0.0317	0	0.0033	0.0041
J62_63	26	71	86.4875	2.3887	1.7509	0.0953	26.2104	0.0019	-0.0061	0.063	0	0.0031	0.0007	0.0141	0.0107
K64	6	61	214.2981	3.3865	0.4488	0.0176	36.3846	0.0202	0.0015	0.0025	0	0.0171	0.0001	0.02	0.008
K65	1	41	129.5476	1.9359	0.8417	0.074	25.8076	0.0189	0.0073	0.0032	0	0.0519	0.0001	0.0032	0.0015
K66	8	24	65.63	3.4499	3.4776	0.1987	27.7649	0.0299	0.0015	0.001	0	0.0007	0	0.0005	0.0003
L68A	14	34	528.3746	1.9306	0.1355	0.0515	22.8184	0.0218	0.0297	0.0168	0	0.1842	0.0141	0.0004	0
M69_70	69	151	85.6611	2.2496	1.5542	0.0585	26.3086	0.0007	-0.0009	0.0218	0	0.0076	0.0022	0.0195	0.0439
M71	19	51	77.2271	2.3867	0.6943	0.0417	24.3274	0.0019	-0.0041	0.0717	0	0.0007	0.0001	0.0038	0.0001
M72	2	16	75.1256	2.2247	2.3388	0.839	25.2507	0.0007	-0.2664	0.0269	0	0.0002	0.0038	0.0021	0.0025
M73	18	21	100.7593	1.6633	2.3769	0.1005	18.566	0.002	-0.0002	0.0009	0	0.0001	0	0.0014	0.0031
M74_75	22	22	68.635	1.9237	1.2497	0.0643	11.6511	0.0047	-0.0085	0.0008	0	0.003	0	0.0011	0.0014
N77	5	13	210.1032	2.6242	1.1406	0.0429	19.0141	0.0302	0.0442	0.0055	0	0.0182	0	0.0314	0.0674
N78	7	249	18.2019	4.9294	9.3894	0.1897	10.0747	0.0009	-0.01	0.0029	0	0.0002	0.0023	0.0003	0.0009
N79	2	10	174.4929	1.2992	1.5567	0.0317	13.9171	-0.0133	-0.0027	0.0005	0	0.0155	0	0.0023	0
N80-82	16	101	35.9623	2.9084	0.9643	0.0381	11.081	0.0045	-0.0087	0.0022	0	0.0107	0	0.0014	0.0013
O	5	254	77.5868	2.6845	0.1595	0.0273	24.7495	0.0512	0.0031	0.0253	0	0.0143	0.3768	0.0019	0.0003
P	22	245	40.3055	5.2785	0.2315	0.0348	19.4	0.027	0.0012	0.0245	0	0.0101	0.1724	0.0006	0
Q86	36	233	46.0174	3.4401	0.3195	0.0182	17.2718	0.0299	-0.0407	0.0114	0	0.024	0.1831	0.0003	0
Q87_88	12	368	23.1359	3.7579	0.3653	0.0235	11.5328	0.0292	0.0009	0.0014	0	0.0137	0.1695	0	0
R90-92	28	28	76.7376	2.5182	0.3728	0.0309	14.8073	0.0068	0.0024	0.0031	0	0.0183	0.0054	0.0005	0.0005
R93	9	28	51.9745	1.9427	0.1051	0.0057	12.055	0.0451	0.0025	0.0005	0	0.0167	0.0001	0	0
S94	7	36	43.1646	2.6983	0.2396	0.0147	16.9867	0.0502	-0.002	0.0005	0	0.0147	0.0011	0.0001	0
S95	4	4	52.1333	1.9679	3.6944	0.2735	9.0876	0.0151	0.0013	0.0005	0	0.0013	0	0.0002	0.0003
S96	32	32	41.2095	2.6526	0.2908	0.0233	8.1205	0.0188	-0.0093	0.0004	0	0.0158	0	0	0.0005

Note: Sectoral parameters are shown for 2010Q1.

C Neural Network Architecture and Training

This appendix describes the forecasting policy used in Section 2.3.

C.1 Network Architecture

The policy is an MLP with three hidden layers of 256 Swish units: $20 \rightarrow 256 \rightarrow 256 \rightarrow 256 \rightarrow 2$, with 137,474 trainable coefficients. Its inputs comprise six states (k, b, y, r^k, r^b, π) , five parameters $\Gamma = (\beta, \sigma, c_{\text{int}}, \chi_0^b, \chi_1^b)$, and nine belief summaries $(\bar{R}_j, \rho_j, \sigma_j)$ for $j \in \{k, b, \pi\}$. Income persistence and volatility are fixed process parameters, not additional network inputs. Asset, income, preference and belief inputs use min-max scaling with clipping to $[-1, 1]$; rates and inflation are standardised around their perceived stationary means using stationary standard deviations. Initialisation uses He weights for the hidden layers and Glorot weights for the output layer, with policy-head biases set to initial consumption and deposit allocations.

The two raw outputs are transformed into a consumption share and a signed deposit share, $2 \text{sigmoid}(z_d) - 1$. Consumption is funded from liquid resources; positive deposits are bounded by remaining liquid savings and withdrawals by the illiquid stock. The transformation determines k' and b' and charges adjustment costs to consumption. The implicit Euler gaps λ_k, λ_b are computed from the continuation calculation, rather than separate multiplier heads. Numerical floors and clipping are part of this approximation; exact global feasibility and optimality are not established by the network architecture.

C.2 Two-Stage Estimation and Forecasting

Estimation has two stages, followed by forecasting with fixed weights. Policy training uses 8,000 epochs and calibration 2,000 iterations.

Stage 1: Amortised policy training. Network weights are trained while states, preference parameters and belief summaries are sampled over their support. The loss combines two implicit Euler/complementarity residuals:

$$\mathcal{L} = \frac{1}{n} \sum_{i=1}^n \frac{\bar{R} (R_{k,i}^2 + R_{b,i}^2)}{\bar{R} + R_{k,i}^2 + R_{b,i}^2}, \quad \bar{R} = 0.25. \quad (118)$$

The bond residual contains the direct shifted convenience wedge described in Section 2.2.2, not a separable bond-utility marginal term normalised by consumption marginal utility. Conditional expectations use Stroud-3 quadrature: eight equally weighted nodes over the capital-return, bond-return, inflation and income shocks. The routine transforms the raw CRRA log discount factor ℓ to $10 \tanh(\ell/10)$ before exponentiating. Training uses Adam, learning rate 3×10^{-4} decaying exponentially to 3×10^{-6} , and gradient clipping at unit norm. Neither the capped loss nor reported diagnostic residuals imply a globally exact household solution.

Stage 2: Moment calibration. The network is fixed while the five policy parameters are calibrated by simulated moment matching using differentiable forward passes. The moments are

APC, K_1/B_1 , and MPCs with respect to income, capital and bonds. The targets are $APC = 0.8958$, $MPC_y = 0.33$, $MPC_k = 0.047$ and $MPC_b = 0.04$; the capital-to-positive-bond ratio is taken from the input cross-section. APC and ratio moment errors have weights 5, and each MPC error weight 1. Adam uses learning rate 0.05. Calibration is evaluated on an evenly spaced household subsample of up to 1,000 observations; income perturbations are 0.1 and asset perturbations 0.01 in normalised units.

Forecasting. Both calibrated preferences and network weights remain fixed within each forecast path. Return and inflation beliefs are updated from the expanding observed history and supplied as network inputs. The forecasting wrapper deflates nominal asset and income states by the stored household price index, evaluates the policy and converts consumption and capital decisions back into nominal ABM units. No online network-gradient updates are used.

Quarterly initialisation. A separate network is built for each quarterly calibration, rather than requiring a warm start from the previous quarter. The forecasts cover 40 origins from 2010Q1 to 2019Q4. Robustness across training seeds remains unverified.

C.3 Batch Construction

Training uses batches of 1,024 state–parameter–belief observations: half are sampled from the low-wealth third of the empirical cross-section, one quarter from the full cross-section and one quarter from a broader uniform state box, with jitter applied to sampled household states. Preference and return/inflation-belief parameters are drawn over their configured ranges, with realised rates drawn around each sample’s belief mean. The reference state bounds are $k \in [0, 350]$, $b \in [-15, 350]$ and $y \in [0.1, 20]$; the effective liquid floor is $\max(-0.6y, -15)$. For each observation, the same eight quadrature nodes evaluate future shocks. There are no independent double-draw products in this training objective.

D Internal Validity under Alternative Expectations

The correlation figures below use a bond-liquidity variant of the household block, not the two-account Euler policy used for forecasting. They diagnose the shared ABM framework; a multi-origin internal-validity exercise for the forecasting policy is not reported here.

This appendix presents the auto- and cross-correlation diagnostics for the bond-liquidity variant under ARX, VAR, and VARX expectations, complementing the AR-expectations analysis in Section 5. The simulation setup is identical: 100 Monte Carlo simulations from the 2012Q1 calibration origin over a 20-quarter horizon, with HP-filtered ($\lambda = 1,600$) cyclical components.

D.1 ARX Expectations

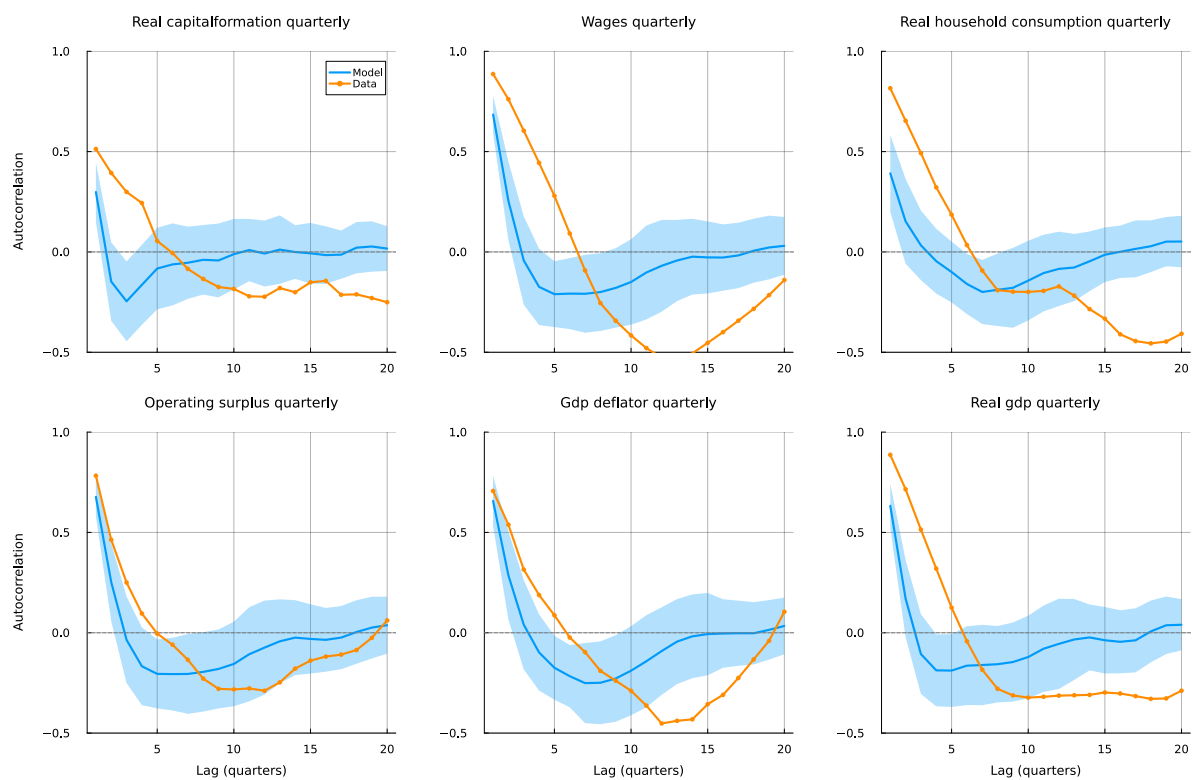


Figure 14: Bond-liquidity variant: auto-correlations of HP-filtered ($\lambda = 1,600$) cyclical components under ARX expectations. Blue line: mean across 100 Monte Carlo simulations from origin 2012Q1 (20-quarter horizon). Shaded area: ± 1 standard deviation. Orange line: empirical ACF (1997Q1–2019Q4). Compared to Figure 12 (AR expectations), the GDP deflator persistence is reduced under ARX expectations.

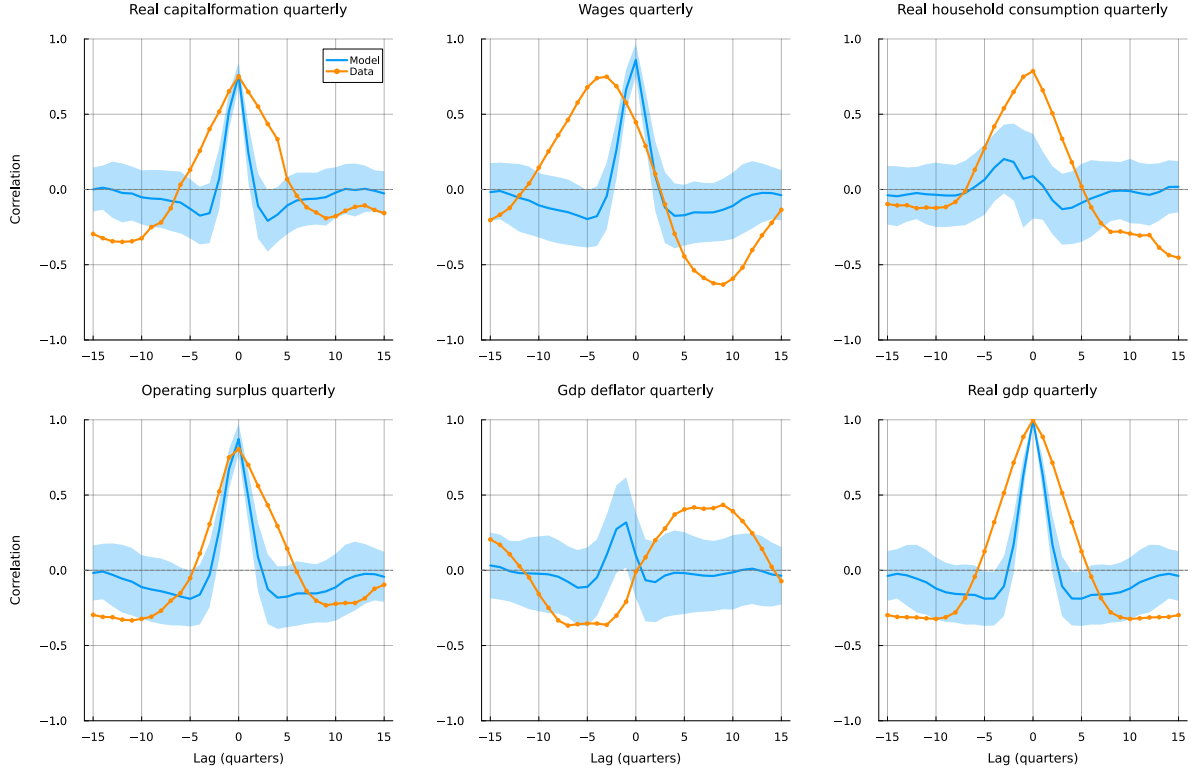


Figure 15: Bond-liquidity variant: cross-correlations between HP-filtered ($\lambda = 1,600$) cyclical GDP and other variables under ARX expectations. Positive lags: variable lags GDP. Negative lags: variable leads GDP. Blue line: mean across 100 Monte Carlo simulations from origin 2012Q1 (20-quarter horizon). Shaded area: ± 1 standard deviation. Orange line: empirical cross-correlation (1997Q1–2019Q4). The GDP deflator cross-correlations improve markedly relative to AR expectations (Figure 13), aligning more closely with the empirical pattern.

D.2 VAR Expectations

D.3 VARX Expectations

D.4 Interpretation

Comparing the alternative-expectations diagnostics with the AR-expectations results in Section 5, two improvements are evident across all three mechanisms. First, the GDP deflator auto-correlations decay more rapidly under ARX, VAR, and VARX expectations, reducing the excess persistence identified under AR expectations. This suggests that richer expectation processes, whether conditioning on exogenous variables (ARX, VARX) or exploiting cross-variable dynamics (VAR, VARX), discipline the model's price dynamics, anchoring inflation expectations closer to their empirical counterparts. Second, the GDP deflator's cross-correlations with GDP at positive lags improve, with the model generating a more realistic decay pattern that aligns more closely with the empirical profile.

