Protein transition in a dynamic food environment: An agent-based model to simulate consumption practices at the household level

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EXTENDED ABSTRACT (ESSA@WORK SESSION)

1 Introduction

A transition from predominantly animal-based proteins towards more plant-based diets in western countries is essential in safeguarding planetary health (McMichael et al. 2007) and future food provision (de Boer and Aiking 2011; Shepon et al. 2018; Willett et al. 2019). Current dietary data do, however, not reflect such a transition (FAO 2023). Available literature points at several aspects constraining the protein transition at the consumption level, which are conveniently summarized by Graça et al. (2019) and Stoll-Kleemann and Schmidt (2016).

One unit of inquiry that is essential in food decision-making is the household, in which "enjoying a meal together" is a common social practice (Gillespie and Johnson-Askew 2009). At the dinner table, several scenarios could unfold that are deterministic for the consumption practices of protein sources at the population level. If one of the household members follows a vegetarian diet, will the family meal default to vegetarian, or will two meals be prepared? Under what social and practical conditions are food preferences catered to? These dynamics within the household are driven by both food preferences and social relationships (Sobal and Bisogni 2009). What happens if the cook of the day prepares a meal that contradicts with the food preferences of a family member? What mechanisms at the individual and the interpersonal level can help us to explain the resulting behaviour?

The type of protein sources that are served within households in western countries depend largely on the assortment of food outlets (e.g. supermarkets). Several studies demonstrated the effect of changes in choice architecture on purchase of meat or its alternatives (Bianchi et al. 2017). To what extent would a change in the availability of animal- and plant-based protein sources affect the eating habits within households? What is more, if consumption practices in families shift towards more plant-based, how would food outlets respond, assuming their primary objective is to make a profit?

The interpersonal interactions within the household and the reciprocal relationship of households and food outlets can be represented as embedded in a complex system, where the household and food outlets are sub-systems of a wider system of the food environment (Sawyer et al. 2021; Waterlander et al. 2020). Product availability reflects the eating practices within household and, likewise, the eating practices can respond to food outlets. Do either or both of these sub-systems have to change in order to shift towards more plant-based diets and what are the necessary prerequisites?

Before we can answer such questions about change, we need to improve our understanding of consumption practices embedded in a complex system. As experimental studies are limited in their possibilities to address the complexities in the food environment all at once, agent-based models (ABMs) are increasingly used to simulate such systems. ABM allows inclusion of heterogeneous, individual decision-making entities, observation of the emergence of current practices under particular conditions (e.g. traditions of meat consumption), and potential path dependencies (e.g. availability of meat analogues) (Epstein 1999). In a review by Langellier et al. (2019), complex system approaches to diet were evaluated, revealing that social influence is often modelled using the so-called "follow-the-average"-mechanism, modified with a threshold for behaviour change based on individual susceptibility and social or environmental triggers (Mercuur et al. 2017).

This research aims to identify the mechanisms that are responsible for the social practice of consuming animal- and plant-based protein foods in relation to assortments of food outlets, by using an agent-based model. In particular, this research will focus on:

1) The dynamics of social influence within households;
2) The reciprocal relationship between households and food outlets.

2 Theoretical framework

2.1 Relevant concepts and theories

Food environments. Consumption practices are embedded in and reinforced by the food environment. Here we define the food environment as the "collective physical, economic, policy and sociocultural surroundings, opportunities and conditions that influence people's food and beverage choices and nutritional status" (Swinburn et al. 2013: 2). In the present study, "households" are considered part of the socio-cultural, and "food outlets" part of the physical elements of the food environment.

Social practice theory. In this study we assume the habitual, social and interconnected nature of consumption practices of protein sources and use the domain-independent framework as proposed by Mercuur et al. (2020) to translated social practice theory into an agent framework.

Status-power theory. To simulate the interpersonal dynamics in the household, we will use the assumption by Kemper (2011) that any interpersonal relationship should address the standing of both actors vis-à-vis in terms of status and power.

Profit maximization theory. The traditional economic model of rational decision-making is applied here for food outlet stores (Tripathi 2019).

