Diffusion of goods with multiple characteristics and price premiums v1.0.0. Model ODD description

Pedro Lopez-Merino*[1,2,3]

[1]Lamsade/Université Paris Dauphine-PSL, Place du Maréchal de Lattre de Tassigny - 75775 PARIS Cedex 16 France
[2]Écodéveloppement/INRAE, Domaine Saint-Paul, Site Agroparc, 84914 Avignon Cedex 9 France
[3]Agence de la transition écologique (ADEME), 20 Avenue du Grésillé, 49004 Angers Cedex 01 France

February 18, 2022

1 Model description

1.1 Overview

General purpose, entities, state variables and process.

1.1.1 Purpose

This model was conceived as a theoretical abstraction in order to explore questions related to the diffusion of purchases of multi-dimensional goods within a human network. It uses and expands the *innovation diffusion* framework. Theoretical, empirical and modelling work has been done over the past few decades on how innovations become adopted in societies (or fail to do so), and has consistently described S-shaped curves as characterising the process of diffusion—the result of network economies and social influence.

Our model belongs to the class of *network threshold models*, whereby an agent whose network (immediate or otherwise) reaches a given proportion of adoptees automatically adopts. Although an obvious simplification of reality, these models have a number of advantages in terms of fitting theoretical and empirical findings relating to the diffusion of innovations.

*Corresponding author. p.lopez-merino@dauphine.eu

We seek to study an emerging properties that comes out of this, and how it can inform theoretical and empirical work. Namely, we test how purchases are dependent on social interaction as more dimensions of characteristics are included. As the complexity of goods increases, it is natural to wonder what factors can move consumers towards adopting a multiple array of characteristics—and we pose that social interaction is an increasing determinant of this.

1.1.2 Entities, state variables and scales

There are three types of entities in the model: consumers, goods and links. The model is run on a number of parameters that are set before starting a simulation. Tables 1, 2, 3 and 4 describe the entities with their main related variables as well as the parameters.

Table 1: Consumer variables, their description and type.

Variable	Description	Type
w_i	Budget. Each consumer i is endowed randomly with an individual budget, reacquired at each time-step	Exogenous-continuous
$\mathbf{I_i}$	Intention. The set of intentions to purchase each of the characteristics of a given consumer i, the result of a dynamic process (written $I_{i,a}$ to denote intention on a single characteristic a)	Endogenous-binary-vector
$\mathbf{B_i}$	Purchase. The set of characteristics a consumer i actually purchases at a given time-step, with or without intention for each (written $B_{i,a}$ to denote purchase of a single characteristic a).	Endogenous-binary-vector
$\mathbf{A_i}$	Adoption. The set of characteristics a consumer i adopts, related to $\mathbf{I_i}$ and w_i (written $A_{i,a}$ to denote purchase of a single characteristic a)	Endogenous-binary-vector
$\mathbf{J_i}$	The *network of influence* of an agent i, defined as the set of agents in i's vicinity whose distance falls within the d parameter. Each agent in $\mathbf{J_i}$ is denoted by the letter j	Exogenous

Table 2: Goods' variables, description and type.

Variable	Description	Type
$\mathbf{C_g}$	Characteristics. The set of characteristics a good g has (written $C_{g,a}$ to denote a single characteristic a)	Exogenous-binary-vector
p_g	Price. The cost of purchasing a given good g, defined as a function of the number of 1s in $\mathbf{C_g}$	Exogenous-discrete

Table 4: Model's parameters and their description.

Parameter	Description

n_c	Number of consumer agents
n_d	Number of dimensions. This determines the number of characteristics goods can have and that consumers can purchase
ι	Proportion of consumers with intention at $t = 0$. The model is preset so that a given proportion of consumers has the intention to purchase a characteristic right from the outset (they can be seen as the *early adopters* of the innovation diffusion literature).
ρ	Random consumer links. Consumers are linked to their immediate neighbours in a circle lattice, following a regular-small world algorithm (**?**). ρ defines the average number of additional L_c in the lattice.
d	Distance of influence. Consumers are influenced by their more or less immediate network according to the value of this parameter. A value of 1 means that only a consumer's direct links are taken into account
τ	Influence threshold. A consumer with $I_{i,a} = 0$ on a given dimension a is likely to change this variable to $I_{i,a} = 1$ once a proportion τ of M_i has reached $A_{j,a} = 1$
κ	Probability of influence. A consumer i whose $\mathbf{J_i}$ reaches a given threshold of adoption regarding a goods' characteristic a will modify its $I_{i,a}$ with a given probability $\kappa \in [0, 1]$
π	Price premium. The higher price paid by consumers adopting a good containing one or more characteristics. It is defined as a percent value to be added on each additional characteristic present ($\pi \in [0, 1]$)
t^{max}	The duration of a simulation run. This time is fixed so as to ensure that all S-shaped curves of diffusion reach an equilibrium

Spatial considerations are not explicitly considered in the model.