The wage timing discrepancy persists under all alternative expectations: wages remain coincident with GDP rather than leading. This confirms that the wage timing discrepancy originates in the labour market module's immediate wage adjustment mechanism rather than in the expectation formation process. The capital formation and household consumption cross-correlations remain well-matched at lag zero across all specifications, indicating that these demand-side comovements of the bond-liquidity variant do not depend on the choice of ag-

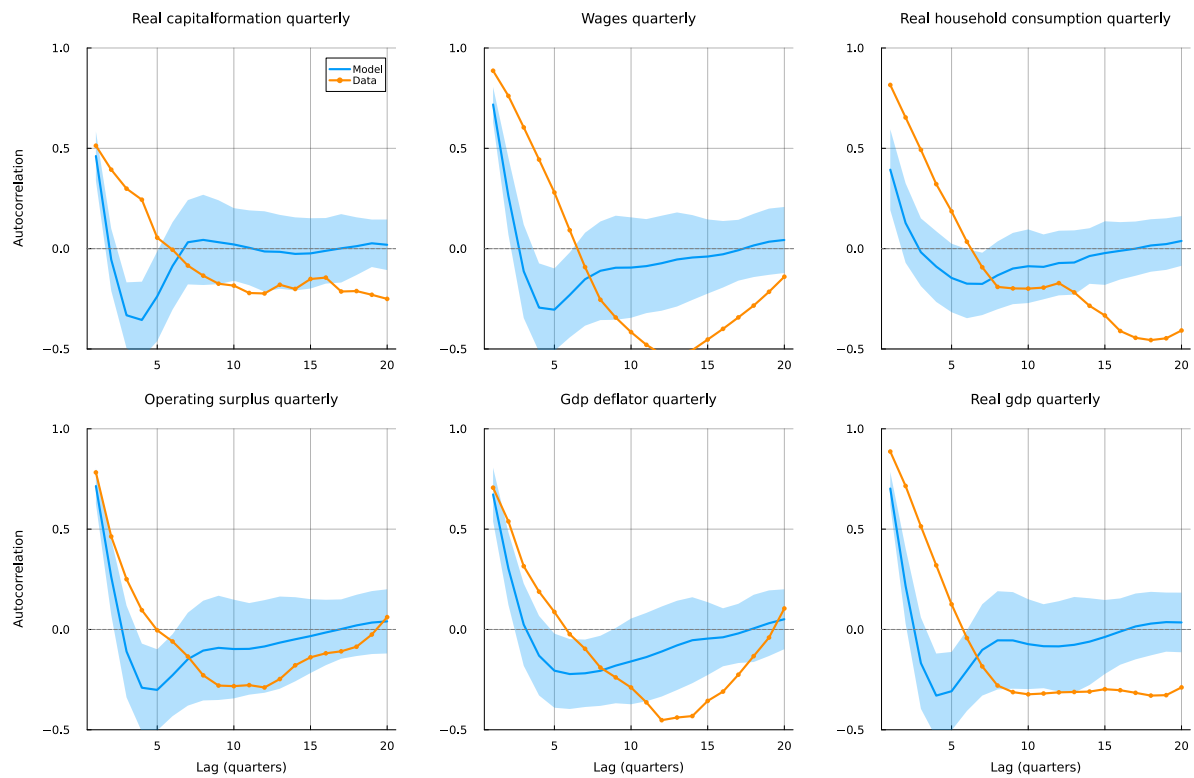


Figure 16: Bond-liquidity variant: auto-correlations of HP-filtered ($\lambda = 1,600$) cyclical components under VAR expectations. Blue line: mean across 100 Monte Carlo simulations from origin 2012Q1 (20-quarter horizon). Shaded area: ± 1 standard deviation. Orange line: empirical ACF (1997Q1–2019Q4).

gregate expectations.

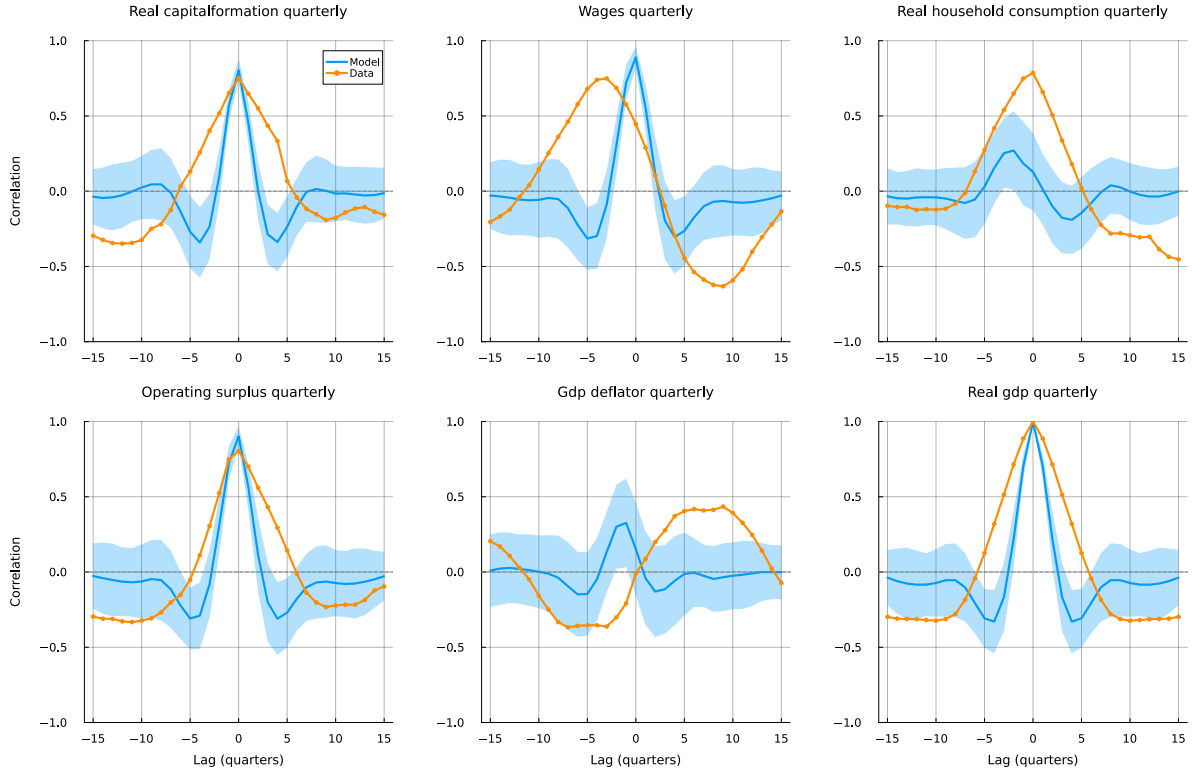


Figure 17: Bond-liquidity variant: cross-correlations between HP-filtered ($\lambda = 1,600$) cyclical GDP and other variables under VAR expectations. Positive lags: variable lags GDP. Negative lags: variable leads GDP. Blue line: mean across 100 Monte Carlo simulations from origin 2012Q1 (20-quarter horizon). Shaded area: ± 1 standard deviation. Orange line: empirical cross-correlation (1997Q1–2019Q4).

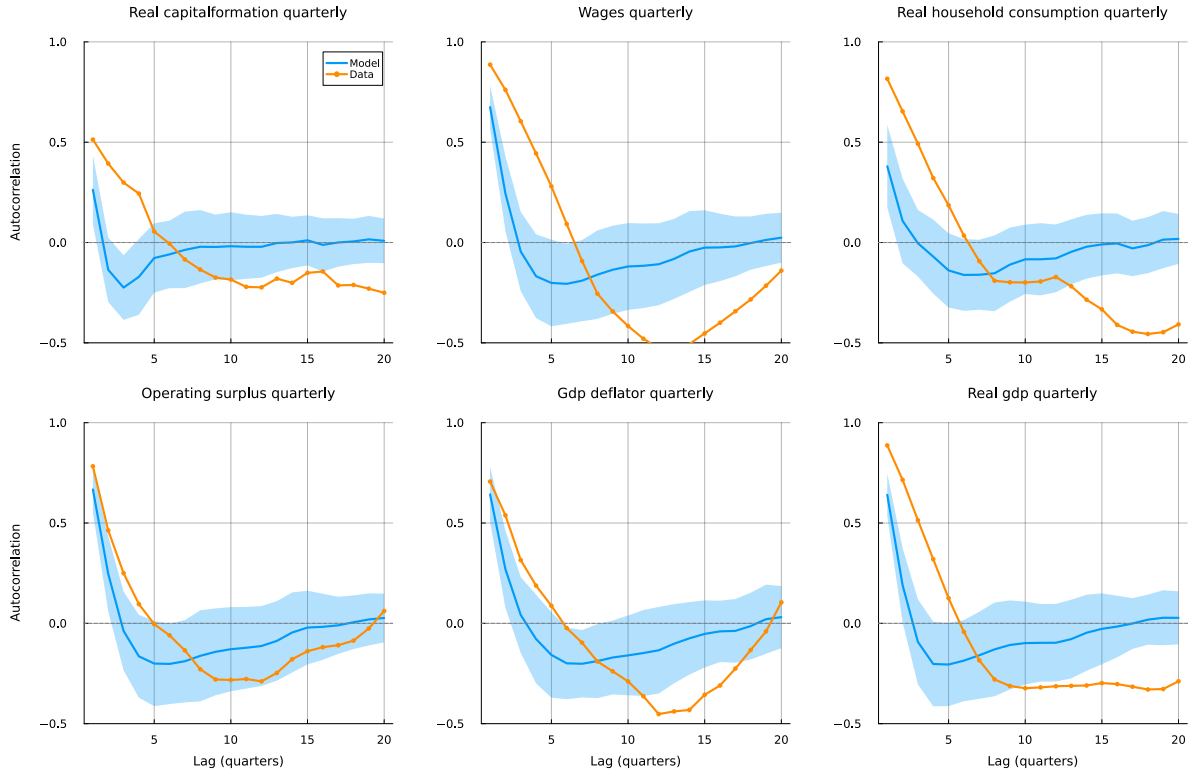


Figure 18: Bond-liquidity variant: auto-correlations of HP-filtered ($\lambda = 1,600$) cyclical components under VARX expectations. Blue line: mean across 100 Monte Carlo simulations from origin 2012Q1 (20-quarter horizon). Shaded area: ± 1 standard deviation. Orange line: empirical ACF (1997Q1–2019Q4).

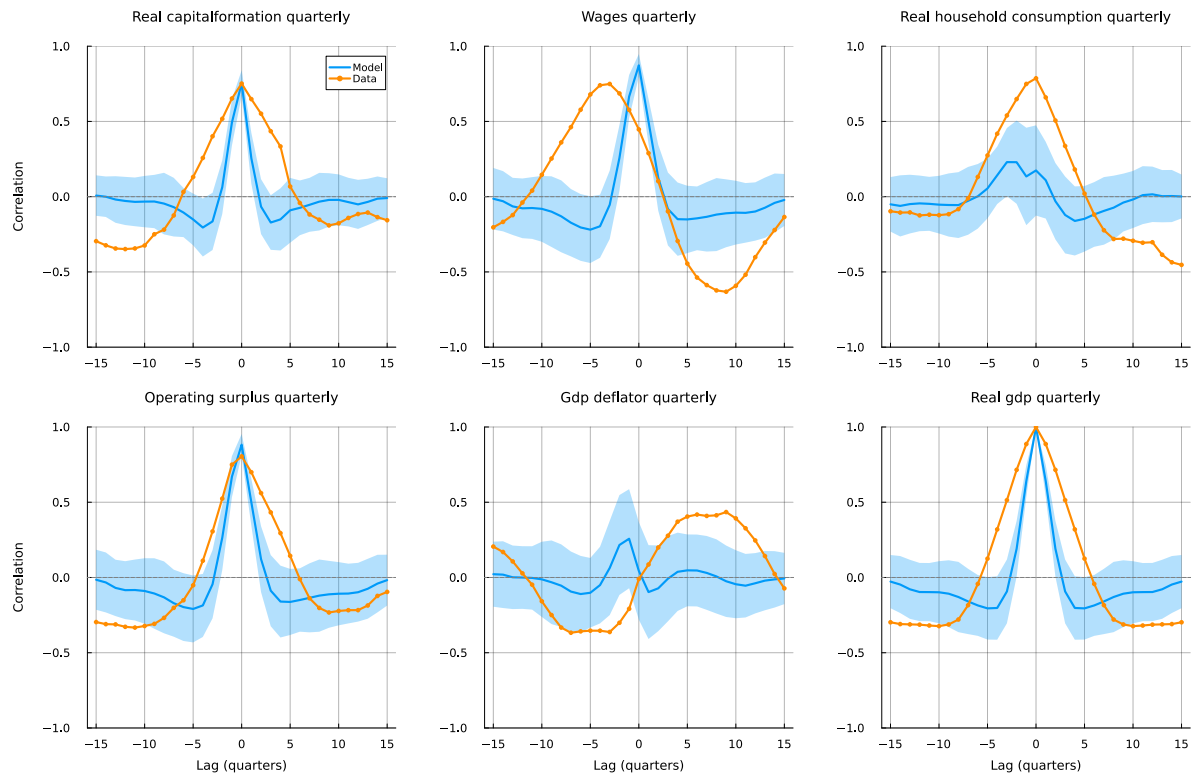


Figure 19: Bond-liquidity variant: cross-correlations between HP-filtered ($\lambda = 1,600$) cyclical GDP and other variables under VARX expectations. Positive lags: variable lags GDP. Negative lags: variable leads GDP. Blue line: mean across 100 Monte Carlo simulations from origin 2012Q1 (20-quarter horizon). Shaded area: ± 1 standard deviation. Orange line: empirical cross-correlation (1997Q1–2019Q4).

E Forecasting Results of Heuristic ABMs

This appendix reports the full forecast results for the seven core heuristic ABM variants (H1–H7, defined in Section 2.4) under all four expectation mechanisms. Section 4 presents selected comparisons; here we provide the complete set for reference. All seven heuristics allow liquid dissaving to a flat floor; the OC-ABM uses a different income-dependent floor (Section 2.4). All reported p -values use the corrected method in Section 4; stars denote nominal exploratory significance against the stated benchmark, not differences between ABM variants. There are 39, 38, 36, 32 and 28 eligible origins at horizons 1, 2, 4, 8 and 12 quarters respectively.

E.1 Heuristic ABMs under AR expectations

Table 13: Heuristic ABM forecast performance under AR expectations, relative to AR(1)

	GDP	Inflation	Household cons.	Investment	Euribor
AR(1)	<i>RMSFE for different forecast horizons</i>				
1q	0.41	0.57	0.56	3.3	0.03
2q	0.67	0.57	0.82	4.48	0.06
4q	1.32	0.56	1.47	6.21	0.11
8q	2.59	0.58	2.72	9.61	0.16
12q	3.47	0.6	3.68	13.27	0.2
H1-ABM	<i>Percentage improvements (+) or losses (-) relative to AR(1) model</i>				
1q	-0.6 (0.942)	-1.4 (0.671)	-35.3** (0.013)	8.8 (0.263)	-80.9*** (< 0.001)
2q	-17.9 (0.331)	-2.5 (0.231)	-61.0*** (0.005)	0.7 (0.876)	-38.9*** (0.009)
4q	-60.8* (0.098)	-2.9 (0.123)	-103.5** (0.014)	-8.5 (0.346)	-17.7 (0.261)
8q	-29.6 (0.614)	-2.6 (0.160)	-195.5** (0.041)	-2.3 (0.823)	-8.9 (0.740)
12q	-91.9 (0.384)	-2.4 (0.605)	-292.2** (0.023)	-14.0 (0.575)	-5.5 (0.866)
H2-ABM	<i>Percentage improvements (+) or losses (-) relative to AR(1) model</i>				
1q	-0.6 (0.946)	-1.4 (0.671)	-38.2*** (0.009)	8.8 (0.263)	-80.9*** (< 0.001)
2q	-18.8 (0.308)	-1.3 (0.589)	-65.0*** (0.004)	0.4 (0.934)	-39.2*** (0.008)
4q	-61.0* (0.097)	-2.2 (0.168)	-107.1** (0.012)	-9.1 (0.317)	-16.9 (0.290)
8q	-31.4 (0.596)	0.5 (0.775)	-214.7** (0.031)	-2.3 (0.826)	-6.3 (0.818)
12q	-96.9 (0.358)	0.8 (0.687)	-307.9** (0.019)	-14.8 (0.569)	-2.7 (0.937)
H3-ABM	<i>Percentage improvements (+) or losses (-) relative to AR(1) model</i>				
1q	-1.3 (0.881)	-1.4 (0.671)	2.6 (0.767)	8.8 (0.263)	-80.9*** (< 0.001)
2q	-7.5 (0.652)	0.5 (0.794)	10.1 (0.440)	1.2 (0.770)	-39.4*** (0.009)
4q	-31.1 (0.338)	-2.6 (0.166)	-13.6 (0.645)	-5.1 (0.520)	-15.7 (0.352)
8q	9.4 (0.851)	0.4 (0.744)	-30.7 (0.409)	7.3 (0.303)	-8.8 (0.751)
12q	6.2 (0.938)	-3.4 (0.540)	-25.9 (0.670)	6.5 (0.448)	-3.4 (0.921)
H4-ABM	<i>Percentage improvements (+) or losses (-) relative to AR(1) model</i>				
1q	-1.3 (0.886)	-1.4 (0.671)	3.0 (0.730)	8.8 (0.263)	-80.9*** (< 0.001)
2q	-4.6 (0.782)	3.4** (0.036)	8.8 (0.507)	1.7 (0.694)	-40.5*** (0.006)
4q	-29.5 (0.371)	-1.9 (0.305)	-15.1 (0.613)	-4.2 (0.595)	-17.6 (0.289)
8q	3.4 (0.946)	0.0 (0.984)	-37.2 (0.326)	5.3 (0.482)	-7.3 (0.788)
12q	-0.4 (0.996)	-0.7 (0.736)	-37.0 (0.547)	5.6 (0.532)	-2.8 (0.933)
H5-ABM	<i>Percentage improvements (+) or losses (-) relative to AR(1) model</i>				
1q	-1.3 (0.878)	-1.4 (0.671)	-3.5 (0.689)	8.8 (0.263)	-80.9*** (< 0.001)
2q	-12.8 (0.434)	0.1 (0.956)	-8.8 (0.451)	0.6 (0.885)	-39.4*** (0.010)
4q	-43.1 (0.208)	-0.5 (0.694)	-42.4 (0.205)	-7.3 (0.384)	-16.1 (0.346)
8q	-1.8 (0.970)	-1.9* (0.077)	-26.8 (0.634)	2.7 (0.680)	-8.0 (0.779)
12q	-4.0 (0.955)	1.4 (0.788)	-27.0 (0.758)	4.2 (0.385)	-2.4 (0.949)

