Narrative Model Documentation

A Two-Firm Agent-Based Model of Green Consumption and Tipping Dynamics

1 Purpose

This model is a stylised agent-based model (ABM) designed to study **tipping dynamics in green consumption markets**. Its primary purpose is to demonstrate how weak individual preferences, when combined with habit formation, peer influence, and firm price adaptation, can generate **non-linear transitions** in aggregate market outcomes.

The model is intended as an *existence proof* rather than a predictive or calibrated tool. It focuses on mechanisms and feedbacks rather than quantitative forecasting.

The simulation is shared publicly at this stage to enable **peer review of the computational model itself** by domain experts in agent-based modelling, behavioural economics, and sustainability transitions. Empirical findings and systematic analysis of simulation results are reported separately in a forthcoming research article targeted at a specialised academic journal.

2 Entities, State Variables, and Scales

2.1 Entities

The model consists of three types of entities:

- **Households** (agents), indexed by $i = 1, \ldots, N$.
- **Firms**, indexed by $k \in \{1, 2\}$.
- A single **Economy** object coordinating interactions and timing.

2.2 Households

Each household is characterised by the following state variables:

- β_i: intrinsic preference for greenness,
- η_i: disutility weight on embodied emissions,
- λ_i: price sensitivity parameter,
- $h_{i,k}$: habit strength toward firm k,
- history of observed peer signals.

Households consume a unit mass each period and allocate consumption across firms:

$$\sum_k q_{i,k} = 1, \quad q_{i,k} \geq 0.$$

2.3 Firms

Each firm is characterised by:

- s_k: fixed share of green content in its product,
- p_k: price,
- c_k: unit cost,
- μ_k: cost-plus markup,
- histories of prices, quantities, and profits.

2.4 Scales

Time is discrete and indexed by simulation cycles. Quantities are normalised such that each household consumes one unit per cycle. Prices, costs, and utility are dimensionless and interpreted in relative terms.

3 Process Overview and Scheduling

Each simulation cycle proceeds in the following order:

1. Households observe prices, product greenness, emissions intensity, and a peer signal.
2. Households choose consumption shares via utility maximisation.
3. Household habits are updated based on realised consumption.
4. Firm market shares are aggregated.
5. The peer signal is updated for the next cycle.
6. Firms update prices using an elasticity-based pricing rule.
7. Market shares are recorded and tipping conditions are evaluated.

All updates are synchronous at the cycle level.

4 Design Concepts

4.1 Adaptation and Learning

Households adapt indirectly through habit formation, which increases the utility weight of previously chosen bundles. Firms adapt prices using a Lerner-style rule based on estimated demand elasticity. In extended versions, firms may also experiment with product greenness when profits fall below a threshold.

4.2 Sensing

Households observe:

- current prices,
- product greenness,
- emissions intensity,
- a scalar peer signal summarising recent aggregate behaviour.

Firms observe their own past prices and quantities.

4.3 Interaction

Interaction occurs indirectly through:

- price-mediated competition,
- a shared peer signal capturing social influence,
- aggregate market outcomes feeding back into future decisions.

4.4 Stochasticity

Household preferences are heterogeneous and drawn from probability distributions at initialisation. Firm experimentation (where enabled) is stochastic. All randomness is controlled via seeded pseudo-random number generators to ensure reproducibility.

5 Household Decision-Making

Households maximise a utility function of the form:

$$U_i = \sum_k \alpha_k \ln(q_{i,k}) + \beta_i \sum_k g_k q_{i,k} + \gamma \sum_k h_{i,k} q_{i,k} + \delta \cdot \text{peer}_t \sum_k g_k q_{i,k} - \lambda_i \sum_k p_k q_{i,k} - \eta_i \sum_k e_k q_{i,k}.$$

Utility maximisation is implemented numerically via grid search over feasible two-firm consumption splits.

6 Firm Behaviour

6.1 Costs and Pricing

Firm unit costs are a weighted average of green and brown components:

$$c_k = s_k(c_g - \sigma) + (1 - s_k)(c_b + \tau),$$

where τ is a carbon tax and σ is a green subsidy.

Prices are set using a cost-plus rule:

$$p_k = c_k(1 + \mu_k).$$

6.2 Price Adaptation

Markups are updated toward a Lerner benchmark:

$$L = \frac{p - c}{p} = \frac{1}{|\varepsilon|},$$

where ε is an estimated arc elasticity computed from recent price–quantity observations. Adjustment is gradual to avoid instability.

7 Peer Influence

The peer signal is defined as the previous cycle's market share of the greener firm. It enters household utility as a social reinforcement term, amplifying the utility of green consumption when green behaviour is socially prevalent.

8 Tipping Definition

A tipping point is recorded when the market share of the greener firm exceeds a threshold (e.g. 65%) for a specified number of consecutive cycles. This definition captures both **level** and **persistence**, ensuring that tipping reflects a stable regime shift rather than a transient fluctuation.

9 Outputs

The model produces time series of:

- firm prices,
- market shares,
- peer signals,
- profits and quantities.

These outputs are used for post-simulation analysis and visualisation.

10 Code Documentation and Verification

The source code accompanying this model is intentionally and extensively documented. All core classes and methods include detailed in-line comments and multi-line documentation strings (`""" """`) that explicitly describe the economic interpretation of each component, decision rule, and update mechanism.

These comments do not merely restate the code, but explain the *economic ideas embedded in the implementation*, including behavioural assumptions, sign conventions, and the rationale for specific modelling choices (e.g. elasticity floors, habit updating, peer influence, and pricing rules).

Reviewers wishing to verify that the scope and logic of the simulation align with the model description presented here are strongly encouraged to read these code-level explanations alongside the narrative documentation. The comments are designed to make the mapping between economic theory, model assumptions, and executable code explicit, and to minimise the risk of misinterpretation arising from implicit or hidden assumptions.

In this sense, the narrative documentation and the commented source code should be treated as complementary: the former provides a structured, high-level description of the model (following the ODD protocol), while the latter offers a detailed, line-by-line exposition of how these concepts are operationalised computationally.

11 Relation to Publications

This computational model forms part of an ongoing research project. A dedicated research paper analysing simulation results, mechanisms, and policy implications is currently in preparation for submission to a specialised peer-reviewed journal.

The present upload to the CoMSES Net Model Library is intended to facilitate **early expert scrutiny of the model structure, assumptions, and implementation**. Feedback from the modelling community is expected to inform refinements prior to final publication.

12 Reproducibility

All stochastic elements are controlled via explicit random seeds. Given identical parameter settings and seeds, simulation runs are fully reproducible.