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Supplement to: *Do Sustainability Standards Exclude Small Farms? Modelling the Kenyan Floricultural Sector*

ABM model description

The model description follows the ODD (Overview, Design concepts, Details) protocol for describing agent-based models (Grimm et al. 2020[1]).

The model was developed using NetLogo 6.0.4.

1. Purpose and patterns

In this study, we focused on small farms, which are considered by many scholars to be of fundamental importance for social and economic development, greatly contributing to the environmental sustainability of agriculture and land use in general.

As international and national buyers increasingly request environmental and social sustainability certifications before buying products from farms, especially in developing countries, the study tries to answer two recurring questions about small farms:

1) Do environmental and social sustainability certification requests form barriers or increase opportunities for smaller farms?

2) At what size can a farm be defined as a "small farm"?

Since the scientific literature has provided very diverse and sometimes conflicting answers to these questions, mainly due to the different socioeconomic conditions that exist in different parts of the world, we developed a new method, using an agent-based model, to analyse this issue for each production and geographical context. In this way, we can precisely identify which farms are too small to meet the sustainability certification costs in each context; this requires external support policies to ensure their survival in a competitive business scenario.

As a pattern, the model simulates a B2B agricultural market, in which a variety of farms sell their products to national and international buyers, with the presence of requests for sustainability certifications. In this market variations in supply and demand are simulated, observing how farms and buyers react to these variations and how they are affected by certification requests.

As an application case, the study considered the case of cut rose cultivation in Kenya, regarding the four types of certification standards that are the most widespread in Kenyan floriculture: KFC, MPS, Fairtrade and GlobalGAP.

2. Entities, state variables and scales

The model defines three types of agents: the *farms*, the *buyers* and the *auction*.

The *farm* agents have the following attributes:

Farm attribute	Description	Type
opening_tick	The tick at which the farm entered rose production	integer
quantitygrown	The number of flowers that is grown weekly on a farm	integer
init_quantitysupplied	The number of flowers the farm has to sell at the beginning of each tick	integer

[1] Grimm, V. et al. (2020), The ODD Protocol for Describing Agent-Based and Other Simulation Models: A Second Update to Improve Clarity, Replication, and Structural Realism. Journal of Artificial Societies and Social Simulation, 23 (2) 7.

Farm attribute	Description	Type
quantitysupplied	The number of flowers the farm still tries to sell in the current tick	integer
quantity_sold_contract	The number of flowers the farm sold with contracts	integer
quantity_sold_auction	The number of flowers the farm sold with auction	integer
rejection:toosmall	This takes score of how many times a farm is 'rejected' for not being able to supply the desired quantity of flowers	integer
problemKFC rejection:noMPS rejection:noFairtrade problemGGAP	These attributes take score of how many times a supplier is 'rejected' for not being certified	integer
KFC_asking MPS_asking Fairtrade_asking GGAP_asking	List of buyers who have asked for each certification standard	list
MPS GlobalGAP KFC Fairtrade	These attributes capture whether a farm is certified for each certification standard	boolean
rejection:tooexpensive	Takes score of how many times a supplier is 'rejected' for being too expensive—asking for an excessive price	integer
problemquality	Takes score of how many times a supplier is 'rejected' for not delivering sufficiently high-quality roses	integer
shock	Captures a farm's specific shock, which creates problems in terms of quality, quantity, communication, etc. Too many shocks will damage the farm's relationships	integer
list_of_rejections	This captures the reasons why buyers did not buy from the farm	char
buyerlist	Captures buyers it has a contract with	list
revenues	Sum of revenues in the current tick	decimal

Farm attribute	Description	Type
profit	The profit made by the farm in the current tick	decimal
unit_profit	The unitary profit (profit per rose) a farm is trying to obtain. This is calculated with a random function, which returns a profit of several percentage points on the production cost of a rose	decimal
lastprofit	The farm's total profit of the last tick	decimal
profitseries	The farm's profits of the last 24 ticks	decimal
costs	The general costs of a farm to grow a rose. These are calculated on the basis of the average cost of growing a rose that we detected via the interviews, also taking into account the certifications held by a farm (which increase the costs) and the possible economies of scale	decimal
idiosyncraticcost	The specific costs of a farm to grow and sell a rose. Sort of random noise that is not captured in the general costs. They are calculated in a random way and serve to simulate, among others, the transaction costs	decimal
price	The price the farm is asking for a rose. Initially, it is calculated as follows: costs + idiosyncraticcost + unit_profit. However, it is periodically adjusted in accordance with the market trend (see *rejection:tooexpensive* attribute)	decimal
failed_certif_attempt	Stores all the negative certification attempts made by the farm	integer
MPS_tick GlobalGAP_tick KFC_tick Fairtrade_tick	The tick at which the farm obtained each certification	integer
expertise	The farm's level of expertise in growing flowers without paying for it, for example, due to a high level of experience	integer