Continued on next page

Table 13: Heuristic ABM forecast performance under AR expectations, relative to AR(1) (continued)

	GDP	Inflation	Household cons.	Investment	Euribor
H6-ABM	<i>Percentage improvements (+) or losses (-) relative to AR(1) model</i>				
1q	-2.0 (0.818)	-1.4 (0.671)	-2.9 (0.711)	8.8 (0.263)	-80.9*** (< 0.001)
2q	-5.8 (0.712)	-1.0 (0.625)	10.1* (0.077)	1.4 (0.741)	-39.1*** (0.010)
4q	-22.4 (0.472)	-1.5 (0.357)	10.9 (0.617)	-4.8 (0.517)	-17.4 (0.274)
8q	14.3 (0.749)	-1.2 (0.469)	20.0 (0.645)	7.0* (0.090)	-8.4 (0.748)
12q	17.1 (0.798)	0.7 (0.748)	31.6 (0.662)	8.2** (0.011)	-1.5 (0.965)
H7-ABM	<i>Percentage improvements (+) or losses (-) relative to AR(1) model</i>				
1q	-2.7 (0.759)	-1.4 (0.671)	-40.7*** (0.008)	8.8 (0.263)	-80.9*** (< 0.001)
2q	-1.6 (0.907)	2.3* (0.058)	-15.7 (0.223)	1.6 (0.702)	-39.7*** (0.010)
4q	-14.7 (0.600)	-1.2 (0.525)	7.5 (0.377)	-3.7 (0.574)	-17.1 (0.281)
8q	13.0 (0.710)	2.3 (0.100)	9.7 (0.680)	5.2** (0.034)	-8.8 (0.734)
12q	11.2 (0.829)	-1.4 (0.520)	13.7 (0.756)	6.9*** (0.008)	-3.2 (0.925)

Note: The table depicts the RMSFE of the forecast period 2010Q1 to 2019Q4. The AR(1) is estimated starting in 1997Q1 and is re-estimated each quarter. The ABM is calibrated to 40 different reference quarters from 2010Q1 to 2019Q4 and the ABM results are obtained as an average of 100 Monte Carlo simulations. We report the p-values of the Diebold-Mariano tests (Harvey et al., 1997). We test the null hypothesis whether the tested models have the same accuracy as the AR(1) model. We denote 10 percent, 5 percent and 1 percent significance by *, **, and *** respectively.

Table 14: Heuristic ABM forecast performance under AR expectations, relative to VAR(1)

	GDP	Inflation	Household cons.	Gov. cons.	Exports	Imports	GDP EA	Infl. EA	Euribor
VAR(1)	<i>RMSFE for different forecast horizons</i>								
1q	0.39	0.75	0.6	0.57	1.26	1.38	0.36	0.15	0.04
2q	0.7	0.7	0.84	0.94	2.61	2.35	0.76	0.16	0.07
4q	1.52	0.85	1.4	1.66	5.42	4.85	1.69	0.18	0.16
8q	3.45	1.11	2.76	3.04	9.88	8.85	3.71	0.2	0.37
12q	4.71	1.44	3.94	4.38	13.08	11.45	4.95	0.28	0.5
H1-ABM	<i>Percentage improvements (+) or losses (-) relative to VAR(1) model</i>								
1q	-5.7 (0.687)	22.4*** (0.008)	-27.8** (0.029)	5.6 (0.465)	-16.2 (0.391)	-75.2*** (< 0.001)	-67.7*** (< 0.001)	4.7 (0.709)	-63.3*** (< 0.001)
2q	-12.5 (0.437)	16.0 (0.261)	-57.5*** (< 0.001)	-0.6 (0.937)	16.0 (0.390)	-58.7*** (0.009)	8.0 (0.538)	1.1 (0.926)	-21.5 (0.142)
4q	-40.3 (0.166)	31.5** (0.043)	-113.8*** (< 0.001)	-1.4 (0.876)	34.3* (0.077)	-23.7 (0.358)	28.6 (0.116)	11.6 (0.493)	18.2 (0.122)
8q	2.9 (0.958)	46.1** (0.049)	-191.1** (0.024)	-15.9 (0.456)	43.1** (0.028)	-14.8 (0.698)	37.4 (0.426)	18.0 (0.497)	53.0*** (0.005)
12q	-41.4 (0.661)	57.4* (0.054)	-266.6** (0.016)	-12.0 (0.535)	38.2 (0.109)	-31.0 (0.579)	30.1 (0.702)	36.8* (0.066)	56.9*** (0.007)
H2-ABM	<i>Percentage improvements (+) or losses (-) relative to VAR(1) model</i>								
1q	-5.7 (0.689)	22.4*** (0.008)	-30.5** (0.019)	6.2 (0.496)	-16.1 (0.392)	-76.1*** (< 0.001)	-67.7*** (< 0.001)	4.7 (0.709)	-63.3*** (< 0.001)
2q	-13.3 (0.418)	17.0 (0.245)	-61.4*** (< 0.001)	4.3 (0.570)	14.9 (0.427)	-60.3*** (0.006)	9.5 (0.477)	2.5 (0.836)	-21.8 (0.145)
4q	-40.4 (0.163)	31.9** (0.038)	-117.7*** (< 0.001)	0.2 (0.976)	33.4* (0.092)	-26.1 (0.318)	28.8 (0.117)	16.0 (0.407)	18.7 (0.120)
8q	1.6 (0.978)	47.7** (0.045)	-210.0** (0.018)	-17.2 (0.437)	42.1** (0.032)	-18.8 (0.629)	36.7 (0.442)	12.1 (0.614)	54.1*** (0.005)
12q	-45.1 (0.631)	58.8* (0.050)	-281.3** (0.013)	-13.3 (0.556)	36.0 (0.136)	-35.8 (0.529)	29.2 (0.713)	36.8* (0.056)	58.0*** (0.007)

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Table 14: Heuristic ABM forecast performance under AR expectations, relative to VAR(1) (continued)

	GDP	Inflation	Household cons.	Gov. cons.	Exports	Imports	GDP EA	Infl. EA	Euribor
H3-ABM	<i>Percentage improvements (+) or losses (-) relative to VAR(1) model</i>								
1q	-6.4 (0.652)	22.4*** (0.008)	8.0 (0.449)	5.3 (0.549)	-18.4 (0.331)	-69.3*** (< 0.001)	-67.7*** (< 0.001)	4.7 (0.709)	-63.3*** (< 0.001)
2q	-2.5 (0.876)	18.5 (0.214)	12.0 (0.444)	5.6 (0.347)	14.2 (0.441)	-51.9** (0.012)	11.7 (0.362)	4.2 (0.733)	-22.0 (0.142)
4q	-14.4 (0.562)	31.7** (0.040)	-19.4 (0.413)	0.4 (0.962)	33.0* (0.089)	-21.8 (0.369)	30.1 (0.104)	12.1 (0.518)	19.6 (0.106)
8q	32.2 (0.538)	47.7** (0.039)	-28.8 (0.170)	-12.3 (0.519)	41.5** (0.036)	-9.7 (0.789)	37.5 (0.428)	21.7 (0.426)	53.0*** (0.005)
12q	30.9 (0.721)	57.1* (0.050)	-17.7 (0.629)	-14.4 (0.547)	35.4 (0.136)	-21.1 (0.694)	30.0 (0.705)	39.1* (0.055)	57.7*** (0.007)
H4-ABM	<i>Percentage improvements (+) or losses (-) relative to VAR(1) model</i>								
1q	-6.4 (0.654)	22.4*** (0.008)	8.4 (0.423)	5.6 (0.491)	-18.4 (0.332)	-68.9*** (< 0.001)	-67.7*** (< 0.001)	4.7 (0.709)	-63.3*** (< 0.001)
2q	0.3 (0.987)	20.8 (0.177)	10.8 (0.492)	5.1 (0.431)	14.2 (0.444)	-54.2** (0.017)	8.8 (0.501)	1.0 (0.930)	-22.9 (0.128)
4q	-13.0 (0.609)	32.1** (0.040)	-21.0 (0.382)	-0.4 (0.967)	32.7* (0.100)	-21.5 (0.397)	30.3 (0.102)	13.6 (0.439)	18.3 (0.124)
8q	27.6 (0.597)	47.5** (0.041)	-35.2 (0.103)	-14.3 (0.462)	39.8** (0.044)	-12.0 (0.746)	37.0 (0.437)	22.0 (0.426)	53.7*** (0.005)
12q	26.0 (0.762)	58.2* (0.053)	-28.1 (0.462)	-13.4 (0.564)	33.7 (0.161)	-24.1 (0.664)	29.2 (0.713)	38.7* (0.057)	57.9*** (0.007)
H5-ABM	<i>Percentage improvements (+) or losses (-) relative to VAR(1) model</i>								
1q	-6.5 (0.650)	22.4*** (0.008)	2.2 (0.810)	6.2 (0.472)	-17.0 (0.369)	-73.1*** (< 0.001)	-67.7*** (< 0.001)	4.7 (0.709)	-63.3*** (< 0.001)
2q	-7.6 (0.614)	18.1 (0.245)	-6.4 (0.430)	-0.1 (0.987)	14.2 (0.453)	-54.9** (0.012)	10.4 (0.406)	4.2 (0.732)	-22.0 (0.134)
4q	-24.8 (0.364)	33.0** (0.037)	-49.6** (0.025)	-4.3 (0.666)	33.9* (0.081)	-22.6 (0.359)	30.1* (0.097)	17.0 (0.309)	19.3 (0.102)
8q	23.7 (0.645)	46.4** (0.043)	-25.0 (0.506)	-18.2 (0.455)	41.7** (0.030)	-8.1 (0.825)	38.7 (0.418)	19.2 (0.452)	53.3*** (0.005)
12q	23.4 (0.769)	59.1* (0.061)	-18.7 (0.761)	-18.5 (0.524)	35.3 (0.118)	-17.6 (0.740)	31.1 (0.697)	38.0* (0.055)	58.1*** (0.009)
H6-ABM	<i>Percentage improvements (+) or losses (-) relative to VAR(1) model</i>								
1q	-7.2 (0.616)	22.4*** (0.008)	2.8 (0.817)	3.3 (0.726)	-18.6 (0.326)	-69.1*** (< 0.001)	-67.7*** (< 0.001)	4.7 (0.709)	-63.3*** (< 0.001)
2q	-0.9 (0.952)	17.2 (0.228)	12.1 (0.465)	2.4 (0.702)	12.6 (0.511)	-55.0*** (0.010)	9.5 (0.448)	3.6 (0.749)	-21.8 (0.138)
4q	-6.7 (0.782)	32.4** (0.043)	6.3 (0.489)	-1.8 (0.834)	33.3* (0.087)	-21.2 (0.417)	28.9 (0.109)	13.7 (0.439)	18.4 (0.120)
8q	35.8 (0.473)	46.8** (0.042)	21.2 (0.298)	-17.1 (0.409)	40.2** (0.038)	-10.6 (0.777)	36.7 (0.436)	22.3 (0.401)	53.2*** (0.005)
12q	38.9 (0.628)	58.7* (0.053)	36.1 (0.385)	-18.4 (0.481)	34.0 (0.143)	-20.7 (0.706)	29.2 (0.714)	38.6* (0.062)	58.5*** (0.007)
H7-ABM	<i>Percentage improvements (+) or losses (-) relative to VAR(1) model</i>								
1q	-7.8 (0.586)	22.4*** (0.008)	-32.9* (0.078)	6.0 (0.508)	-19.6 (0.303)	-66.6*** (< 0.001)	-67.7*** (< 0.001)	4.7 (0.709)	-63.3*** (< 0.001)
2q	3.1 (0.827)	19.9 (0.199)	-13.2 (0.581)	2.3 (0.686)	12.2 (0.525)	-49.7** (0.020)	9.5 (0.442)	0.2 (0.988)	-22.3 (0.135)
4q	-0.1 (0.997)	32.6** (0.038)	2.8 (0.856)	-1.9 (0.824)	31.7 (0.109)	-18.2 (0.474)	29.0 (0.116)	14.6 (0.376)	18.6 (0.116)
8q	34.8 (0.429)	48.7** (0.037)	11.1 (0.261)	-16.0 (0.449)	40.0** (0.040)	-9.5 (0.802)	36.6 (0.432)	17.1 (0.471)	53.0*** (0.004)
12q	34.5 (0.622)	57.9* (0.053)	19.3 (0.332)	-14.3 (0.549)	34.2 (0.143)	-21.6 (0.698)	29.7 (0.708)	37.6* (0.066)	57.8*** (0.007)

Note: The table depicts the RMSFE of the forecast period 2010Q1 to 2019Q4. The VAR(1) is estimated starting in 1997Q1 and is re-estimated each quarter. The ABM is calibrated to 40 different reference quarters from 2010Q1 to 2019Q4 and the ABM results are obtained as an average of 100 Monte Carlo simulations. We report the p-values of the Diebold-Mariano tests (Harvey et al., 1997). We test the null hypothesis whether the tested models have the same accuracy as the VAR(1) model. We denote 10 percent, 5 percent and 1 percent significance by *, **, and *** respectively.

E.2 Heuristic ABMs under ARX expectations

Table 15: Heuristic ABM forecast performance under ARX expectations, relative to ARX(1)