2.2 Existing models about consumption practices of animal vs plant-based food

In simulating meat consumption of the British population, Scalco et al. (2019) assumed the physical environment offered two choices: meat or vegetarian. In addition, advertising campaigns aimed at reducing meat consumption were tested for their effectiveness. Social interaction was modelled using a "follow-the-average" mechanism, where an individual's choice depends on the averaged meal preference of the present group. Individuals were attributed with an awareness of environment, health, and animal welfare, which determined their meal preference based on a regression function.

Thomopoulos et al. (2019) aimed to understand the impact of multiple types of arguments that could influence an individual's choice for protein sources and the diffusion of opinions at the collective level. Their individuals were attributed with values for food quality: importance of environment, ethics, health, and taste, and a level of resistance against change. When the perception of meat exceeded their need for this food, the individual would opt for meat, and vice versa. The physical environment consisted of advertising campaigns aiming to increase meat consumption, and crises (e.g. sanitary problems, environmental disaster), both of which could impact an individual's perception of meat. In the social environment, each individual communicated with other consumers in their direct vicinity, which could lead to a change in perception. The mechanism applied is an opinion diffusion model, that updates the perception based on the difference in opinion between two individuals and their resistance rate.

3 Model description (ODD protocol)

3.1 Overview

The central idea of the model is that agents are part of a household and share a meal three times a day. We assume each meal is prepared by only one agent, though the food-preparing agent (cook) can differ depending on household composition and (appreciation of) cooking skills. A cook will prepare a meal based on the preferences of whom to prepare the meal for, and the available food products in a food outlet. After the meal, the prepared food is evaluated to each household member's liking. Depending on the type of interpersonal relationships, each agent will express his (dis-)liking or not towards the cook and may (not) update his food preference. Type of interpersonal relationship is expressed in terms of status and power. The food outlets aim to maximize profit. They evaluate their sales and may update their assortment based on shifts in demand. For this model we assume that no online food purchases or food orders are made. Distance to a food outlet and availability of food products are not limiting purchases.

The intended audience is researchers and policy-makers interested in understanding the mutual interaction between food supply and food norms and habits.

3.1.1 Purpose

This model aims to allow researchers and policy-makers to explore the interactions between the household and food outlet assortment and investigate for which conditions we can observe emergence (or not) of current consumption practices of protein sources at the population level. Specifically, the model aims to:

1. Simulate mechanisms at the individual and interpersonal level in a household setting that can help us to explain consumption of different protein sources (i.e. meat vs. vegetarian);
2. Simulate the reciprocal relationship between the household level (social environment) and food retail (physical environment) within the food environment;
    a. Simulate the influence of taking into account whom to cook for in purchase decisions at the supermarket;
    b. Simulate the influence of changing assortment of protein sources in food outlets on consumption of meat vs vegetarian in households;
    c. Simulate the influence of changing consumption of protein sources in households on assortment of meat vs vegetarian in food outlets.

Main dependent variable is the number of meat and vegetarian meals consumed. Secondary dependent variable is the ratio of meat and vegetarian meals in the assortment of food outlets.

3.1.2 Entities, state variables, and scales

The model includes two types of entities: individuals and food outlets. Individuals are part of a household but can have relationships with individuals in other households and invite these for a meal. Food outlets are situated in the neighbourhood and accessible to all households.

State variables of individuals: food preference (discrete (meat, vegetarian)), "strength of preference" (continuous [0,1], can be dependent on other attributes such as knowledge/attitude/openness), social status (continuous, [0,1], a type of status that is visible and accepted by everyone and determined by age, cooking skills, and appreciation of cooking skills), life-phase (fixed, discrete, child or adult), age (continuous), household-number (fixed, continuous).

Households are generated randomly but with some user-set distribution of parents & children, couples, and friends/students.

Each individual has a personal liking for each other individual with whom he will share a meal. (So technically a list of likings per relevant individual.) This liking is determined by similarity/discrepancy in food preference and social status.

Idea: individuals have the opportunity to perform an act of power to prioritize their food preference (in case of none-cooks) or express their opinion about the way food is (not) consumed (cooks). Real-life situations can be a child throwing a tantrum or a parent showing disappointment when a child did not try/finish the plate.

State variables of food outlets: ratio of meat and vegetarian in assortment, "sensitivity to demand" (fixed), price (continuous, per portion).

Scale is a neighbourhood. Number of households and food outlets will be matched with neighbourhood size of [to be determined]. Physical distance does not play a role.