Farm attribute	Description	Type
boughtexpertise	Expertise level that is acquired through consultancy or hiring better educated workers	integer

The *buyer* agents have the following attributes:

Buyer attribute	Description	Type
number	The number of farms a buyer prefers to buy from	integer
quantitytotal	The total number of roses a buyer needs	integer
quantitypersupplier	This is the initial quantity demanded/number. Currently, florist buyers work with twice as many suppliers as retail buyers	integer
quantitydemanded	The number of roses the buyer is still trying to buy in the current tick	integer
MPS GlobalGAP KFC Fairtrade	These attributes capture whether a buyer demands each certification standard	boolean
price	The price the buyer is offering for a rose. This is calculated as follows: (costs + idiosyncraticprice) * price_correction_factor. It is periodically adjusted in accordance with the market trend	decimal
costs	The part of the price the buyer is offering, relating to requested quality and certifications	decimal
idiosyncraticprice	The part of the price the buyer is offering, relating to random factors	decimal
price_correction_factor	Price correction factor that takes into account the relationship between supply and demand for roses	decimal
contacts	Holds a list of suppliers living up to the buyer's requirements	list
list_of_offers	Lists the prices demanded by the farms who live up to the buyer's requirements	list
best_offer	The item in the list_of_offers that is the lowest	integer
best_offerer	The farm that has the lowest price in the list_of_offers	string

The *auction* agent has no attributes.

In the model, there are three linking objects that link farms with the buyers and the auction: *informing*, *contract* and *auctionsale*.

The *informing* object links a buyer with a farm, so that the buyer can get information about the characteristics of the farm: number of available roses, quality, price and certifications owned. This object has no attributes

The *auctionsale* object links a farm to the auction when the farm sells to the auction. This object has no attributes.

The *contract* object links a buyer with a farm with which a supply contract has been established. This object has these attributes:

Attributes	Description	Type
duration	The number of ticks passed since the contract was established	integer
shocks	A number that represents how many times the contract has had some problems to be solved	integer
quantitycontract	The number of roses bought in the last tick in relation to this contract	integer
value	The total monetary value of the last sale in relation to this contract	integer
contract_price	The price of a rose fixed in this contract	decimal
price_last_revision	The number of ticks passed since the price was fixed	integer
no_of_certif	The number of certifications owned by the farm with which this contract has been established	integer

In the model, there are the following global (or environmental) variables:

Variable	Description	Type
supply	The average weekly supply per farm	integer
supply_	The overall weekly supply	integer
demand	The average weekly demand per buyer	integer
demand_	The overall weekly demand	integer
auctionprice	The average auction price in the current tick	decimal
max_auction_price	The maximum auction price that the buyers are willing to pay for a rose	decimal
min_auction_price	The minimum auction price that the farms are willing to accept for a rose	decimal
startauctionprice	The average auction price in the model setup phase	decimal
demandshock	A sudden change in flower demand by consumers—a random shock	integer
bankrupt	The number of farms that ceased the production of roses	integer
bankrupt_hectares	A list of the dimensions of the farms that ceased the production of roses	list
bankrupt_certif	A list of the number of certifications owned by the farms that ceased the production of roses	list
newentrant	The number of new farms that have entered the rose market since the start of the model running	integer
unsat_demand_list	A list that records the unsatisfied demand at each tick	list
last_farm_qgrown	The number of roses that is grown weekly by the last farm that entered the rose market	integer

The model is temporally explicit; each step (named "tick" in NetLogo) has a duration of one week, and the model runs for 1664 weeks (32 years), simulating the market trend. We chose the duration of the tick as one week because the statistical data that are normally available deal with quantities and prices on a weekly basis. It was decided to run the model for a sufficiently long period of time (30 years) to be able to evaluate highly significant market variations, also considering that a commercial cutting rose orchard has an average production life of several years. Two additional years were added to the simulation, after having verified that about 100 ticks are needed for the model to reach a good starting stability.

The model does not represent spatial attributes or locations.

3. Process overview and scheduling

In short, the model is built on the relationship between farms and buyers, who can establish supply agreements. Farms obtain a profit (positive or negative) by selling their production through these supply agreements or through the auction. By calculating the profit of each farm, we can verify the degree to which certification costs impact the farm's budget and which farms fail to meet these costs.

In pseudocode, the fundamental model's processes that occur in each tick, after the initialization phase, are shown below.