	GDP	Inflation	Household cons.	Investment	Euribor
ARX(1)	<i>RMSFE for different forecast horizons</i>				
1q	0.38	0.61	0.59	3.46	0.04
2q	0.67	0.58	0.86	4.54	0.06
4q	1.29	0.56	1.33	6.09	0.1
8q	2.6	0.58	2.44	9.67	0.16
12q	3.51	0.6	3.27	13.41	0.21
ABM	<i>Percentage improvements (+) or losses (-) relative to ARX(1) model</i>				
1q	-7.7 (0.488)	1.4 (0.776)	9.1 (0.267)	12.2 (0.178)	-60.5*** (< 0.001)
2q	-21.8 (0.142)	1.9 (0.176)	4.2 (0.744)	0.2 (0.957)	-42.4*** (0.001)
4q	-37.9 (0.214)	5.3* (0.094)	-20.6 (0.182)	-8.5 (0.209)	-28.4*** (0.010)
8q	2.2 (0.957)	-4.8 (0.102)	-8.1 (0.622)	2.6 (0.569)	-8.3 (0.583)
12q	1.5 (0.979)	-2.0 (0.409)	-7.6 (0.731)	4.7** (0.028)	1.6 (0.933)
H1-ABM	<i>Percentage improvements (+) or losses (-) relative to ARX(1) model</i>				
1q	-6.4 (0.536)	1.4 (0.776)	-29.4** (0.012)	12.2 (0.178)	-60.5*** (< 0.001)
2q	-32.5* (0.054)	3.2 (0.186)	-56.5*** (< 0.001)	-0.0 (0.992)	-38.9*** (0.003)
4q	-64.2* (0.075)	3.5 (0.428)	-112.1*** (0.005)	-11.0 (0.181)	-26.6** (0.026)
8q	-24.9 (0.657)	0.7 (0.759)	-213.9** (0.037)	-0.4 (0.966)	-5.8 (0.745)
12q	-82.8 (0.420)	5.9 (0.589)	-318.4** (0.028)	-11.2 (0.627)	2.0 (0.923)
H2-ABM	<i>Percentage improvements (+) or losses (-) relative to ARX(1) model</i>				
1q	-6.4 (0.537)	1.4 (0.776)	-32.0*** (0.008)	12.2 (0.178)	-60.5*** (< 0.001)
2q	-33.7* (0.052)	3.3 (0.144)	-59.4*** (< 0.001)	0.2 (0.967)	-39.8*** (0.002)
4q	-65.8* (0.069)	6.4 (0.106)	-116.8*** (0.003)	-11.3 (0.164)	-26.4** (0.015)
8q	-33.4 (0.559)	1.7 (0.324)	-239.7** (0.027)	-2.3 (0.807)	-7.2 (0.650)
12q	-93.4 (0.382)	5.7 (0.626)	-338.0** (0.022)	-14.2 (0.557)	1.3 (0.942)
H3-ABM	<i>Percentage improvements (+) or losses (-) relative to ARX(1) model</i>				
1q	-6.4 (0.563)	1.4 (0.776)	5.6 (0.648)	12.2 (0.178)	-60.5*** (< 0.001)
2q	-14.0 (0.317)	2.9 (0.143)	10.9 (0.446)	1.8 (0.674)	-40.2*** (0.003)
4q	-33.3 (0.275)	6.6* (0.072)	-15.9 (0.467)	-7.0 (0.307)	-25.5** (0.025)
8q	6.5 (0.891)	1.5 (0.534)	-33.2 (0.273)	6.1 (0.323)	-7.1 (0.670)
12q	2.8 (0.971)	3.3 (0.313)	-35.6 (0.536)	6.7 (0.433)	1.6 (0.938)
H4-ABM	<i>Percentage improvements (+) or losses (-) relative to ARX(1) model</i>				
1q	-6.3 (0.566)	1.4 (0.776)	5.9 (0.631)	12.2 (0.178)	-60.5*** (< 0.001)
2q	-14.4 (0.334)	1.4 (0.353)	10.1 (0.472)	1.8 (0.673)	-38.2*** (0.004)
4q	-34.2 (0.261)	5.2 (0.179)	-18.5 (0.413)	-7.4 (0.272)	-26.1** (0.019)
8q	5.6 (0.910)	0.6 (0.747)	-41.0 (0.188)	6.5 (0.339)	-5.5 (0.751)
12q	-2.9 (0.971)	1.0 (0.706)	-44.8 (0.442)	5.8 (0.531)	4.5 (0.830)
H5-ABM	<i>Percentage improvements (+) or losses (-) relative to ARX(1) model</i>				
1q	-7.1 (0.512)	1.4 (0.776)	0.3 (0.974)	12.2 (0.178)	-60.5*** (< 0.001)
2q	-24.9 (0.117)	4.7** (0.021)	-9.6 (0.194)	0.6 (0.883)	-38.8*** (0.004)
4q	-51.6 (0.125)	3.9 (0.265)	-55.9** (0.042)	-10.0 (0.176)	-22.3** (0.050)
8q	-10.1 (0.829)	0.8 (0.786)	-43.3 (0.376)	0.5 (0.930)	-8.3 (0.598)
12q	-11.2 (0.881)	0.0 (0.997)	-47.4 (0.583)	2.3 (0.740)	3.7 (0.865)
H6-ABM	<i>Percentage improvements (+) or losses (-) relative to ARX(1) model</i>				
1q	-7.3 (0.514)	1.4 (0.776)	1.6 (0.905)	12.2 (0.178)	-60.5*** (< 0.001)
2q	-17.0 (0.222)	1.7 (0.225)	11.1 (0.439)	1.4 (0.751)	-39.8*** (0.002)
4q	-33.5 (0.252)	4.0 (0.121)	-1.9 (0.863)	-7.7 (0.213)	-24.9** (0.012)
8q	9.4 (0.828)	-2.5 (0.310)	9.0 (0.778)	4.5 (0.305)	-6.3 (0.692)
12q	9.3 (0.894)	-1.1 (0.603)	15.4 (0.806)	7.3 (0.178)	3.1 (0.879)

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Table 15: Heuristic ABM forecast performance under ARX expectations, relative to ARX(1) (continued)

	GDP	Inflation	Household cons.	Investment	Euribor
H7-ABM	<i>Percentage improvements (+) or losses (-) relative to ARX(1) model</i>				
1q	-7.9 (0.489)	1.4 (0.776)	-37.8* (0.060)	12.2 (0.178)	-60.5*** (< 0.001)
2q	-10.7 (0.382)	2.9* (0.096)	-16.0 (0.477)	1.9 (0.654)	-38.9*** (0.002)
4q	-22.6 (0.387)	4.9 (0.208)	-10.6 (0.539)	-6.9 (0.203)	-24.3** (0.027)
8q	9.5 (0.784)	-3.9 (0.112)	-6.7 (0.432)	5.6* (0.059)	-6.0 (0.717)
12q	7.2 (0.899)	2.8* (0.052)	-0.9 (0.974)	6.5** (0.016)	2.2 (0.908)

Note: ABMs under ARX expectations vs. ARX(1). The ARX(1) is estimated from 1997Q1 and re-estimated each quarter. ABM results average 100 Monte Carlo simulations per reference quarter (2010Q1–2019Q4). Diebold–Mariano p -values in parentheses; *, **, ***: 10%, 5%, 1% significance.

Table 16: Heuristic ABM forecast performance under ARX expectations, relative to VARX(1)

	GDP	Inflation	Household cons.	Gov. cons.	Exports	Imports	GDP EA	Infl. EA	Euribor
VARX(1)	<i>RMSFE for different forecast horizons</i>								
1q	0.39	0.75	0.6	0.57	1.26	1.38	0.36	0.15	0.04
2q	0.65	0.71	0.83	0.94	2.44	2.23	0.71	0.16	0.07
4q	1.3	0.87	1.39	1.68	4.64	4.23	1.46	0.18	0.12
8q	2.87	1.17	2.76	3.11	8.34	7.66	3.19	0.19	0.23
12q	4.04	1.64	4.07	4.37	11.91	10.74	4.5	0.25	0.31
H1-ABM	<i>Percentage improvements (+) or losses (-) relative to VARX(1) model</i>								
1q	-5.6 (0.636)	19.3** (0.016)	-28.4** (0.029)	4.9 (0.609)	-15.9 (0.399)	-75.9*** (< 0.001)	-67.7*** (< 0.001)	4.7 (0.709)	-63.3*** (< 0.001)
2q	-35.2** (0.044)	21.6 (0.185)	-61.2*** (< 0.001)	0.6 (0.933)	9.1 (0.646)	-70.0*** (0.005)	3.6 (0.785)	9.7 (0.419)	-35.6** (0.024)
4q	-62.2* (0.071)	37.3** (0.050)	-102.9*** (0.003)	0.4 (0.963)	23.3 (0.274)	-42.5 (0.148)	20.2 (0.274)	15.7 (0.379)	-11.5 (0.313)
8q	-12.8 (0.822)	50.4* (0.075)	-176.6** (0.031)	-12.4 (0.568)	31.9 (0.148)	-34.2 (0.446)	27.3 (0.590)	15.7 (0.571)	25.0 (0.105)
12q	-58.6 (0.551)	65.5 (0.151)	-236.5** (0.019)	-12.9 (0.662)	29.5 (0.341)	-41.3 (0.526)	22.6 (0.791)	33.1* (0.093)	33.7* (0.066)
H2-ABM	<i>Percentage improvements (+) or losses (-) relative to VARX(1) model</i>								
1q	-5.6 (0.638)	19.3** (0.016)	-31.1** (0.020)	5.1 (0.607)	-15.9 (0.399)	-75.5*** (< 0.001)	-67.7*** (< 0.001)	4.7 (0.709)	-63.3*** (< 0.001)
2q	-36.5** (0.039)	21.7 (0.168)	-64.2*** (< 0.001)	1.0 (0.895)	9.0 (0.647)	-70.9*** (0.005)	1.2 (0.927)	-0.3 (0.980)	-36.4** (0.026)
4q	-63.7* (0.066)	39.2** (0.038)	-107.3*** (0.002)	-0.5 (0.951)	22.0 (0.308)	-45.0 (0.130)	16.0 (0.365)	10.6 (0.540)	-11.4 (0.343)
8q	-20.5 (0.722)	50.9* (0.069)	-199.3** (0.023)	-13.7 (0.529)	30.0 (0.193)	-37.4 (0.398)	25.8 (0.603)	12.3 (0.654)	24.0 (0.102)
12q	-67.7 (0.503)	65.4 (0.151)	-252.2** (0.015)	-12.8 (0.664)	29.4 (0.360)	-43.0 (0.515)	21.5 (0.800)	30.8 (0.116)	33.3* (0.054)
H3-ABM	<i>Percentage improvements (+) or losses (-) relative to VARX(1) model</i>								
1q	-5.5 (0.644)	19.3** (0.016)	6.3 (0.574)	0.2 (0.982)	-18.2 (0.337)	-68.5*** (< 0.001)	-67.7*** (< 0.001)	4.7 (0.709)	-63.3*** (< 0.001)
2q	-16.3 (0.286)	21.4 (0.176)	8.2 (0.628)	0.5 (0.941)	10.7 (0.581)	-57.2*** (0.010)	4.2 (0.744)	6.9 (0.535)	-36.9** (0.026)
4q	-31.7 (0.269)	39.3** (0.037)	-10.9 (0.610)	-0.9 (0.907)	23.9 (0.265)	-34.5 (0.202)	20.2 (0.271)	9.2 (0.579)	-10.6 (0.325)
8q	15.6 (0.760)	50.7* (0.072)	-17.4 (0.303)	-12.6 (0.541)	31.2 (0.161)	-25.0 (0.552)	28.3 (0.572)	13.9 (0.594)	24.1 (0.111)
12q	15.7 (0.849)	64.6 (0.143)	-9.1 (0.639)	-14.1 (0.658)	28.9 (0.348)	-25.7 (0.675)	24.0 (0.777)	30.3 (0.140)	33.4* (0.067)

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Table 16: Heuristic ABM forecast performance under ARX expectations, relative to VARX(1) (continued)

	GDP	Inflation	Household cons.	Gov. cons.	Exports	Imports	GDP EA	Infl. EA	Euribor
H4-ABM	<i>Percentage improvements (+) or losses (-) relative to VARX(1) model</i>								
1q	-5.5 (0.647)	19.3** (0.016)	6.6 (0.557)	6.3 (0.480)	-18.2 (0.337)	-69.3*** (0.001)	-67.7*** (0.001)	4.7 (0.709)	-63.3*** (0.001)
2q	-16.8 (0.285)	20.2 (0.206)	7.4 (0.655)	1.8 (0.775)	8.0 (0.688)	-61.7*** (0.007)	2.2 (0.864)	1.7 (0.886)	-34.9** (0.026)
4q	-32.6 (0.252)	38.4** (0.043)	-13.3 (0.542)	-2.9 (0.743)	22.5 (0.304)	-37.4 (0.176)	18.6 (0.313)	15.9 (0.347)	-11.1 (0.324)
8q	14.7 (0.778)	50.3* (0.075)	-24.2 (0.163)	-11.6 (0.591)	30.6 (0.188)	-27.2 (0.527)	27.0 (0.593)	13.2 (0.614)	25.2* (0.097)
12q	10.7 (0.899)	63.7 (0.145)	-16.4 (0.416)	-14.4 (0.661)	27.1 (0.395)	-29.5 (0.636)	21.4 (0.802)	30.6 (0.129)	35.4* (0.053)
H5-ABM	<i>Percentage improvements (+) or losses (-) relative to VARX(1) model</i>								
1q	-6.2 (0.604)	19.3** (0.016)	1.0 (0.918)	5.2 (0.573)	-16.7 (0.376)	-72.7*** (0.001)	-67.7*** (0.001)	4.7 (0.709)	-63.3*** (0.001)
2q	-27.5* (0.097)	22.8 (0.160)	-12.9 (0.138)	1.9 (0.776)	8.1 (0.689)	-66.2*** (0.007)	2.5 (0.849)	7.9 (0.502)	-35.4** (0.029)
4q	-49.8 (0.124)	37.6** (0.044)	-49.1** (0.023)	0.4 (0.960)	21.7 (0.320)	-42.3 (0.171)	17.7 (0.340)	12.1 (0.479)	-7.7 (0.474)
8q	0.5 (0.991)	50.4* (0.074)	-26.2 (0.365)	-12.7 (0.539)	28.2 (0.217)	-26.2 (0.552)	25.7 (0.603)	14.0 (0.604)	23.2 (0.106)
12q	3.6 (0.964)	63.3 (0.144)	-18.6 (0.661)	-14.5 (0.657)	26.9 (0.383)	-27.7 (0.664)	21.8 (0.799)	35.5* (0.063)	34.9* (0.063)
H6-ABM	<i>Percentage improvements (+) or losses (-) relative to VARX(1) model</i>								
1q	-6.4 (0.594)	19.3** (0.016)	2.3 (0.857)	5.6 (0.547)	-18.4 (0.332)	-68.9*** (0.001)	-67.7*** (0.001)	4.7 (0.709)	-63.3*** (0.001)
2q	-19.4 (0.195)	20.4 (0.197)	8.4 (0.631)	2.1 (0.729)	7.5 (0.704)	-59.0** (0.012)	2.8 (0.832)	4.2 (0.736)	-36.4** (0.021)
4q	-31.9 (0.253)	37.6** (0.040)	2.5 (0.794)	-0.2 (0.975)	22.1 (0.309)	-35.0 (0.233)	17.4 (0.343)	12.9 (0.474)	-10.1 (0.360)
8q	18.1 (0.702)	48.8* (0.080)	19.8* (0.065)	-11.5 (0.563)	28.2 (0.223)	-26.0 (0.557)	25.9 (0.602)	14.4 (0.599)	24.7* (0.087)
12q	21.3 (0.782)	62.9 (0.143)	32.0** (0.049)	-13.6 (0.659)	26.3 (0.412)	-27.5 (0.669)	21.4 (0.800)	28.5 (0.175)	34.4* (0.051)
H7-ABM	<i>Percentage improvements (+) or losses (-) relative to VARX(1) model</i>								
1q	-7.0 (0.568)	19.3** (0.016)	-36.8* (0.061)	3.4 (0.728)	-19.3 (0.309)	-65.9*** (0.001)	-67.7*** (0.001)	4.7 (0.709)	-63.3*** (0.001)
2q	-12.9 (0.325)	21.4 (0.193)	-19.5 (0.445)	3.5 (0.647)	7.0 (0.723)	-58.8** (0.017)	3.8 (0.769)	3.3 (0.774)	-35.6** (0.026)
4q	-21.1 (0.405)	38.3** (0.042)	-5.8 (0.794)	-2.8 (0.743)	20.3 (0.352)	-35.2 (0.227)	17.8 (0.345)	13.0 (0.448)	-9.5 (0.393)
8q	18.2 (0.651)	48.1* (0.078)	6.0 (0.735)	-12.5 (0.562)	29.6 (0.191)	-23.0 (0.602)	26.4 (0.600)	11.3 (0.666)	24.8* (0.099)
12q	19.5 (0.768)	64.4 (0.140)	18.9 (0.271)	-14.5 (0.649)	27.2 (0.385)	-25.4 (0.696)	21.5 (0.800)	33.9 (0.103)	33.9* (0.053)

Note: The table depicts the RMSFE of the forecast period 2010Q1 to 2019Q4. The VARX(1) is estimated starting in 1997Q1 and is re-estimated each quarter. The ABM with ARX expectations is calibrated to 40 different reference quarters from 2010Q1 to 2019Q4 and the ABM results are obtained as an average of 100 Monte Carlo simulations. We report the p-values of the Diebold-Mariano tests (Harvey et al., 1997). We test the null hypothesis whether the tested models have the same accuracy as the VARX(1) model. We denote 10 percent, 5 percent and 1 percent significance by *, **, and *** respectively.