Our model being largely a theoretical abstraction, we choose parameters' values so as to produce diffusion curves that stabilise within a relatively short time span ($t^{max} = 50$). We do not strictly define what a time-step represents. Since the model is inspired by the notion of sustainable food purchases, however, a step of time and its corresponding purchase can be imagined as a weekly basket of items that cannot be avoided.

Table 3: Types of links.

Variable	Description	Type
L_c	Consumer links. The links between a consumer and other ones in the network. Can be more or less randomly defined	Exogenous
M_i	The number of nodes in a consumer's $\mathbf{J_i}$	Endogenous
L_b	Purchase links. Created between consumers and goods at every time-step according to a rule described in Subsection 1.1.3	Endogenous

1.1.3 Process

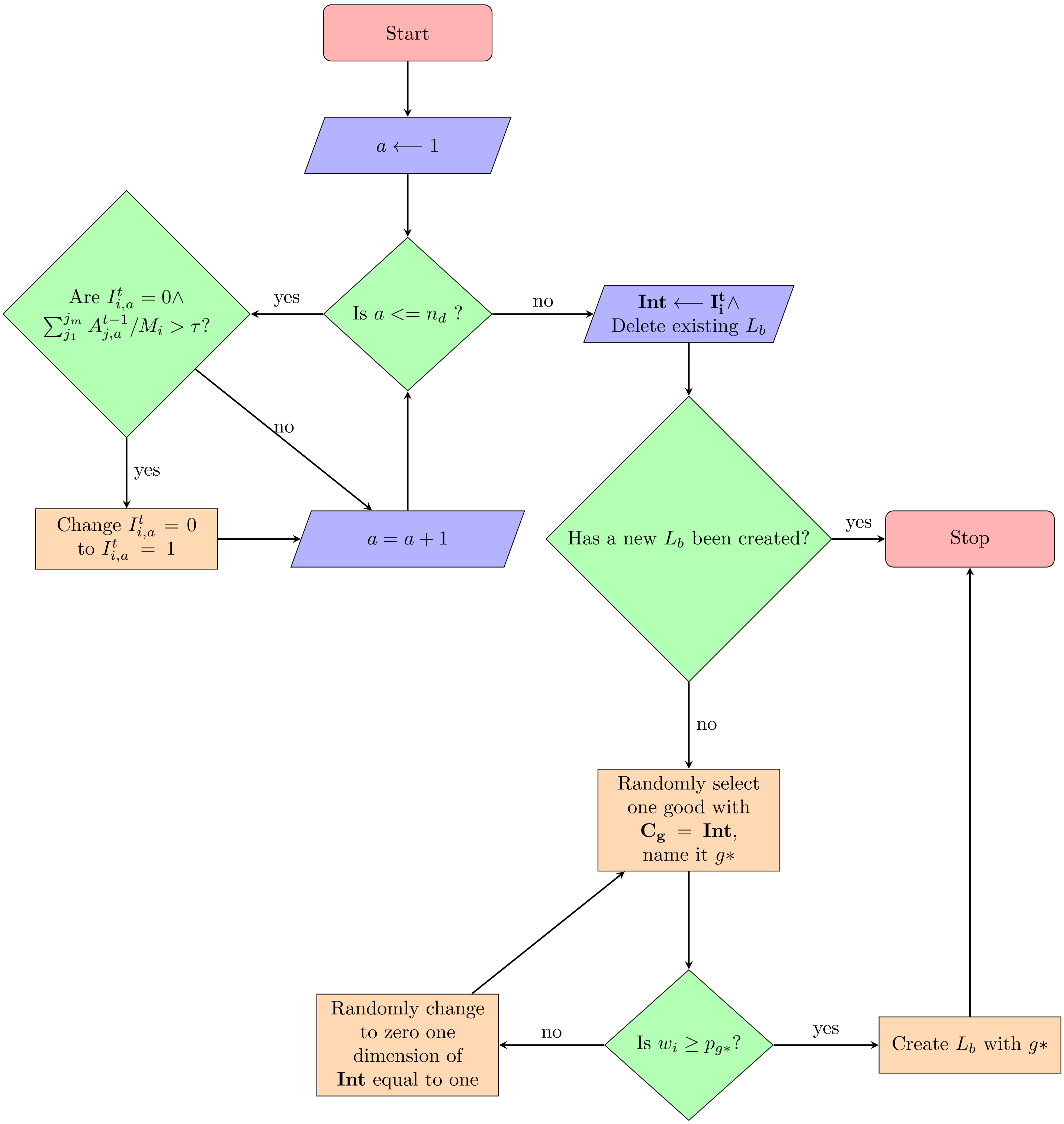
Consumers face 2^{n_d} types of goods, as each one can have or not any of the n_d characteristics available (for $n_d = 1$, there are two goods: the one that has the existing characteristic and the one that doesn't). There is no difficulty in identifying a good or in purchasing it other than that created by π. Consumers *have* to purchase a unit of good at each time-step, represented in the model through the creation of one L_b between the consumer and a good. The chosen good will depend on the consumer's own $\mathbf{I_i}$ and w_i, as well as on an element of randomness for any characteristic a where $I_{i,a} = 0$. The consumers' individual algorithm at each time-step (intention formation and purchase) can be described as follows, with its corresponding flowchart on the following page:

Algorithm 1 Intention formation and purchase for consumer i at every time-step

```
START
procedure INTENTION FORMATION
    a ⟵ 1
    while a <= n_d do
        if I^t_{i,a} = 0 ∧ Σ_{j_1}^{j_m} A^{t−1}_{j,a}/M_i > τ then
            Set I^t_{i,a} = 1
        end if
        Make a = a + 1
    end while
end procedure

procedure PURCHASE
    Delete existing L_b
    Int ⟵ I_i^t
    while No new L_b has been created do
        Randomly select one good with C_g = Int, name it g∗
        if w_i ≥ p_{g∗} then
            Create L_b with g∗
        else
            Randomly select one dimension of Int equal to one and change it to zero
        end if
    end while
end procedure
END
```

Flowchart 1: A Consumer's individual intention formation and purchase.



It should be noticed that the goods that do not contain any characteristics ($C_g = \mathbf{0}$) can be purchased by all consumers, and so the algorithm always comes to an end. A consumer purchasing a good costing less than the consumer's w_i does not save any money, and w_i is reset to its same value at each time-step. Borrowing to purchase an expensive good is not allowed either. Note also that characteristics are independent from one another from a consumer's point of view, and so having intention on one of them does not imply having it on the other.

The equations underlying the algorithm are shown on Subsection **??**.

1.2 Design Concepts

Basic principles, individual decision-making, learning, collectives, heterogeneity, stochasticity and observation & emergence.

1.2.1 Basic principles

We use a basic threshold model of innovation diffusion, and expand it to multiple characteristics. Despite its simplicity, the diffusion of purchases in our model is less straightforward than in traditional threshold models: a consumer will not automatically adopt once a threshold is reached on a dimension a, but will develop an intention ($I_{i,a}$) to do so. $I_{i,a} = 1$ with a corresponding w_i availability will thus translate as $A_{i,a} = 1$. A purchase can happen without a corresponding adoption, as a consumer with enough budget may purchase a good containing a characteristic for which he or she is not necessarily interested in.

Although characteristics are not interdependent *per se* (neither in the case of goods nor for consumers' intentions), they are subject to a common w_i constraint, and in this may have to be arbitrated by consumers with a limited w_i and more than one $I_{i,a} = 1$. In the example of sustainable food consumption, this can be pictured as a person wanting to purchase plastic-free, locally-sourced, organic and fair-trade, and yet being unable to satisfy all four due to budget issues (the arbitration in our model is done randomly, which precludes the possibility of a consumer having a higher *preference* on one or the other of the dimensions).

1.2.2 Individual Decision-Making

The decision-making process of individuals is exceedingly simple. They chose a good at each time-step, related to their intention and budget as has already been described. There's no particular rationality other than the fact that they have to purchase a unit of a good (in economic terms, the demand for a unit of a good per time-step is perfectly inelastic). Decisions are chiefly the outcome of a process of social influence, as the intention to adopt a given dimension is related to the proportion of consumers who have adopted it in the consumer's network of influence. In this, adoption can be seen as a cultural phenomena, which also has a counterpart in the consumption of food.

1.2.3 Learning, Sensing and Prediction

A consumer i with a sufficient level of w_i can randomly purchase a good with a characteristic a while $I_{i,a} = 0$ (much like a person in the supermarket may purchase an eco-labelled coffee without caring for it), although such a consumer is not considered as having changed its adoption. In this, only consumers with a formed intention can be considered as being able to *sense* a dimension, thus consisting of the only learning issue we can identify in the model.

No element of prediction is included in the model.

1.2.4 Collectives

All consumers belong to an interconnected network created using the algorithm proposed by **?**, which includes a parameter for the number of random links (ρ in our model) that determines the *clustering coefficient* of the network. We tested our model on more or less clustered networks. We present results for a perfectly regular lattice ($\rho = 0$, *clustering coefficient* of 0.5) and a Small World one ($\rho = 1$, with a mean observed *clustering coefficien*t of 0.646).

L_c links do not change during the course of a simulation.

1.2.5 Heterogeneity

Consumers are heterogeneous in their budget and intention, the latter of which are set randomly to 1 according to the proportion ι. They also belong to different networks of influence. Decision-making and the remaining aspects of the model are common to all consumers.

Goods are heterogeneous, in that no good fully resembles another. There are 2^{n_d}, each of them having or not each of the n_d dimensions considered. $\mathbf{C_g}$ and π determine each good's p_g, with supply for each being perfectly inelastic.

1.2.6 Stochasticity

Stochasticity is included in that w_i is allocated randomly (uniformly distributed across consumers), that only a given proportion is randomly preset with intention at $t = 0$, and that a consumer i for whom the proportion of adoptees in $\mathbf{J_i}$ reaches τ in a characteristic a will develop $I_{i,a} = 1$ with a fixed probability κ. $B_{i,a}$ is a variable subject to an element of stochasticity also, as a consumer with a sufficiently high w_i may well buy a good with a characteristic it has no intention of purchasing.