Repeat for 1664 ticks {a tick is a week; 1664 weeks are 32 years}
each buyer
creates random connections with some farms
gathering quantities offered and requested prices
if needs any new suppliers
makes supply agreement with the best bidders of connected farms, if they havethe required certifications and quantities

each farm lacking certifications
tries to obtain the requested ones, if it has sufficient financial capacity

each farm with rejected supply agreements due to price
adjusts the price it requests

each farm with stocks
tries to sell at the auction

each farm
calculates the profit obtained in the current tick
if a supply agreement suffers problems
it can terminate
each farm with rejected supply agreements due to quality
tries to increase quality by purchasing better expertise
if ticks > 104 {after the first 2 years, required for the model's stability}
if demand has constantly exceeded supply
new farms can enter the market
if a farm has had a long period of negative profits
ceases the production of roses
set market trend {buyers' demand and farms' supply can change randomly}
each farm
tries to slightly adapt its production
to the current fluctuations in demand
each farm
updates the profit series of the last 2 years

4. Design concepts

The model simulates the international market of agricultural products, which in the application case concerns the market of stem roses produced in Kenya. The model is based on literature data and data obtained from our on-site interviews. All these data, both qualitative and quantitative, have allowed us to effectively highlight the dynamics of this specific market, in particular, the relationship between farms and national or international buyers, so that they can be reproduced in the model.

The model worked in two distinct modes: hypothetical, in which buyers do not require any certification; reality, in which buyers require sustainability certifications. In the two modes of operation, the environmental characteristics and behaviour of the agents are identical (apart from the request for certification); in this way, it was possible to verify how the request for certification affects the competitiveness of the farms.

4.1. Emergence

The basic principle is that the farm must have sufficient financial capacity to meet the costs of certification, which depends on the profits that the farm is able to obtain, according to the level of costs and revenues, calculated as a result of the interviews with the farms and other Kenyan stakeholders.

The primary result of the model determines whether each farm has sufficient financial availability to meet the costs of certification (the model identifies the number of attempts made before obtaining it); whether, once certified, it is able to obtain sufficient profits to allow the continuation of the production of roses; or if the farm is forced to stop production. All this is considered in relation to the size of the farm, so as to verify if there is a minimum size that determines its competitiveness.

4.2. Adaptation

The farm has the following capacities of adaptation: it can vary the selling price according to the market trend; it can decide whether to try to obtain a certification as a result of the buyers' requests; thanks to some agronomic practices, the amount of production can vary by a small percentage over a certain period of time.

Buyers can vary the price offered, and change the supplier farms in accordance with supply or requested price problems.

4.3. Objectives

If the farms are unable to sell all or part of their products due to a lack of certification, they verify whether their financial capacity is sufficient to pay the higher costs of certification, which can be attributed both to the annual fee they have to pay and the increase in production costs due to compliance with certification standards. The financial capacity was determined by the average profits of the last two years, and the higher costs were calculated on the basis of data collected by us from interviews with the farms.

4.4. Learning

A simple learning mechanism for buyers was implemented in the model: the longer the duration from fixing a supply agreement with a farm without any problems, the greater the trust the buyer has in that farm and, therefore, the lower the probability that the agreement will be terminated. This is consistent with what has been reported in the literature and in our interviews.

4.5. Prediction

In the model, when the demand exceeds the supply by a significant amount and for a relatively long time, other farms enter the market of cut roses due to new orchards; in this way, the supply adapts, rather slowly, to the demand. Therefore, the new farms "bet" on the forecast that the increase in demand will remain stable, at least for the economic life of the new orchards.

4.6. Sensing

In the model, there is a fundamental parameter that influences the behaviour of farms and buyers: the auction price of roses. This price varies over time as a function of global supply and demand; it also influences the determination of prices in supply agreements, together with other parameters relating to product quality and required certifications. In reality, in the supply agreements, the price is always slightly higher than in the auction, but the auction price always influences it, which is immediately known to all agents of the model.

4.7. Interaction

There are two types of interaction between model agents: between buyer and farm and between farm and auction. Buyers have the opportunity to contact as many farms as they wish, obtaining information on the available quantities, prices and possession of the required certifications. In the model, over the years, buyers are able to have contact with practically all farms that grow roses, so that they can generate the supply agreements best suited to the needs of each buyer. The farms interact with the auction when they do not have sufficient supply agreements to try to sell their unsold products.

4.8. Stochasticity

The model includes a main random process: the trend of rose demand. In the real Kenyan market, in recent decades, the demand has had a fundamentally increasing trend, with some instances of temporary sharp decreases, as documented in the literature. We, however, implemented a random market trend in the normal functioning of the model, with the aim of creating both situations favourable to the entry of new farms into the market (increasing demand) and stress situations (decreasing demand). In this way, it is possible to verify which farms are able to remain on the market and continue the production of roses and how the certification requests influence this possibility.