E.3 Heuristic ABMs under VAR expectations

Table 17: Heuristic ABM forecast performance under VAR expectations, relative to AR(1)

	GDP	Inflation	Household cons.	Investment	Euribor
AR(1)	<i>RMSFE for different forecast horizons</i>				
1q	0.41	0.57	0.56	3.3	0.03
2q	0.67	0.57	0.82	4.48	0.06
4q	1.32	0.56	1.47	6.21	0.11
8q	2.59	0.58	2.72	9.61	0.16
12q	3.47	0.6	3.68	13.27	0.2
ABM	<i>Percentage improvements (+) or losses (-) relative to AR(1) model</i>				
1q	-3.8 (0.690)	-3.7 (0.337)	4.2 (0.489)	8.8 (0.264)	-80.9*** (< 0.001)
2q	-10.2 (0.508)	0.6 (0.703)	0.6 (0.945)	0.9 (0.839)	-39.6*** (0.007)
4q	-27.8 (0.372)	3.4 (0.148)	-1.5 (0.949)	-5.6 (0.461)	-19.0 (0.196)
8q	4.1 (0.920)	-1.0 (0.701)	5.8 (0.834)	2.6 (0.502)	-8.7 (0.735)
12q	6.7 (0.893)	1.2 (0.633)	6.6 (0.810)	6.4** (0.016)	-2.5 (0.941)
H1-ABM	<i>Percentage improvements (+) or losses (-) relative to AR(1) model</i>				
1q	-2.1 (0.817)	-3.7 (0.337)	-35.2** (0.012)	8.8 (0.264)	-80.9*** (< 0.001)
2q	-22.4 (0.204)	1.3 (0.579)	-60.9*** (0.005)	0.2 (0.966)	-40.6*** (0.005)
4q	-60.7* (0.092)	4.7 (0.251)	-92.0** (0.026)	-9.8 (0.270)	-17.5 (0.280)
8q	-26.3 (0.653)	-2.4 (0.183)	-181.4* (0.059)	-1.4 (0.884)	-8.0 (0.766)
12q	-91.8 (0.388)	3.6 (0.709)	-274.0** (0.036)	-13.9 (0.583)	-0.9 (0.979)
H2-ABM	<i>Percentage improvements (+) or losses (-) relative to AR(1) model</i>				
1q	-2.1 (0.821)	-3.7 (0.337)	-38.2*** (0.009)	8.8 (0.264)	-80.9*** (< 0.001)
2q	-21.6 (0.235)	3.4* (0.068)	-64.2*** (0.005)	0.2 (0.961)	-38.5** (0.015)
4q	-61.2 (0.102)	4.1 (0.347)	-96.1** (0.025)	-9.5 (0.283)	-18.1 (0.259)
8q	-26.6 (0.654)	0.2 (0.934)	-201.8** (0.048)	-1.7 (0.865)	-9.0 (0.735)
12q	-93.3 (0.388)	6.7 (0.615)	-287.8** (0.035)	-14.4 (0.564)	-1.3 (0.969)
H3-ABM	<i>Percentage improvements (+) or losses (-) relative to AR(1) model</i>				
1q	-2.8 (0.762)	-3.7 (0.337)	1.2 (0.890)	8.8 (0.264)	-80.9*** (< 0.001)
2q	-6.7 (0.686)	0.4 (0.840)	8.3 (0.500)	1.6 (0.688)	-39.6*** (0.009)
4q	-29.0 (0.372)	3.9 (0.229)	-5.7 (0.835)	-5.2 (0.499)	-16.9 (0.302)
8q	10.0 (0.841)	0.3 (0.907)	-18.8 (0.628)	6.9 (0.276)	-10.2 (0.694)
12q	3.0 (0.969)	4.4** (0.016)	-17.8 (0.784)	6.0 (0.467)	-2.9 (0.931)
H4-ABM	<i>Percentage improvements (+) or losses (-) relative to AR(1) model</i>				
1q	-2.7 (0.766)	-3.7 (0.337)	1.7 (0.850)	8.8 (0.264)	-80.9*** (< 0.001)
2q	-7.4 (0.651)	1.1 (0.680)	7.2 (0.587)	1.1 (0.792)	-39.6*** (0.009)
4q	-25.4 (0.427)	4.4 (0.263)	-6.8 (0.804)	-4.4 (0.569)	-16.9 (0.319)
8q	11.3 (0.820)	3.3*** (0.003)	-25.1 (0.522)	7.3 (0.254)	-8.4 (0.756)
12q	5.9 (0.939)	2.4 (0.250)	-24.5 (0.703)	5.9 (0.462)	-3.7 (0.912)
H5-ABM	<i>Percentage improvements (+) or losses (-) relative to AR(1) model</i>				
1q	-3.0 (0.752)	-3.7 (0.337)	-3.8 (0.653)	8.8 (0.264)	-80.9*** (< 0.001)
2q	-16.0 (0.345)	1.6 (0.423)	-11.4 (0.335)	0.5 (0.912)	-38.9*** (0.010)
4q	-43.5 (0.203)	4.9 (0.147)	-39.8 (0.226)	-7.2 (0.399)	-17.7 (0.298)
8q	-1.0 (0.984)	-1.5 (0.147)	-22.6 (0.682)	2.5 (0.670)	-6.7 (0.817)
12q	-3.0 (0.966)	-0.3 (0.809)	-23.0 (0.790)	2.9 (0.550)	-1.0 (0.978)
H6-ABM	<i>Percentage improvements (+) or losses (-) relative to AR(1) model</i>				
1q	-3.6 (0.700)	-3.7 (0.337)	-4.6 (0.576)	8.8 (0.264)	-80.9*** (< 0.001)
2q	-5.1 (0.728)	2.1 (0.322)	7.8 (0.214)	1.7 (0.669)	-40.0*** (0.007)
4q	-22.0 (0.467)	2.1 (0.491)	12.3 (0.536)	-4.7 (0.508)	-18.6 (0.229)
8q	14.3 (0.746)	0.6 (0.838)	21.9 (0.605)	5.3 (0.237)	-9.2 (0.731)
12q	17.8 (0.793)	4.4* (0.073)	32.9 (0.645)	9.0** (0.011)	-2.7 (0.934)

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Table 17: Heuristic ABM forecast performance under VAR expectations, relative to AR(1) (continued)

	GDP	Inflation	Household cons.	Investment	Euribor
H7-ABM	<i>Percentage improvements (+) or losses (-) relative to AR(1) model</i>				
1q	-4.2 (0.649)	-3.7 (0.337)	-45.1*** (0.007)	8.8 (0.264)	-80.9*** (< 0.001)
2q	-2.6 (0.839)	1.8 (0.374)	-21.4 (0.164)	1.7 (0.675)	-42.3*** (0.002)
4q	-11.3 (0.676)	3.8 (0.170)	0.6 (0.914)	-3.7 (0.537)	-18.4 (0.261)
8q	14.8 (0.640)	2.3 (0.381)	4.4 (0.804)	6.0** (0.025)	-8.7 (0.740)
12q	10.2 (0.839)	2.3 (0.571)	9.8 (0.794)	6.7** (0.036)	-2.4 (0.945)

Note: ABMs under VAR expectations vs. AR(1). The AR(1) is estimated from 1997Q1 and re-estimated each quarter. ABM results average 100 Monte Carlo simulations per reference quarter (2010Q1–2019Q4). Diebold–Mariano *p*-values in parentheses; *, **, ***: 10%, 5%, 1% significance.

Table 18: Heuristic ABM forecast performance under VAR expectations, relative to VAR(1)

	GDP	Inflation	Household cons.	Gov. cons.	Exports	Imports	GDP EA	Infl. EA	Euribor
VAR(1)	<i>RMSFE for different forecast horizons</i>								
1q	0.39	0.75	0.6	0.57	1.26	1.38	0.36	0.15	0.04
2q	0.7	0.7	0.84	0.94	2.61	2.35	0.76	0.16	0.07
4q	1.52	0.85	1.4	1.66	5.42	4.85	1.69	0.18	0.16
8q	3.45	1.11	2.76	3.04	9.88	8.85	3.71	0.2	0.37
12q	4.71	1.44	3.94	4.38	13.08	11.45	4.95	0.28	0.5
ABM	<i>Percentage improvements (+) or losses (-) relative to VAR(1) model</i>								
1q	-9.1 (0.547)	20.6*** (0.010)	9.5 (0.300)	10.1 (0.258)	-17.8 (0.347)	-72.2*** (< 0.001)	-67.7*** (< 0.001)	4.7 (0.709)	-63.3*** (< 0.001)
2q	-5.1 (0.735)	18.5 (0.211)	2.7 (0.879)	5.9 (0.365)	14.5 (0.440)	-56.5** (0.013)	8.0 (0.552)	5.4 (0.637)	-22.1 (0.143)
4q	-11.5 (0.647)	35.7** (0.035)	-6.7 (0.520)	0.7 (0.928)	33.8* (0.084)	-22.3 (0.383)	28.1 (0.104)	11.9 (0.496)	17.3 (0.145)
8q	28.2 (0.547)	46.9** (0.043)	7.2 (0.467)	-15.6 (0.460)	40.0** (0.043)	-9.4 (0.809)	36.8 (0.434)	21.0 (0.426)	53.0*** (0.005)
12q	31.3 (0.647)	59.0** (0.050)	12.7 (0.120)	-17.1 (0.526)	33.4 (0.162)	-19.0 (0.736)	29.0 (0.715)	39.3** (0.046)	58.1*** (0.007)
H1-ABM	<i>Percentage improvements (+) or losses (-) relative to VAR(1) model</i>								
1q	-7.3 (0.621)	20.6*** (0.010)	-27.7** (0.032)	2.6 (0.762)	-16.2 (0.391)	-75.4*** (< 0.001)	-67.7*** (< 0.001)	4.7 (0.709)	-63.3*** (< 0.001)
2q	-16.7 (0.285)	19.1 (0.193)	-57.4*** (< 0.001)	1.9 (0.767)	15.4 (0.407)	-62.2*** (0.005)	9.0 (0.490)	6.7 (0.549)	-23.0 (0.127)
4q	-40.1 (0.156)	36.6** (0.039)	-101.8*** (0.002)	-0.8 (0.916)	33.9* (0.084)	-26.1 (0.307)	29.4 (0.113)	12.2 (0.457)	18.3 (0.119)
8q	5.4 (0.922)	46.2** (0.048)	-177.3** (0.037)	-16.0 (0.459)	40.8** (0.034)	-17.9 (0.642)	36.7 (0.437)	17.3 (0.491)	53.4*** (0.005)
12q	-41.4 (0.662)	60.0* (0.067)	-249.6** (0.026)	-10.5 (0.591)	34.0 (0.153)	-35.5 (0.536)	28.4 (0.720)	37.2* (0.055)	58.7*** (0.007)
H2-ABM	<i>Percentage improvements (+) or losses (-) relative to VAR(1) model</i>								
1q	-7.2 (0.623)	20.6*** (0.010)	-30.5** (0.021)	2.9 (0.722)	-16.1 (0.393)	-75.6*** (< 0.001)	-67.7*** (< 0.001)	4.7 (0.709)	-63.3*** (< 0.001)
2q	-16.0 (0.331)	20.8 (0.167)	-60.6*** (< 0.001)	1.2 (0.857)	16.7 (0.374)	-58.9*** (0.009)	9.8 (0.436)	7.1 (0.508)	-21.2 (0.150)
4q	-40.6 (0.173)	36.2** (0.045)	-106.1*** (0.003)	-2.1 (0.807)	34.6* (0.080)	-24.2 (0.348)	29.6 (0.100)	16.8 (0.330)	17.9 (0.134)
8q	5.2 (0.926)	47.6** (0.039)	-197.3** (0.031)	-18.3 (0.435)	42.9** (0.035)	-16.8 (0.670)	37.0 (0.431)	16.1 (0.523)	52.9*** (0.005)
12q	-42.4 (0.658)	61.3* (0.068)	-262.5** (0.026)	-12.7 (0.551)	36.4 (0.133)	-34.0 (0.546)	29.0 (0.715)	38.4** (0.049)	58.6*** (0.007)

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Table 18: Heuristic ABM forecast performance under VAR expectations, relative to VAR(1) (continued)

	GDP	Inflation	Household cons.	Gov. cons.	Exports	Imports	GDP EA	Infl. EA	Euribor
H3-ABM	<i>Percentage improvements (+) or losses (-) relative to VAR(1) model</i>								
	-8.0	20.6***	6.7	5.3	-18.5	-69.2***	-67.7***	4.7	-63.3***
1q	(0.589)	(0.010)	(0.558)	(0.585)	(0.330)	(< 0.001)	(< 0.001)	(0.709)	(< 0.001)
	-1.7	18.3	10.3	5.2	13.7	-52.9**	8.0	-0.1	-22.1
2q	(0.915)	(0.221)	(0.541)	(0.452)	(0.468)	(0.014)	(0.543)	(0.994)	(0.139)
	-12.5	36.0**	-11.1	1.2	33.5*	-19.2	29.0	15.8	18.8
4q	(0.610)	(0.037)	(0.612)	(0.880)	(0.094)	(0.452)	(0.104)	(0.436)	(0.112)
	32.6	47.6**	-17.1	-13.8	41.4**	-8.4	36.5	23.3	52.4***
8q	(0.533)	(0.045)	(0.403)	(0.472)	(0.033)	(0.817)	(0.431)	(0.370)	(0.005)
	28.6	60.3*	-10.1	-14.5	34.6	-21.0	28.6	38.4*	57.9***
12q	(0.740)	(0.052)	(0.800)	(0.536)	(0.141)	(0.701)	(0.716)	(0.059)	(0.007)
H4-ABM	<i>Percentage improvements (+) or losses (-) relative to VAR(1) model</i>								
	-7.9	20.6***	7.1	2.4	-18.4	-69.4***	-67.7***	4.7	-63.3***
1q	(0.592)	(0.010)	(0.532)	(0.803)	(0.331)	(< 0.001)	(< 0.001)	(0.709)	(< 0.001)
	-2.4	19.0	9.2	0.2	13.8	-50.7**	10.5	-1.5	-22.2
2q	(0.876)	(0.189)	(0.583)	(0.978)	(0.463)	(0.019)	(0.415)	(0.901)	(0.130)
	-9.4	36.3**	-12.2	-4.1	34.0*	-19.3	31.9	12.6	18.8*
4q	(0.704)	(0.040)	(0.562)	(0.646)	(0.089)	(0.436)	(0.100)	(0.475)	(0.100)
	33.5	49.2**	-23.2	-15.8	41.2**	-9.4	37.7	20.1	53.2***
8q	(0.522)	(0.037)	(0.269)	(0.464)	(0.037)	(0.797)	(0.428)	(0.424)	(0.005)
	30.7	59.4*	-16.4	-16.1	35.2	-21.3	29.7	37.8*	57.6***
12q	(0.720)	(0.051)	(0.681)	(0.551)	(0.134)	(0.693)	(0.707)	(0.081)	(0.007)
H5-ABM	<i>Percentage improvements (+) or losses (-) relative to VAR(1) model</i>								
	-8.2	20.6***	2.0	5.7	-17.0	-72.9***	-67.7***	4.7	-63.3***
1q	(0.584)	(0.010)	(0.835)	(0.505)	(0.369)	(< 0.001)	(< 0.001)	(0.709)	(< 0.001)
	-10.6	19.4	-9.0	1.5	13.6	-58.2***	11.0	3.0	-21.5
2q	(0.499)	(0.186)	(0.302)	(0.830)	(0.469)	(0.007)	(0.382)	(0.780)	(0.145)
	-25.2	36.7**	-46.9**	-1.7	33.4*	-24.8	30.9*	14.0	18.2
4q	(0.356)	(0.036)	(0.030)	(0.863)	(0.082)	(0.323)	(0.088)	(0.423)	(0.115)
	24.4	46.7**	-20.7	-17.1	40.3**	-9.9	38.2	21.5	53.9***
8q	(0.635)	(0.043)	(0.566)	(0.452)	(0.040)	(0.794)	(0.424)	(0.448)	(0.005)
	24.1	58.3*	-15.0	-17.1	34.2	-21.4	29.9	36.2*	58.7***
12q	(0.763)	(0.054)	(0.804)	(0.521)	(0.141)	(0.695)	(0.707)	(0.076)	(0.007)
H6-ABM	<i>Percentage improvements (+) or losses (-) relative to VAR(1) model</i>								
	-8.8	20.6***	1.2	6.8	-18.6	-69.2***	-67.7***	4.7	-63.3***
1q	(0.554)	(0.010)	(0.928)	(0.477)	(0.326)	(< 0.001)	(< 0.001)	(0.709)	(< 0.001)
	-0.3	19.8	9.8	3.8	12.9	-50.0**	8.5	6.4	-22.5
2q	(0.985)	(0.174)	(0.581)	(0.528)	(0.496)	(0.021)	(0.516)	(0.546)	(0.130)
	-6.4	34.8**	7.8	-0.7	33.1*	-18.5	30.5*	14.4	17.6
4q	(0.786)	(0.044)	(0.378)	(0.931)	(0.089)	(0.464)	(0.087)	(0.417)	(0.135)
	35.8	47.8**	23.0	-16.8	40.7**	-8.1	38.1	19.9	52.9***
8q	(0.472)	(0.042)	(0.241)	(0.449)	(0.037)	(0.828)	(0.420)	(0.476)	(0.005)
	39.5	60.3*	37.2	-15.5	34.6	-18.4	29.5	37.2*	58.0***
12q	(0.627)	(0.054)	(0.359)	(0.519)	(0.144)	(0.740)	(0.711)	(0.064)	(0.007)
H7-ABM	<i>Percentage improvements (+) or losses (-) relative to VAR(1) model</i>								
	-9.5	20.6***	-37.1*	6.6	-19.6	-66.5***	-67.7***	4.7	-63.3***
1q	(0.528)	(0.010)	(0.063)	(0.497)	(0.303)	(< 0.001)	(< 0.001)	(0.709)	(< 0.001)
	2.1	19.5	-18.7	4.9	13.9	-53.6**	7.6	1.4	-24.5
2q	(0.878)	(0.197)	(0.469)	(0.471)	(0.458)	(0.013)	(0.583)	(0.909)	(0.112)
	2.9	35.9**	-4.4	-1.6	32.7*	-19.2	30.3*	13.4	17.7
4q	(0.893)	(0.037)	(0.833)	(0.829)	(0.094)	(0.441)	(0.095)	(0.439)	(0.131)
	36.2	48.7**	5.8	-16.4	41.0**	-10.1	36.8	22.9	53.1***
8q	(0.394)	(0.037)	(0.624)	(0.445)	(0.034)	(0.792)	(0.436)	(0.385)	(0.005)
	33.8	59.4*	15.7	-16.9	34.5	-20.4	29.3	39.0*	58.1***
12q	(0.625)	(0.058)	(0.321)	(0.507)	(0.145)	(0.715)	(0.713)	(0.064)	(0.007)

Note: ABMs under VAR expectations vs. VAR(1). The VAR(1) is estimated from 1997Q1 and re-estimated each quarter. ABM results average 100 Monte Carlo simulations per reference quarter (2010Q1–2019Q4). Diebold–Mariano *p*-values in parentheses; *, **, ***: 10%, 5%, 1% significance.