Run time of the simulation: eventually ~60 years/three generations, including one or three meals a day.

3.1.3 Process overview, scheduling

Flowcharts are shown in Figure 1. Initially, all individuals are part of a household. During the model run, they can change household, so children moving out or couples starting living together. At old age, individuals die.

The procedure for sharing a meal is chosen so it can represent several situations that are known to occur based on literature and conversations of the authors with friends, family and colleagues. When one or more group members are vegetarian, will the cook prepare one vegetarian meal or one vegetarian and one meat-based meal? If the cook is an individual of high social status, for example your boss or grandmother, will you eat

the meal this individual has prepared, even though it does not match your food preference? If an individual has a minority food preference, will he succumb to the "average" of the group or still choose his own preference?

Each individual has a food preference that determines meal choice but also is responsive to the quality of relationships with other individuals that are part of the group sharing a meal. When a cook, individuals aim to cater to the preferences of the meal group. Food preferences of meal group members that are liked most (based on liking) will be prioritized by the cook. When sharing a meal, an individual can express his (dis-)liking of the meal towards the cook by changing his personal liking of this cook and can also change the appreciation of the cooking skills of the cook. An individual will be milder in his disliking of the cooking skills if he has a high liking of the cook. A cook can improve his cooking skills by preparing a meal more frequently. It is assumed this skill is for life i.e. will not decay over time.

The procedure for the activities of the food outlet store are simplified and rationalized: store owners only respond to demand to maximize profit. However, to simulate developments in food supply from World War II onwards, an additional variable or fixed event in time might have to be added that can influence the assortment or demand as well.

Food outlets evaluate the food products purchased by costumers and compare the difference in supply and demand to a threshold that is dependent on the "sensitivity to demand". When necessary, the food outlet will update his assortment.

In reality people do not usually buy ingredients for each separate meal. In this model we assume that people can know in advance whom to they have to prepare a meal for but for simplicity of model flow the moment of purchase is scheduled after the meal group has gathered and before meal preparation.

3.2 Design concepts

3.2.1 Concepts

Basic principles: development of food preference in relation to an individual's environment; social dynamics; profit maximization.

Emergence: the main emergent phenomenon is the consumption of meat or vegetarian meals.

Objectives: the individuals aim to harmonize their social interactions whilst eating their preferred food. The food outlets aim to respond to demand in order to maximize profit.

Adaptation: During a meal, individuals will regulate their response to eating and evaluating the food depending on the cook and others. Food outlets adapt their assortment based on demand.

Sensing: Individuals have relationships outside their own household and are as such aware of the existence of individuals outside their own household. Individuals have complete information about social status and food preference of all individuals in the meal group. Liking of others is calculated once a meal is shared together. Food outlets can only respond to actual demand based on purchases by individuals.

Learning: Individuals keep track of their personal liking of each member of groups with whom they shared meals. Food outlets do not learn.

Stochasticity: Households and relationships with individuals in other households are set up randomly. State variables are set up using a random distribution. The random seed can be fixed.

Interaction: individuals can interact with household members and individuals with whom they have a relationship. Individuals can interact with food outlets.

Observation: consumption of meat and vegetarian meals, possibly aggregated for community/socio-cultural groups; assortment of food outlet stores; development of changeable attributes (e.g. food preference). Results presented as distributions and scatter plots. Scenario discovery will be used to find out for which conditions in the model emergence of different meals and assortments occur.

Collectives: Households and relationships exist statically, creating static communities that can make use of the same food outlets.

3.2.2 Environment

Square, bounded space with households represented as rows of houses and food outlets represented as a building.

3.3 Details

Several sources of input data are envisioned for this model.

- Survey data from a study in food preference to attribute individuals (to be selected)
- FAO data on consumption of animal- and plant-based protein sources since WW II.
- Recipes from a cook book and magazine to inform food outlet agents in more detail about portion size and ratio of meat and vegetarian products to be sold.
- Qualitative data from interviews where participants explained how social context influences their shared meals (results expected: July 2023)
- Food diaries for two consecutive days in multiple households (results expected: July 2023)
- Qualitative data from interviews where couples of which one partner is vegetarian and the other is not deal with food-decision making (*in prep.*)
- Food diaries for two consecutive days in multiple households (RIVM)
- Historical data about events external to the food environment that have impacted supply or demand, e.g. developments in agriculture or disease outbreak.