4.9. Collectives

In the model, we deliberately did not implement any form of aggregation of agents because we wanted to study the individual farms in relation to their size, verifying how they behave in the presence of a very competitive market, which is equivalent to the current real market. One of the main conclusions that can also be drawn from the results of the model is the need to form aggregations of small farms in relation to sustainability certification, to allow them to withstand competition, which otherwise favours medium–large farms.

4.10. Observation

The model allows us to store a large database containing the starting settings, all the variations that occur during its operation and the final situation.

The main types of data stored in the database are as follows:

For each farm: size, duration of presence in the rose market (number of ticks), eventual tick of exit from the market, profits obtained over time, certifications acquired and number of failed certification attempts;

For each buyer: numbers of roses and certifications required;

Average price trend in each tick: price requested by the farms, price offered by buyers, price fixed in the supply agreements and auction price;

Total number of roses in each tick: buyers' requests, produced by the farms, sold by the farms through the supply agreements and sales through the auction.

5. Initialization

In the setup phase, 71 buyers, 100 farms and one auction are defined. The attribution of values to agents' variables is described in Sections 3.3, 3.4 and 3.5 of this article. This attribution varies randomly at each repetition of the model's operation, but in such a way that the total quantities produced, the distribution of farm sizes and the average starting prices are always respected, since these values reflect the real data found in the literature or collected by us.

6. Input data

The sources of input data thoroughly described at the beginning of Section 3 of this article.

7. Submodels

7.1. Buyer to farm connection

At the beginning of each tick, each buyer creates random connections with some farms with which it does not have a supply agreement, verifying that the connected farm produces a sufficient quantity for the minimum batch required and creating a list of price offers.

7.2. Agreement between buyer and farm

Subsequently, each buyer, according to the supply agreements already made, buys the quantity of flowers specified, or concludes new supply agreements with some of the farms with which it has a new connection, starting from the best bidder farm and verifying that it still has a sufficient quantity for the minimum batch required. If the buyer requests one or more certifications, an agreement is made only if the farm has these. In this phase, the unit price of the supply is fixed, based on a negotiation between the two parties that considers the price offered by the buyer, the price requested by the farm and the price found in the auction sales. As verified by the conducted interviews, the supply agreement is generally not a binding contract for the two parties, and often, it is not even in written form; it remains valid for an indefinite period of time, until there are factors that lead to its modification or termination (see below). The fixed unit price remains valid for a few months, then it is renegotiated. The model reflects these behaviours.

7.3. Farm's certification

The farms that have not been able to establish supply agreements due to a lack of certifications try to obtain those required by the buyers they are in contact with. However, only farms that have sufficient financial capacity to meet the direct and indirect costs of certification can obtain this.

Then, the farms that succeed in obtaining the certifications will try to establish supply agreements.

7.4 Auction sales

Farms that still have quantities of flowers to sell, either because they do not have sufficient supply agreements or because they do not have them at all, try to sell their product through the auction. The auction price is established on the basis of the ratio between supply and demand.

7.5. Supply agreement problems

Previously established supply agreements can encounter problems for various reasons, the main one being product quality, and other unforeseen issues. This can lead to the termination of the agreement. This is more likely to happen in the first few years of the agreement being established; indeed, as reported in the literature, the oldest agreements tend to be the most stable ones.

If a farm has had problems with product quality, it can acquire better skills through consultancy or hiring better educated workers; this leads to an increase in production costs.

7.6. Farms initiating and ceasing production

Farms that have had negative profits for a significantly long period cease rose production. This leads to a decrease in the global supply of roses, which tends to restore the supply/demand equilibrium in the oversupply periods.

If demand has constantly exceeded supply for a significant period of time, new farms can enter the rose market, gradually restoring the supply/demand equilibrium.

7.7. Market trend

Each tick the model sets changes to the current demand and supply. Before the model setup, we can choose one of four different operating modes of the market trend: random, stable, growing or falling. The normal functioning of the model is with the random market trend, in which gradual but random changes in the demand for roses occur; this operating mode allowed us to obtain the realistic results of the model. The other three operating modes were only implemented to verify and validate the model: analysing the results of the model with each of these three constant market trends, we could check if it works as expected.

Through some agronomic practices, farms can try to respond to small variations in demand, but not to larger variations. The larger variations involve the farms' entry into and exit from the market, as reported above.

7.8. Farms' profit calculation

At the end of each tick, the farms calculate the profit obtained in the past week. Certified farms also deduct a weekly quota paid for the certification fees.

The mean profits obtained in the last two years determine the financial capacity of each farm, which allows them to meet any certification costs.