E.4 Heuristic ABMs under VARX expectations

Table 19: Heuristic ABM forecast performance under VARX expectations, relative to ARX(1)

	GDP	Inflation	Household cons.	Investment	Euribor
ARX(1)	<i>RMSFE for different forecast horizons</i>				
1q	0.38	0.61	0.59	3.46	0.04
2q	0.67	0.58	0.86	4.54	0.06
4q	1.29	0.56	1.33	6.09	0.1
8q	2.6	0.58	2.44	9.67	0.16
12q	3.51	0.6	3.27	13.41	0.21
ABM	<i>Percentage improvements (+) or losses (-) relative to ARX(1) model</i>				
1q	-7.7 (0.489)	1.4 (0.776)	9.3 (0.255)	12.2 (0.178)	-60.5*** (< 0.001)
2q	-20.1 (0.155)	2.8 (0.176)	4.8 (0.717)	1.1 (0.802)	-38.0*** (0.003)
4q	-41.7 (0.180)	3.9 (0.186)	-20.7 (0.177)	-8.0 (0.222)	-26.8** (0.011)
8q	1.4 (0.973)	1.3 (0.362)	-7.3 (0.696)	3.1 (0.437)	-8.1 (0.629)
12q	2.3 (0.969)	-3.8 (0.220)	-6.1 (0.809)	5.3** (0.019)	1.6 (0.934)
H1-ABM	<i>Percentage improvements (+) or losses (-) relative to ARX(1) model</i>				
1q	-6.4 (0.536)	1.4 (0.776)	-29.4** (0.012)	12.2 (0.178)	-60.5*** (< 0.001)
2q	-31.3* (0.059)	4.1** (0.022)	-56.2*** (< 0.001)	0.3 (0.937)	-38.9*** (0.002)
4q	-64.1* (0.075)	5.1 (0.306)	-113.6*** (0.005)	-11.6 (0.154)	-25.7** (0.022)
8q	-25.8 (0.650)	-0.2 (0.908)	-216.4** (0.036)	-0.9 (0.922)	-8.7 (0.582)
12q	-86.0 (0.409)	4.5 (0.754)	-321.6** (0.029)	-12.7 (0.584)	1.6 (0.934)
H2-ABM	<i>Percentage improvements (+) or losses (-) relative to ARX(1) model</i>				
1q	-6.4 (0.537)	1.4 (0.776)	-32.1*** (0.008)	12.2 (0.178)	-60.5*** (< 0.001)
2q	-31.4* (0.064)	4.0** (0.023)	-59.3*** (< 0.001)	0.2 (0.956)	-40.0*** (0.003)
4q	-66.9* (0.063)	5.1 (0.199)	-118.1*** (0.004)	-12.1 (0.132)	-27.5*** (0.007)
8q	-28.6 (0.612)	-0.1 (0.956)	-239.2** (0.027)	-1.2 (0.897)	-8.0 (0.602)
12q	-90.1 (0.385)	6.4 (0.636)	-337.6** (0.020)	-13.1 (0.585)	2.8 (0.892)
H3-ABM	<i>Percentage improvements (+) or losses (-) relative to ARX(1) model</i>				
1q	-6.4 (0.563)	1.4 (0.776)	5.6 (0.650)	12.2 (0.178)	-60.5*** (< 0.001)
2q	-14.0 (0.348)	2.5 (0.221)	10.8 (0.438)	1.8 (0.683)	-39.8*** (0.003)
4q	-34.4 (0.253)	4.4 (0.179)	-15.2 (0.501)	-7.5 (0.264)	-27.1*** (0.009)
8q	4.5 (0.925)	-1.5 (0.306)	-33.3 (0.274)	5.4 (0.360)	-6.3 (0.704)
12q	-2.0 (0.979)	3.4 (0.415)	-37.1 (0.517)	5.8 (0.496)	2.4 (0.902)
H4-ABM	<i>Percentage improvements (+) or losses (-) relative to ARX(1) model</i>				
1q	-6.3 (0.566)	1.4 (0.776)	5.9 (0.630)	12.2 (0.178)	-60.5*** (< 0.001)
2q	-18.3 (0.208)	1.9 (0.286)	10.7 (0.443)	1.4 (0.753)	-38.4*** (0.004)
4q	-38.4 (0.211)	4.6 (0.147)	-19.3 (0.380)	-7.5 (0.266)	-25.0** (0.029)
8q	5.1 (0.916)	3.6** (0.026)	-40.8 (0.187)	6.0 (0.375)	-5.0 (0.775)
12q	-0.8 (0.992)	1.7 (0.610)	-45.7 (0.428)	6.6 (0.476)	2.9 (0.890)
H5-ABM	<i>Percentage improvements (+) or losses (-) relative to ARX(1) model</i>				
1q	-7.1 (0.512)	1.4 (0.776)	0.3 (0.971)	12.2 (0.178)	-60.5*** (< 0.001)
2q	-28.1* (0.060)	2.6 (0.106)	-10.2 (0.159)	0.6 (0.881)	-40.5*** (0.002)
4q	-53.3 (0.109)	4.8 (0.263)	-56.5** (0.042)	-9.6 (0.203)	-26.4** (0.018)
8q	-9.1 (0.854)	0.5 (0.846)	-41.8 (0.396)	0.9 (0.891)	-6.3 (0.685)
12q	-13.3 (0.864)	-1.4 (0.568)	-47.1 (0.591)	1.5 (0.846)	3.8 (0.853)
H6-ABM	<i>Percentage improvements (+) or losses (-) relative to ARX(1) model</i>				
1q	-7.3 (0.515)	1.4 (0.776)	1.6 (0.902)	12.2 (0.178)	-60.5*** (< 0.001)
2q	-16.8 (0.220)	4.2** (0.026)	11.6 (0.408)	1.3 (0.765)	-39.8*** (0.002)
4q	-31.4 (0.278)	5.2 (0.163)	-0.2 (0.982)	-7.3 (0.243)	-23.7** (0.037)
8q	6.1 (0.892)	1.3 (0.353)	9.0 (0.775)	4.6 (0.367)	-7.9 (0.616)
12q	7.0 (0.921)	-3.3* (0.087)	16.1 (0.795)	6.7 (0.175)	1.5 (0.943)

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Table 19: Heuristic ABM forecast performance under VARX expectations, relative to ARX(1) (continued)

	GDP	Inflation	Household cons.	Investment	Euribor
H7-ABM	<i>Percentage improvements (+) or losses (-) relative to ARX(1) model</i>				
1q	-7.9 (0.490)	1.4 (0.776)	-37.8* (0.060)	12.2 (0.178)	-60.5*** (< 0.001)
2q	-12.9 (0.292)	1.2 (0.470)	-15.7 (0.490)	1.4 (0.732)	-36.8*** (0.005)
4q	-24.2 (0.359)	3.6 (0.341)	-9.0 (0.599)	-6.5 (0.241)	-25.5** (0.022)
8q	4.0 (0.908)	-4.0 (0.304)	-4.0 (0.670)	4.3* (0.068)	-7.7 (0.634)
12q	3.6 (0.949)	1.0 (0.551)	-0.3 (0.992)	5.0* (0.055)	1.5 (0.940)

Note: ABMs under VARX expectations vs. ARX(1). The ARX(1) is estimated from 1997Q1 and re-estimated each quarter. ABM results average 100 Monte Carlo simulations per reference quarter (2010Q1–2019Q4). Diebold–Mariano *p*-values in parentheses; *, **, ***: 10%, 5%, 1% significance.

Table 20: Heuristic ABM forecast performance under VARX expectations, relative to VARX(1)

	GDP	Inflation	Household cons.	Gov. cons.	Exports	Imports	GDP EA	Infl. EA	Euribor
VARX(1)	<i>RMSFE for different forecast horizons</i>								
1q	0.39	0.75	0.6	0.57	1.26	1.38	0.36	0.15	0.04
2q	0.65	0.71	0.83	0.94	2.44	2.23	0.71	0.16	0.07
4q	1.3	0.87	1.39	1.68	4.64	4.23	1.46	0.18	0.12
8q	2.87	1.17	2.76	3.11	8.34	7.66	3.19	0.19	0.23
12q	4.04	1.64	4.07	4.37	11.91	10.74	4.5	0.25	0.31
ABM	<i>Percentage improvements (+) or losses (-) relative to VARX(1) model</i>								
1q	-6.9 (0.572)	19.3** (0.016)	9.9 (0.260)	3.9 (0.675)	-17.6 (0.352)	-75.0*** (< 0.001)	-67.7*** (< 0.001)	4.7 (0.709)	-63.3*** (< 0.001)
2q	-22.5 (0.139)	21.3 (0.184)	1.9 (0.907)	1.9 (0.770)	6.4 (0.744)	-64.8*** (0.007)	4.4 (0.735)	10.0 (0.375)	-34.7** (0.030)
4q	-40.0 (0.181)	37.6** (0.041)	-15.4 (0.163)	-0.7 (0.926)	19.6 (0.360)	-42.0 (0.153)	16.8 (0.344)	9.6 (0.581)	-11.7 (0.309)
8q	11.0 (0.813)	50.7* (0.071)	5.5 (0.544)	-12.1 (0.539)	27.4 (0.222)	-25.5 (0.562)	26.8 (0.591)	16.0 (0.565)	23.4 (0.119)
12q	15.3 (0.819)	62.0 (0.144)	14.7 (0.378)	-14.8 (0.630)	25.9 (0.399)	-24.1 (0.707)	22.1 (0.794)	35.9* (0.075)	33.5* (0.058)
H1-ABM	<i>Percentage improvements (+) or losses (-) relative to VARX(1) model</i>								
1q	-5.6 (0.636)	19.3** (0.016)	-28.4** (0.029)	4.0 (0.661)	-15.9 (0.399)	-75.2*** (< 0.001)	-67.7*** (< 0.001)	4.7 (0.709)	-63.3*** (< 0.001)
2q	-34.0** (0.049)	22.3 (0.168)	-61.0*** (< 0.001)	0.6 (0.929)	9.2 (0.646)	-69.5*** (0.006)	3.1 (0.810)	4.7 (0.673)	-35.5** (0.024)
4q	-62.1* (0.071)	38.4** (0.047)	-104.3*** (0.003)	-1.0 (0.890)	22.9 (0.284)	-43.9 (0.136)	17.6 (0.345)	15.7 (0.356)	-10.7 (0.358)
8q	-13.6 (0.813)	49.9* (0.077)	-178.7** (0.031)	-12.2 (0.549)	32.0 (0.155)	-34.1 (0.445)	26.6 (0.589)	12.2 (0.645)	23.0 (0.118)
12q	-61.3 (0.537)	65.0 (0.158)	-239.0** (0.020)	-12.2 (0.675)	29.7 (0.342)	-42.1 (0.515)	21.9 (0.795)	29.8 (0.132)	33.4* (0.058)
H2-ABM	<i>Percentage improvements (+) or losses (-) relative to VARX(1) model</i>								
1q	-5.6 (0.638)	19.3** (0.016)	-31.1** (0.020)	7.7 (0.403)	-15.9 (0.401)	-75.1*** (< 0.001)	-67.7*** (< 0.001)	4.7 (0.709)	-63.3*** (< 0.001)
2q	-34.1** (0.050)	22.3 (0.175)	-64.2*** (< 0.001)	5.6 (0.385)	9.5 (0.632)	-69.3*** (0.006)	0.7 (0.960)	2.5 (0.839)	-36.7** (0.026)
4q	-64.8* (0.058)	38.4** (0.042)	-108.6*** (0.002)	0.5 (0.951)	24.8 (0.249)	-42.6 (0.169)	17.8 (0.310)	16.2 (0.292)	-12.3 (0.260)
8q	-16.2 (0.776)	50.0* (0.077)	-198.8** (0.022)	-13.2 (0.557)	32.1 (0.148)	-36.4 (0.427)	26.3 (0.592)	14.9 (0.588)	23.4 (0.107)
12q	-64.9 (0.511)	65.7 (0.154)	-251.9** (0.014)	-11.4 (0.695)	29.5 (0.337)	-43.1 (0.503)	22.5 (0.790)	31.7 (0.117)	34.2* (0.059)

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Table 20: Heuristic ABM forecast performance under VARX expectations, relative to VARX(1) (continued)

	GDP	Inflation	Household cons.	Gov. cons.	Exports	Imports	GDP EA	Infl. EA	Euribor
H3-ABM	<i>Percentage improvements (+) or losses (-) relative to VARX(1) model</i>								
1q	-5.5 (0.644)	19.3** (0.016)	6.2 (0.576)	3.6 (0.708)	-18.2 (0.337)	-68.5*** (< 0.001)	-67.7*** (< 0.001)	4.7 (0.709)	-63.3*** (< 0.001)
2q	-16.3 (0.300)	21.1 (0.178)	8.1 (0.622)	3.0 (0.601)	9.6 (0.623)	-59.5** (0.012)	2.1 (0.878)	6.7 (0.547)	-36.4** (0.025)
4q	-32.8 (0.247)	37.9** (0.041)	-10.2 (0.641)	-2.1 (0.768)	22.7 (0.294)	-36.7 (0.196)	17.1 (0.322)	12.9 (0.478)	-12.0 (0.300)
8q	13.7 (0.786)	49.3* (0.079)	-17.4 (0.311)	-10.0 (0.596)	28.5 (0.221)	-30.0 (0.496)	26.3 (0.597)	15.1 (0.574)	24.7* (0.099)
12q	11.5 (0.888)	64.6 (0.144)	-10.3 (0.586)	-12.1 (0.678)	27.1 (0.394)	-27.9 (0.659)	21.8 (0.797)	31.0* (0.087)	34.0* (0.055)
H4-ABM	<i>Percentage improvements (+) or losses (-) relative to VARX(1) model</i>								
1q	-5.5 (0.647)	19.3** (0.016)	6.6 (0.556)	-0.9 (0.928)	-18.2 (0.338)	-68.8*** (< 0.001)	-67.7*** (< 0.001)	4.7 (0.709)	-63.3*** (< 0.001)
2q	-20.7 (0.179)	20.5 (0.213)	7.9 (0.629)	-2.3 (0.739)	9.1 (0.644)	-55.6** (0.014)	3.2 (0.800)	7.4 (0.521)	-35.1** (0.028)
4q	-36.7 (0.204)	38.1** (0.041)	-14.1 (0.505)	-3.3 (0.655)	23.4 (0.271)	-33.5 (0.204)	20.5 (0.257)	11.0 (0.523)	-10.1 (0.359)
8q	14.3 (0.781)	51.8* (0.068)	-24.1 (0.166)	-11.7 (0.542)	29.6 (0.192)	-26.6 (0.536)	27.5 (0.587)	13.8 (0.612)	25.5* (0.097)
12q	12.6 (0.880)	64.0 (0.139)	-17.2 (0.395)	-12.3 (0.672)	28.3 (0.367)	-27.1 (0.668)	23.1 (0.787)	33.2* (0.085)	34.3* (0.065)
H5-ABM	<i>Percentage improvements (+) or losses (-) relative to VARX(1) model</i>								
1q	-6.2 (0.604)	19.3** (0.016)	1.0 (0.916)	4.2 (0.638)	-16.8 (0.376)	-73.3*** (< 0.001)	-67.7*** (< 0.001)	4.7 (0.709)	-63.3*** (< 0.001)
2q	-30.7* (0.054)	21.2 (0.188)	-13.6 (0.120)	2.7 (0.650)	6.7 (0.737)	-68.3*** (0.007)	0.4 (0.977)	5.6 (0.611)	-37.2** (0.025)
4q	-51.5 (0.104)	38.2** (0.043)	-49.7** (0.025)	-1.2 (0.874)	21.7 (0.303)	-42.2 (0.164)	17.0 (0.314)	13.7 (0.424)	-11.4 (0.322)
8q	1.5 (0.977)	50.3* (0.076)	-24.9 (0.398)	-12.8 (0.531)	27.0 (0.212)	-29.3 (0.505)	25.1 (0.613)	13.6 (0.610)	24.6* (0.092)
12q	1.7 (0.983)	62.8 (0.148)	-18.3 (0.675)	-15.3 (0.638)	25.8 (0.399)	-28.7 (0.651)	21.4 (0.802)	32.1* (0.090)	34.9* (0.054)
H6-ABM	<i>Percentage improvements (+) or losses (-) relative to VARX(1) model</i>								
1q	-6.4 (0.594)	19.3** (0.016)	2.3 (0.854)	4.3 (0.654)	-18.4 (0.332)	-68.2*** (< 0.001)	-67.7*** (< 0.001)	4.7 (0.709)	-63.3*** (< 0.001)
2q	-19.2 (0.196)	22.4 (0.160)	8.9 (0.603)	-0.6 (0.923)	7.9 (0.691)	-61.5*** (0.007)	4.7 (0.698)	5.5 (0.625)	-36.4** (0.022)
4q	-29.8 (0.281)	38.4** (0.041)	4.1 (0.667)	-1.2 (0.885)	21.1 (0.330)	-36.4 (0.193)	18.7 (0.314)	16.2 (0.338)	-9.0 (0.412)
8q	15.2 (0.755)	50.7* (0.073)	19.8* (0.069)	-12.7 (0.539)	27.4 (0.228)	-26.8 (0.541)	26.1 (0.600)	14.9 (0.580)	23.5 (0.104)
12q	19.3 (0.803)	62.1 (0.146)	32.6** (0.045)	-14.8 (0.639)	26.2 (0.397)	-25.0 (0.693)	22.6 (0.790)	31.8 (0.102)	33.3* (0.065)
H7-ABM	<i>Percentage improvements (+) or losses (-) relative to VARX(1) model</i>								
1q	-7.0 (0.568)	19.3** (0.016)	-36.8* (0.062)	1.5 (0.885)	-19.3 (0.309)	-66.3*** (< 0.001)	-67.7*** (< 0.001)	4.7 (0.709)	-63.3*** (< 0.001)
2q	-15.2 (0.269)	20.0 (0.206)	-19.3 (0.458)	1.8 (0.774)	5.2 (0.796)	-61.5** (0.012)	5.1 (0.673)	6.6 (0.556)	-33.5** (0.028)
4q	-22.7 (0.374)	37.4** (0.046)	-4.3 (0.846)	-1.0 (0.895)	20.8 (0.332)	-31.6 (0.262)	18.0 (0.314)	14.2 (0.442)	-10.6 (0.353)
8q	13.3 (0.742)	48.0* (0.078)	8.4 (0.619)	-12.4 (0.530)	29.2 (0.208)	-20.9 (0.629)	27.0 (0.584)	12.5 (0.622)	23.6 (0.109)
12q	16.4 (0.804)	63.7 (0.143)	19.3 (0.243)	-14.9 (0.642)	27.8 (0.374)	-23.0 (0.716)	22.9 (0.786)	32.1* (0.097)	33.4* (0.066)