Initialization and sub-models have not been determined yet.

4 Validation

Aim of validation	Type of data source
What do people actually eat?	Dietary call data
What individual / social / cultural determinants are recognized in food decision making?	Literature, expert judgement
What rules and calculations are accepted in simulating food decision behaviour?	Existing models, reviews on dietary behaviour models (e.g. Langellier et al. (2019))
What differences in food decision making are known across contexts?	Literature, expert judgement, existing models

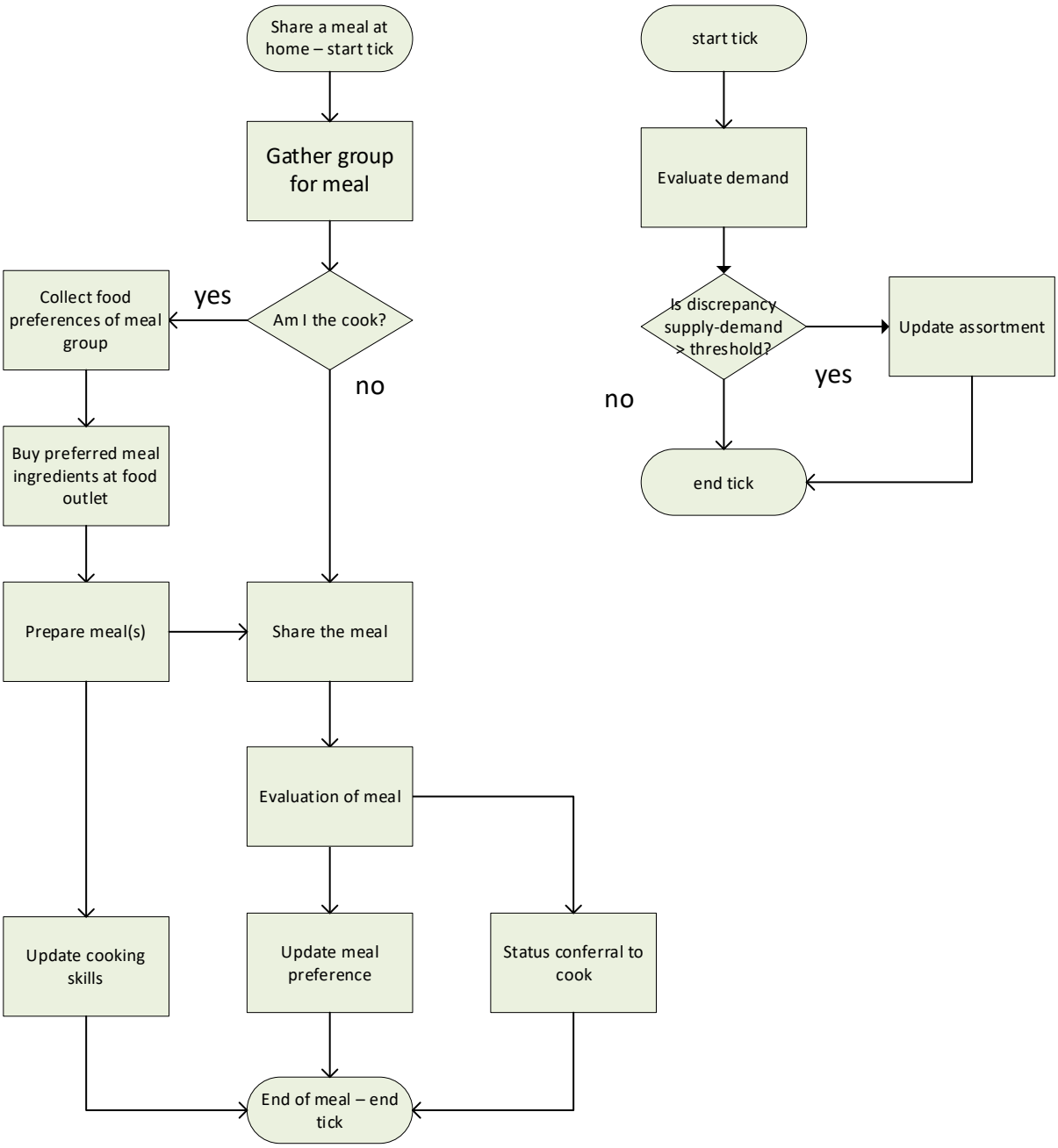

Figure 1 Simplified flow charts of procedures per tick: sharing a meal (left) and food outlet activity (right).