Note: ABMs under VARX expectations vs. VARX(1). The VARX(1) is estimated from 1997Q1 and re-estimated each quarter. ABM results average 100 Monte Carlo simulations per reference quarter (2010Q1–2019Q4). Diebold–Mariano p -values in parentheses; *, **, ***: 10%, 5%, 1% significance.

F Forecast Results under ARX, VAR, and VARX Expectations

This appendix reports the per-mechanism heatmaps and horizon-by-horizon RMSFE tables for the OC-ABM, the base ABM, and the best-performing heuristic under ARX, VAR, and VARX expectations. Section 4 summarises the cross-mechanism pattern via Figure 7 and Section 4.2; the AR-expectations results are presented in detail in Section 4.1.

F.1 ARX expectations

ARX expectations augment the AR specification with exogenous predictors (Euro area variables and the Euribor rate), providing the ABM with additional information about the external environment. The ARX(1) benchmark is correspondingly harder to beat because it, too, conditions on these predictors.

Figure 20 displays twelve-quarter RMSFE relative to ARX(1). The OC-ABM gains 42.6% ($p = 0.465$) in consumption and 14.6% ($p < 0.001$) in investment. H6 gains 15.4% in consumption, H7 loses 0.9%, and static and habit H1–H5 lose between 35.6% and 338%. The OC-ABM has the largest consumption point estimate, but its corrected benchmark test does not reject equal accuracy.

Euribor	1.6%	2.0%	1.3%	1.6%	4.5%	3.7%	3.1%	2.2%	2.1%
Investment	4.7%	-11.2%	-14.2%	6.7%	5.8%	2.3%	7.3%	6.5%	14.6%
Consumption	-7.6%	-318.4%	-338.0%	-35.6%	-44.8%	-47.4%	15.4%	-0.9%	42.6%
Inflation	-2.0%	5.9%	5.7%	3.3%	1.0%	0.0%	-1.1%	2.8%	-1.7%
GDP	1.5%	-82.8%	-93.4%	2.8%	-2.9%	-11.2%	9.3%	7.2%	34.0%
	Base	H1	H2	H3	H4	H5	H6	H7	OC-ABM

Figure 20: Twelve-quarter relative RMSFE of the base ABM, core heuristics H1–H7 and OC-ABM under ARX expectations, relative to ARX(1). Evaluation uses 28 origins (2010Q1–2016Q4) and 100 paths per origin; positive values indicate lower RMSFE. Dashed outlines mark H6 (black) and OC-ABM (red).

Table 21 benchmarks against VARX(1). At twelve quarters the OC-ABM achieves 42.8% ($p = 0.586$) for GDP, 62.7% ($p = 0.146$) for inflation, and 53.8% ($p < 0.001$) for consumption. Only consumption rejects equal accuracy at 5% in this comparison. Government consumption loses 14.4%. These are exploratory nominal comparisons against a secondary benchmark.

Table 21: Forecast performance under ARX expectations, relative to VARX(1)

	GDP	Inflation	Household cons.	Gov. cons.	Exports	Imports	GDP EA	Infl. EA	Euribor
VARX(1)	<i>RMSFE for different forecast horizons</i>								
1q	0.39	0.75	0.6	0.57	1.26	1.38	0.36	0.15	0.04
2q	0.65	0.71	0.83	0.94	2.44	2.23	0.71	0.16	0.07
4q	1.3	0.87	1.39	1.68	4.64	4.23	1.46	0.18	0.12
8q	2.87	1.17	2.76	3.11	8.34	7.66	3.19	0.19	0.23
12q	4.04	1.64	4.07	4.37	11.91	10.74	4.5	0.25	0.31
ABM	<i>Percentage improvements (+) or losses (-) relative to VARX(1) model</i>								
1q	-6.9 (0.570)	19.3** (0.016)	9.7 (0.271)	2.6 (0.789)	-17.6 (0.352)	-68.9*** (< 0.001)	-67.7*** (< 0.001)	4.7 (0.709)	-63.3*** (< 0.001)
2q	-24.3 (0.127)	20.6 (0.196)	1.3 (0.935)	0.5 (0.938)	6.7 (0.737)	-61.2*** (0.008)	2.3 (0.867)	1.8 (0.893)	-38.9** (0.020)
4q	-36.2 (0.216)	38.5** (0.039)	-15.3 (0.143)	-4.0 (0.588)	22.1 (0.312)	-40.1 (0.174)	18.1 (0.323)	11.4 (0.530)	-13.1 (0.280)
8q	11.6 (0.794)	47.6* (0.080)	4.8 (0.620)	-14.1 (0.515)	29.8 (0.184)	-23.9 (0.595)	26.0 (0.599)	15.1 (0.563)	23.2 (0.113)
12q	14.6 (0.823)	62.6 (0.143)	13.4 (0.425)	-15.5 (0.638)	27.9 (0.378)	-22.4 (0.730)	22.0 (0.795)	30.9 (0.112)	33.4* (0.057)
H6-ABM	<i>Percentage improvements (+) or losses (-) relative to VARX(1) model</i>								
1q	-6.4 (0.594)	19.3** (0.016)	2.3 (0.857)	5.6 (0.547)	-18.4 (0.332)	-68.9*** (< 0.001)	-67.7*** (< 0.001)	4.7 (0.709)	-63.3*** (< 0.001)
2q	-19.4 (0.195)	20.4 (0.197)	8.4 (0.631)	2.1 (0.729)	7.5 (0.704)	-59.0** (0.012)	2.8 (0.832)	4.2 (0.736)	-36.4** (0.021)
4q	-31.9 (0.253)	37.6** (0.040)	2.5 (0.794)	-0.2 (0.975)	22.1 (0.309)	-35.0 (0.233)	17.4 (0.343)	12.9 (0.474)	-10.1 (0.360)
8q	18.1 (0.702)	48.8* (0.080)	19.8* (0.065)	-11.5 (0.563)	28.2 (0.223)	-26.0 (0.557)	25.9 (0.602)	14.4 (0.599)	24.7* (0.087)
12q	21.3 (0.782)	62.9 (0.143)	32.0** (0.049)	-13.6 (0.659)	26.3 (0.412)	-27.5 (0.669)	21.4 (0.800)	28.5 (0.175)	34.4* (0.051)
OC-ABM	<i>Percentage improvements (+) or losses (-) relative to VARX(1) model</i>								
1q	-7.5 (0.530)	19.6** (0.014)	-84.6*** (0.001)	5.2 (0.517)	-12.7 (0.497)	-61.9*** (< 0.001)	-78.6*** (< 0.001)	14.1 (0.142)	-64.4*** (< 0.001)
2q	-26.7 (0.158)	21.9 (0.173)	-125.4*** (0.010)	0.2 (0.978)	11.0 (0.573)	-51.1** (0.021)	0.7 (0.958)	12.9 (0.219)	-37.4** (0.025)
4q	-20.2 (0.463)	37.0* (0.052)	-33.2 (0.154)	1.4 (0.846)	20.5 (0.352)	-29.1 (0.281)	17.9 (0.305)	13.5 (0.441)	-11.2 (0.336)
8q	44.2 (0.398)	48.3* (0.081)	26.6* (0.057)	-13.8 (0.537)	28.2 (0.229)	-19.5 (0.645)	26.7 (0.585)	15.4 (0.565)	22.9 (0.109)
12q	42.8 (0.586)	62.7 (0.146)	53.8*** (< 0.001)	-14.4 (0.657)	27.5 (0.392)	-22.3 (0.723)	22.9 (0.786)	32.4* (0.092)	33.8* (0.062)

ABMs under ARX expectations vs. VARX(1). See Section 4 for estimation details. Diebold–Mariano p -values in parentheses; *, **, ***: 10%, 5%, 1% significance.

Table 22 compares the OC-ABM with ARX(1). Its consumption improvement of 42.6% ($p = 0.465$) is smaller than the 49.7% AR gain. GDP improves by 34.0% ($p = 0.617$), but the test does not reject equal accuracy. Investment gains 14.6% ($p < 0.001$). These tests compare each model with the stated benchmark, not with another ABM.

Table 22: Forecast performance under ARX expectations, relative to ARX(1)

	GDP	Inflation	Household cons.	Investment	Euribor
ARX(1)	<i>RMSFE for different forecast horizons</i>				
1q	0.38	0.61	0.59	3.46	0.04
2q	0.67	0.58	0.86	4.54	0.06
4q	1.29	0.56	1.33	6.09	0.1
8q	2.6	0.58	2.44	9.67	0.16
12q	3.51	0.6	3.27	13.41	0.21
ABM	<i>Percentage improvements (+) or losses (-) relative to ARX(1) model</i>				
1q	-7.7 (0.488)	1.4 (0.776)	9.1 (0.267)	12.2 (0.178)	-60.5*** (< 0.001)
2q	-21.8 (0.142)	1.9 (0.176)	4.2 (0.744)	0.2 (0.957)	-42.4*** (0.001)
4q	-37.9 (0.214)	5.3* (0.094)	-20.6 (0.182)	-8.5 (0.209)	-28.4*** (0.010)
8q	2.2 (0.957)	-4.8 (0.102)	-8.1 (0.622)	2.6 (0.569)	-8.3 (0.583)
12q	1.5 (0.979)	-2.0 (0.409)	-7.6 (0.731)	4.7** (0.028)	1.6 (0.933)
H6-ABM	<i>Percentage improvements (+) or losses (-) relative to ARX(1) model</i>				
1q	-7.3 (0.514)	1.4 (0.776)	1.6 (0.905)	12.2 (0.178)	-60.5*** (< 0.001)
2q	-17.0 (0.222)	1.7 (0.225)	11.1 (0.439)	1.4 (0.751)	-39.8*** (0.002)
4q	-33.5 (0.252)	4.0 (0.121)	-1.9 (0.863)	-7.7 (0.213)	-24.9** (0.012)
8q	9.4 (0.828)	-2.5 (0.310)	9.0 (0.778)	4.5 (0.305)	-6.3 (0.692)
12q	9.3 (0.894)	-1.1 (0.603)	15.4 (0.806)	7.3 (0.178)	3.1 (0.879)
OC-ABM	<i>Percentage improvements (+) or losses (-) relative to ARX(1) model</i>				
1q	-8.3 (0.450)	1.8 (0.728)	-85.9*** (< 0.001)	12.3 (0.178)	-61.5*** (< 0.001)
2q	-24.2 (0.164)	3.5* (0.058)	-118.7*** (0.010)	1.5 (0.724)	-40.8*** (0.002)
4q	-21.7 (0.473)	3.0 (0.510)	-39.3** (0.043)	-2.2 (0.785)	-26.2** (0.012)
8q	38.2 (0.416)	-3.4* (0.092)	16.7 (0.598)	14.8*** (0.003)	-8.8 (0.561)
12q	34.0 (0.617)	-1.7 (0.612)	42.6 (0.465)	14.6*** (< 0.001)	2.1 (0.919)

ABMs under ARX expectations vs. ARX(1). See Section 4 for estimation details. Diebold–Mariano p -values in parentheses; *, **, ***: 10%, 5%, 1% significance.

F.2 VAR expectations

Under VAR expectations, the ABM's aggregate forecasting module exploits cross-variable correlations, the same information the VAR(1) benchmark uses.

Figure 21 displays twelve-quarter RMSFE under VAR expectations against AR(1). The OC-ABM achieves 54.2% ($p = 0.455$) for consumption, 40.1% ($p = 0.551$) for GDP and 15.5% ($p < 0.001$) for investment. H6 has the largest heuristic consumption gain (+32.9%, $p = 0.645$), while H7 gains 9.8%. Static and habit H1–H5 lose between 17.8% and 287.8%. Corrected consumption tests do not reject equal accuracy for the OC-ABM or these dynamic heuristics.

Euribor	-2.5%	-0.9%	-1.3%	-2.9%	-3.7%	-1.0%	-2.7%	-2.4%	-2.6%
Investment	6.4%	-13.9%	-14.4%	6.0%	5.9%	2.9%	9.0%	6.7%	15.5%
Consumption	6.6%	-274.0%	-287.8%	-17.8%	-24.5%	-23.0%	32.9%	9.8%	54.2%
Inflation	1.2%	3.6%	6.7%	4.4%	2.4%	-0.3%	4.4%	2.3%	1.6%
GDP	6.7%	-91.8%	-93.3%	3.0%	5.9%	-3.0%	17.8%	10.2%	40.1%
	Base	H1	H2	H3	H4	H5	H6	H7	OC-ABM

Figure 21: Twelve-quarter relative RMSFE of the base ABM, core heuristics H1–H7 and OC-ABM under VAR expectations, relative to AR(1). Evaluation uses 28 origins (2010Q1–2016Q4) and 100 paths per origin; positive values indicate lower RMSFE. Dashed outlines mark H6 (black) and OC-ABM (red).

Table 23 provides the VAR(1) comparison. At twelve quarters the OC-ABM reaches 55.9% ($p = 0.510$) for GDP and 57.2% ($p = 0.145$) for consumption. H6 gains 39.5% in GDP ($p = 0.627$) and 37.2% in consumption ($p = 0.359$), below the OC point estimates. The OC inflation gain of 59.1% ($p = 0.058$) does not reject equal accuracy at 5%; the displayed ABMs share large inflation point-estimate gains against this benchmark.