5 References

Bianchi, F., et al. (2017), 'Effectiveness of interventions restructuring the physical environment to reduce the consumption, purchase, or selection of meat products: protocol for a systematic review with narrative synthesis. PROSPERO'.

de Boer, Joop and Aiking, Harry (2011), 'On the merits of plant-based proteins for global food security: Marrying macro and micro perspectives', *Ecological Economics,* 70 (7), 1259-65.

Epstein, J.M. (1999), 'Agent-based computational models and generative social science.', *Complexity,* 4, 41-60.

FAO (2023), *DAILY CALORIC INTAKE PER PERSON THAT COMES FROM ANIMAL AND VEGETAL PROTEIN*. (May 25, 2023).

Gillespie, Ardyth and Johnson-Askew, Wendy (2009), 'Changing Family Food and Eating Practices: The Family Food Decision-Making System', *Annals of behavioral medicine : a publication of the Society of Behavioral Medicine,* 38 Suppl 1, S31-6.

Graça, João, Godinho, Cristina A., and Truninger, Monica (2019), 'Reducing meat consumption and following plant-based diets: Current evidence and future directions to inform integrated transitions', *Trends in Food Science & Technology,* 91, 380-90.

Kemper, Theodore D. (2011), *Status, power and ritual interaction; a relational reading of durkheim, goffman and collins.* (Ashgate, Farnham).

Langellier, B. A., et al. (2019), 'Complex Systems Approaches to Diet: A Systematic Review', *Americal Journal of Preventive Medicine,* 57 (2), 273-81.

McMichael, A. J., et al. (2007), 'Food, livestock production, energy, climate change, and health', *Lancet,* 370 (9594), 1253-63.

Mercuur, Rijk, Dignum, Frank, and Kashima, Yoshihisa (2017), 'Changing Habits Using Contextualized Decision Making', *Advances in Social Simulation 2015* (Advances in Intelligent Systems and Computing), 267-72.

Mercuur, Rijk, Dignum, Virginia, and Jonker, Catholijn (2020), *Modelling Human Routines: Conceptualising Social Practice Theory for Agent-Based Simulation*.

Sawyer, Alexia D. M., et al. (2021), 'Dynamics of the complex food environment underlying dietary intake in low-income groups: a systems map of associations extracted from a systematic umbrella literature review', *International Journal of Behavioral Nutrition and Physical Activity,* 18 (1), 96.

Scalco, Andrea, et al. (2019), 'An Agent-Based Model to Simulate Meat Consumption Behaviour of Consumers in Britain', *Journal of Artificial Societies and Social Simulation,* 22 (4).

Shepon, Alon, et al. (2018), 'The opportunity cost of animal based diets exceeds all food losses', *Proceedings of the National Academy of Sciences of the United States of America,* 115 (15), 3804-09.

Sobal, J. and Bisogni, C.A. (2009), 'Constructing Food Choice Decisions', *Ann. Behav. Med. ,* 38, 37-46.

Stoll-Kleemann, Susanne and Schmidt, Uta Johanna (2016), 'Reducing meat consumption in developed and transition countries to counter climate change and biodiversity loss: a review of influence factors', *Regional Environmental Change,* 17 (5), 1261-77.

Swinburn, B., et al. (2013), 'INFORMAS (International network for food and obesity/non-communicable diseases research, monitoring and action support): overview and key principles', *Obes. Rev.,* 14, 1-12.

Thomopoulos, Rallou, et al. (2019), 'Reduced Meat Consumption: from Multicriteria Argument Modeling to Agent-Based Social Simulation', *International Journal of Food Studies,* 10.

Tripathi, Abhishek (2019), 'Profit Maximizatoin Theory and Value Maximization Theory', *International Journal of Scientific Development and Research,* 4, 284-89.

Waterlander, Wilma E., et al. (2020), 'Understanding obesity-related behaviors in youth from a systems dynamics perspective: The use of causal loop diagrams', *Obesity Reviews,* n/a (n/a).

Willett, Walter, et al. (2019), 'Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems', *The Lancet,* 393 (10170), 447-92.