Table 23: Forecast performance under VAR expectations, relative to VAR(1)

	GDP	Inflation	Household cons.	Gov. cons.	Exports	Imports	GDP EA	Infl. EA	Euribor
VAR(1)	<i>RMSFE for different forecast horizons</i>								
1q	0.39	0.75	0.6	0.57	1.26	1.38	0.36	0.15	0.04
2q	0.7	0.7	0.84	0.94	2.61	2.35	0.76	0.16	0.07
4q	1.52	0.85	1.4	1.66	5.42	4.85	1.69	0.18	0.16
8q	3.45	1.11	2.76	3.04	9.88	8.85	3.71	0.2	0.37
12q	4.71	1.44	3.94	4.38	13.08	11.45	4.95	0.28	0.5
ABM	<i>Percentage improvements (+) or losses (-) relative to VAR(1) model</i>								
1q	-9.1 (0.547)	20.6*** (0.010)	9.5 (0.300)	10.1 (0.258)	-17.8 (0.347)	-72.2*** (< 0.001)	-67.7*** (< 0.001)	4.7 (0.709)	-63.3*** (< 0.001)
2q	-5.1 (0.735)	18.5 (0.211)	2.7 (0.879)	5.9 (0.365)	14.5 (0.440)	-56.5** (0.013)	8.0 (0.552)	5.4 (0.637)	-22.1 (0.143)
4q	-11.5 (0.647)	35.7** (0.035)	-6.7 (0.520)	0.7 (0.928)	33.8* (0.084)	-22.3 (0.383)	28.1 (0.104)	11.9 (0.496)	17.3 (0.145)
8q	28.2 (0.547)	46.9** (0.043)	7.2 (0.467)	-15.6 (0.460)	40.0** (0.043)	-9.4 (0.809)	36.8 (0.434)	21.0 (0.426)	53.0*** (0.005)
12q	31.3 (0.647)	59.0** (0.050)	12.7 (0.120)	-17.1 (0.526)	33.4 (0.162)	-19.0 (0.736)	29.0 (0.715)	39.3** (0.046)	58.1*** (0.007)
H6-ABM	<i>Percentage improvements (+) or losses (-) relative to VAR(1) model</i>								
1q	-8.8 (0.554)	20.6*** (0.010)	1.2 (0.928)	6.8 (0.477)	-18.6 (0.326)	-69.2*** (< 0.001)	-67.7*** (< 0.001)	4.7 (0.709)	-63.3*** (< 0.001)
2q	-0.3 (0.985)	19.8 (0.174)	9.8 (0.581)	3.8 (0.528)	12.9 (0.496)	-50.0** (0.021)	8.5 (0.516)	6.4 (0.546)	-22.5 (0.130)
4q	-6.4 (0.786)	34.8** (0.044)	7.8 (0.378)	-0.7 (0.931)	33.1* (0.089)	-18.5 (0.464)	30.5* (0.087)	14.4 (0.417)	17.6 (0.135)
8q	35.8 (0.472)	47.8** (0.042)	23.0 (0.241)	-16.8 (0.449)	40.7** (0.037)	-8.1 (0.828)	38.1 (0.420)	19.9 (0.476)	52.9*** (0.005)
12q	39.5 (0.627)	60.3* (0.054)	37.2 (0.359)	-15.5 (0.519)	34.6 (0.144)	-18.4 (0.740)	29.5 (0.711)	37.2* (0.064)	58.0*** (0.007)
OC-ABM	<i>Percentage improvements (+) or losses (-) relative to VAR(1) model</i>								
1q	-9.5 (0.517)	20.9*** (0.009)	-80.6*** (0.002)	6.4 (0.441)	-13.0 (0.489)	-62.3*** (< 0.001)	-78.6*** (< 0.001)	14.1 (0.142)	-64.4*** (< 0.001)
2q	-8.6 (0.648)	18.5 (0.207)	-123.7*** (0.009)	2.8 (0.622)	16.8 (0.368)	-46.7** (0.022)	4.9 (0.734)	12.2 (0.232)	-23.1 (0.130)
4q	-2.3 (0.921)	35.9** (0.038)	-32.0 (0.124)	3.8 (0.583)	33.8* (0.086)	-12.2 (0.601)	29.0* (0.088)	13.4 (0.447)	16.4 (0.166)
8q	60.7 (0.272)	45.1** (0.047)	25.1 (0.233)	-14.7 (0.494)	41.8** (0.037)	-5.3 (0.887)	37.5 (0.420)	19.1 (0.452)	52.6*** (0.005)
12q	55.9 (0.510)	59.1* (0.058)	57.2 (0.145)	-14.9 (0.557)	35.2 (0.138)	-18.0 (0.736)	30.1 (0.704)	38.2* (0.067)	58.1*** (0.007)

ABMs under VAR expectations vs. VAR(1). See Section 4 for estimation details. Diebold–Mariano p -values in parentheses; *, **, ***: 10%, 5%, 1% significance.

Table 24 gives the detail underlying Figure 21. The OC-ABM gains 54.2% ($p = 0.455$) in consumption and 40.1% ($p = 0.551$) in GDP. H6 has the largest heuristic gains, 32.9% in consumption and 17.8% in GDP, neither statistically significant in its corrected benchmark test.

Table 24: Forecast performance under VAR expectations, relative to AR(1)

	GDP	Inflation	Household cons.	Investment	Euribor
AR(1)	<i>RMSFE for different forecast horizons</i>				
1q	0.41	0.57	0.56	3.3	0.03
2q	0.67	0.57	0.82	4.48	0.06
4q	1.32	0.56	1.47	6.21	0.11
8q	2.59	0.58	2.72	9.61	0.16
12q	3.47	0.6	3.68	13.27	0.2
ABM	<i>Percentage improvements (+) or losses (-) relative to AR(1) model</i>				
1q	-3.8 (0.690)	-3.7 (0.337)	4.2 (0.489)	8.8 (0.264)	-80.9*** (< 0.001)
2q	-10.2 (0.508)	0.6 (0.703)	0.6 (0.945)	0.9 (0.839)	-39.6*** (0.007)
4q	-27.8 (0.372)	3.4 (0.148)	-1.5 (0.949)	-5.6 (0.461)	-19.0 (0.196)
8q	4.1 (0.920)	-1.0 (0.701)	5.8 (0.834)	2.6 (0.502)	-8.7 (0.735)
12q	6.7 (0.893)	1.2 (0.633)	6.6 (0.810)	6.4** (0.016)	-2.5 (0.941)
H6-ABM	<i>Percentage improvements (+) or losses (-) relative to AR(1) model</i>				
1q	-3.6 (0.700)	-3.7 (0.337)	-4.6 (0.576)	8.8 (0.264)	-80.9*** (< 0.001)
2q	-5.1 (0.728)	2.1 (0.322)	7.8 (0.214)	1.7 (0.669)	-40.0*** (0.007)
4q	-22.0 (0.467)	2.1 (0.491)	12.3 (0.536)	-4.7 (0.508)	-18.6 (0.229)
8q	14.3 (0.746)	0.6 (0.838)	21.9 (0.605)	5.3 (0.237)	-9.2 (0.731)
12q	17.8 (0.793)	4.4* (0.073)	32.9 (0.645)	9.0** (0.011)	-2.7 (0.934)
OC-ABM	<i>Percentage improvements (+) or losses (-) relative to AR(1) model</i>				
1q	-4.2 (0.646)	-3.3 (0.431)	-91.2*** (0.001)	8.9 (0.264)	-82.2*** (< 0.001)
2q	-13.8 (0.476)	0.6 (0.804)	-128.6*** (0.006)	1.5 (0.721)	-40.6*** (0.003)
4q	-17.3 (0.593)	3.7 (0.285)	-25.6* (0.093)	0.6 (0.946)	-20.2 (0.174)
8q	47.6 (0.324)	-4.5* (0.074)	23.9 (0.571)	17.5*** (< 0.001)	-9.8 (0.700)
12q	40.1 (0.551)	1.6 (0.652)	54.2 (0.455)	15.5*** (< 0.001)	-2.6 (0.940)

ABMs under VAR expectations vs. AR(1). See Section 4 for estimation details. Diebold–Mariano p -values in parentheses; *, **, ***: 10%, 5%, 1% significance.

E.3 VARX expectations

VARX expectations combine multivariate dynamics with exogenous predictors, giving the ABM the richest information set. Under this specification, H6-ABM remains the best heuristic for consumption forecasting, consistent with its performance under the other three mechanisms.

Figure 22 shows results against ARX(1). The OC-ABM improves GDP by 31.0% ($p = 0.649$), consumption by 40.5% ($p = 0.489$) and investment by 14.5% ($p = 0.001$). H6 gains 16.1% in consumption and 7.0% in GDP, while H7 loses 0.3% in consumption. Static and habit H1–H5 lose between 37.1% and 337.6%. The corrected OC consumption test does not reject equal accuracy against this matched univariate benchmark.

Euribor	1.6%	1.6%	2.8%	2.4%	2.9%	3.8%	1.5%	1.5%	2.3%
Investment	5.3%	-12.7%	-13.1%	5.8%	6.6%	1.5%	6.7%	5.0%	14.5%
Consumption	-6.1%	-321.6%	-337.6%	-37.1%	-45.7%	-47.1%	16.1%	-0.3%	40.5%
Inflation	-3.8%	4.5%	6.4%	3.4%	1.7%	-1.4%	-3.3%	1.0%	-1.8%
GDP	2.3%	-86.0%	-90.1%	-2.0%	-0.8%	-13.3%	7.0%	3.6%	31.0%
	Base	H1	H2	H3	H4	H5	H6	H7	OC-ABM

Figure 22: Twelve-quarter relative RMSFE of the base ABM, core heuristics H1–H7 and OC-ABM under VARX expectations, relative to ARX(1). Evaluation uses 28 origins (2010Q1–2016Q4) and 100 paths per origin; positive values indicate lower RMSFE. Dashed outlines mark H6 (black) and OC-ABM (red).

Table 25 reports the VARX(1) comparison. At twelve quarters the OC-ABM delivers 40.1% ($p = 0.607$) for GDP, 62.7% ($p = 0.144$) for inflation and 52.2% ($p < 0.001$) for consumption. Consumption is nominally significant against this secondary benchmark, whereas GDP and inflation are not. The base ABM also gains 62.0% in inflation, consistent with a contribution from the shared price-setting structure.

Table 25: Forecast performance under VARX expectations, relative to VARX(1)

	GDP	Inflation	Household cons.	Gov. cons.	Exports	Imports	GDP EA	Infl. EA	Euribor
VARX(1)	<i>RMSFE for different forecast horizons</i>								
1q	0.39	0.75	0.6	0.57	1.26	1.38	0.36	0.15	0.04
2q	0.65	0.71	0.83	0.94	2.44	2.23	0.71	0.16	0.07
4q	1.3	0.87	1.39	1.68	4.64	4.23	1.46	0.18	0.12
8q	2.87	1.17	2.76	3.11	8.34	7.66	3.19	0.19	0.23
12q	4.04	1.64	4.07	4.37	11.91	10.74	4.5	0.25	0.31
ABM	<i>Percentage improvements (+) or losses (-) relative to VARX(1) model</i>								
1q	-6.9 (0.572)	19.3** (0.016)	9.9 (0.260)	3.9 (0.675)	-17.6 (0.352)	-75.0*** (< 0.001)	-67.7*** (< 0.001)	4.7 (0.709)	-63.3*** (< 0.001)
2q	-22.5 (0.139)	21.3 (0.184)	1.9 (0.907)	1.9 (0.770)	6.4 (0.744)	-64.8*** (0.007)	4.4 (0.735)	10.0 (0.375)	-34.7** (0.030)
4q	-40.0 (0.181)	37.6** (0.041)	-15.4 (0.163)	-0.7 (0.926)	19.6 (0.360)	-42.0 (0.153)	16.8 (0.344)	9.6 (0.581)	-11.7 (0.309)
8q	11.0 (0.813)	50.7* (0.071)	5.5 (0.544)	-12.1 (0.539)	27.4 (0.222)	-25.5 (0.562)	26.8 (0.591)	16.0 (0.565)	23.4 (0.119)
12q	15.3 (0.819)	62.0 (0.144)	14.7 (0.378)	-14.8 (0.630)	25.9 (0.399)	-24.1 (0.707)	22.1 (0.794)	35.9* (0.075)	33.5* (0.058)
H6-ABM	<i>Percentage improvements (+) or losses (-) relative to VARX(1) model</i>								
1q	-6.4 (0.594)	19.3** (0.016)	2.3 (0.854)	4.3 (0.654)	-18.4 (0.332)	-68.2*** (< 0.001)	-67.7*** (< 0.001)	4.7 (0.709)	-63.3*** (< 0.001)
2q	-19.2 (0.196)	22.4 (0.160)	8.9 (0.603)	-0.6 (0.923)	7.9 (0.691)	-61.5*** (0.007)	4.7 (0.698)	5.5 (0.625)	-36.4** (0.022)
4q	-29.8 (0.281)	38.4** (0.041)	4.1 (0.667)	-1.2 (0.885)	21.1 (0.330)	-36.4 (0.193)	18.7 (0.314)	16.2 (0.338)	-9.0 (0.412)
8q	15.2 (0.755)	50.7* (0.073)	19.8* (0.069)	-12.7 (0.539)	27.4 (0.228)	-26.8 (0.541)	26.1 (0.600)	14.9 (0.580)	23.5 (0.104)
12q	19.3 (0.803)	62.1 (0.146)	32.6** (0.045)	-14.8 (0.639)	26.2 (0.397)	-25.0 (0.693)	22.6 (0.790)	31.8 (0.102)	33.3* (0.065)
OC-ABM	<i>Percentage improvements (+) or losses (-) relative to VARX(1) model</i>								
1q	-7.5 (0.530)	19.6** (0.014)	-84.6*** (0.001)	3.7 (0.654)	-12.7 (0.499)	-62.3*** (< 0.001)	-78.6*** (< 0.001)	14.1 (0.142)	-64.4*** (< 0.001)
2q	-26.6 (0.174)	20.4 (0.208)	-125.1*** (0.010)	-2.3 (0.643)	9.1 (0.641)	-54.0** (0.014)	1.2 (0.932)	8.7 (0.403)	-35.6** (0.022)
4q	-21.9 (0.420)	37.5** (0.046)	-35.8 (0.128)	0.0 (0.995)	19.6 (0.371)	-29.3 (0.271)	18.6 (0.302)	17.4 (0.322)	-10.3 (0.350)
8q	42.5 (0.415)	49.3* (0.079)	26.5** (0.045)	-12.2 (0.581)	27.0 (0.239)	-22.6 (0.603)	25.5 (0.603)	11.4 (0.624)	23.6* (0.096)
12q	40.1 (0.607)	62.7 (0.144)	52.2*** (< 0.001)	-16.5 (0.639)	26.4 (0.398)	-24.8 (0.692)	21.9 (0.795)	31.0 (0.127)	33.9* (0.061)

ABMs under VARX expectations vs. VARX(1). See Section 4 for estimation details. Diebold–Mariano p -values in parentheses; *, **, ***: 10%, 5%, 1% significance.

Table 26 details the ARX(1) comparison. The OC-ABM gains 31.0% ($p = 0.649$) in GDP and 40.5% ($p = 0.489$) in consumption; the base ABM loses 6.1% in consumption and H6 gains 16.1%. Investment improves by 14.5% ($p = 0.001$). Remaining specification differences prevent attributing these rankings to one household mechanism.

Table 26: Forecast performance under VARX expectations, relative to ARX(1)

	GDP	Inflation	Household cons.	Investment	Euribor
ARX(1)	<i>RMSFE for different forecast horizons</i>				
1q	0.38	0.61	0.59	3.46	0.04
2q	0.67	0.58	0.86	4.54	0.06
4q	1.29	0.56	1.33	6.09	0.1
8q	2.6	0.58	2.44	9.67	0.16
12q	3.51	0.6	3.27	13.41	0.21
ABM	<i>Percentage improvements (+) or losses (-) relative to ARX(1) model</i>				
1q	-7.7 (0.489)	1.4 (0.776)	9.3 (0.255)	12.2 (0.178)	-60.5*** (< 0.001)
2q	-20.1 (0.155)	2.8 (0.176)	4.8 (0.717)	1.1 (0.802)	-38.0*** (0.003)
4q	-41.7 (0.180)	3.9 (0.186)	-20.7 (0.177)	-8.0 (0.222)	-26.8** (0.011)
8q	1.4 (0.973)	1.3 (0.362)	-7.3 (0.696)	3.1 (0.437)	-8.1 (0.629)
12q	2.3 (0.969)	-3.8 (0.220)	-6.1 (0.809)	5.3** (0.019)	1.6 (0.934)
H6-ABM	<i>Percentage improvements (+) or losses (-) relative to ARX(1) model</i>				
1q	-7.3 (0.515)	1.4 (0.776)	1.6 (0.902)	12.2 (0.178)	-60.5*** (< 0.001)
2q	-16.8 (0.220)	4.2** (0.026)	11.6 (0.408)	1.3 (0.765)	-39.8*** (0.002)
4q	-31.4 (0.278)	5.2 (0.163)	-0.2 (0.982)	-7.3 (0.243)	-23.7** (0.037)
8q	6.1 (0.892)	1.3 (0.353)	9.0 (0.775)	4.6 (0.367)	-7.9 (0.616)
12q	7.0 (0.921)	-3.3* (0.087)	16.1 (0.795)	6.7 (0.175)	1.5 (0.943)
OC-ABM	<i>Percentage improvements (+) or losses (-) relative to ARX(1) model</i>				
1q	-8.3 (0.450)	1.8 (0.728)	-85.9*** (< 0.001)	12.3 (0.178)	-61.5*** (< 0.001)
2q	-24.0 (0.182)	1.7 (0.374)	-118.4** (0.010)	1.1 (0.800)	-38.9*** (0.003)
4q	-23.4 (0.439)	3.8 (0.312)	-42.0** (0.032)	-2.7 (0.735)	-25.2** (0.024)
8q	36.4 (0.439)	-1.5 (0.509)	16.6 (0.594)	14.4*** (0.003)	-7.8 (0.611)
12q	31.0 (0.649)	-1.8 (0.433)	40.5 (0.489)	14.5*** (0.001)	2.3 (0.911)

ABMs under VARX expectations vs. ARX(1). See Section 4 for estimation details. Diebold–Mariano p -values in parentheses; *, **, ***: 10%, 5%, 1% significance.