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Improving Vegetables Quality in Small-Scale Farms Through Stakeholders Collaboration

Esteso A[1], Alemany MME[2], Ortiz A[3]

Small farms are responsible for the 80% of the world's agricultural production although they have difficulties to meet the market quality requirements. Corporate social responsibility (CSR) programs where modern retailers invest in empowering small-farmers have been implemented obtaining an increase of the Supply Chain (SC) profits in cases where supply and demand are balanced. In this paper, a MILP model based on Wahyudin et al. (2015) to select the investments to carry out by modern retailers, and the product flow through the SC in situations of supply and demand imbalance is proposed. Its objective is to find out if collaboration programs have a positive impact on SC profits when supply and demand are not balanced. This model allows the rejection of demand and product wastes. Results show that collaboration programs positively impact on the SC profits and on consumer satisfaction level when there is an imbalance between demand and supply.

Keywords: Agri-Food Supply Chain; Small Farm; Farmer Skills; Mixed-Integer Linear Programming; Food quality;

1 Introduction

Approximately 85% of farms in the world are small farms (less than 2 ha in size) that are responsible for the 80% of the world's agricultural production (Lowder et al. 2016). In general, small-farmers show weaknesses in accessing market, adopting new technology, upgrading skills in managing business, and improving the vegetables safety and quality (Sutopo et al. 2011; Sutopo et al. 2012).

[1]Ana Esteso (e-mail: aneslva@doctor.upv.es)
[2]MME Alemany (e-mail: mareva@cigip.upv.es)
[3]Angel Ortiz Bas (e-mail: aortiz@cigip.upv.es)

[1,2,3] Research Centre on Production Management and Engineering (CIGIP). Universitat Politècnica de València. Camino de Vera S/N, 46022 Valencia, Spain

Simultaneously, consumers demand high quality vegetables (HQV) for which they are willing to pay a high price. The problem arises when demand cannot be fulfilled by farmers since they are not harvesting enough HQV. To reduce the wastes produced by not selling the non-quality vegetables (NQV), small-farmers can sell them at a very low price to alternative markets. However, if quality of products were improved at small farms, the whole agri-food supply chain (AFSC) profits would increase, wastes would be reduced, and consumers' demand would be fulfilled. To increase the capabilities of small farmers and to provide them funds to adopt new technology or machinery impacts on the vegetables quality improvement (Sutopo et al. 2011; Sutopo et al. 2013a; Sutopo et al. 2013; Wahyudin et al. 2015). There are also models for helping AFSC operative decisions while considering the quality of products (Grillo et al. 2017).

An Indonesian research group has proposed to include these activities in corporate social responsibility programs employed for empowering farmers, and consequently, increasing the vegetables quality (Sutopo et al. 2011; Sutopo et al. 2012; Sutopo et al. 2013a; Sutopo et al. 2013b; Sutopo et al. 2013c; Wahyudin et al. 2015). However, none of them study if the results obtained can be extrapolated to environments in which demand is not equal to supply.

The objective of this paper is to fill this gap by answering the Research Question: Is the implementation of a collaboration program (CP) appropriate to empower farmers when demand of vegetables is higher/lower supply? Presumably it is, since collaboration is useful to reduce AFSC costs, ensure product's quality and reach consumers trust while reducing uncertainty of the chain (Esteso et al. 2017). For analysing it, an extension of the MILP model proposed by Wahyudin et al. (2015) is presented and solved for three scenarios: i) demand < supply, ii) demand = supply, and iii) demand > supply.

The rest of the paper is structured as follows. Section 2 exposes the problem under study and the assumptions made. Section 3 formulates the MILP model. Section 4 discusses the results achieved after the model resolution. Finally, section 5 draws a set of conclusions and possible future research lines.

2 Problem Description

The AFSC under study is involved in the production and distribution of vegetables. The AFSC is made up of small-farmers, farmer cooperatives (aggrupation of close farmers), modern retailers, and consumer markets.

Since most small-farmers are not able to produce HQV, farmer cooperatives (FC) classify the whole harvest into HQV and NQV. Vegetables that meet the quality requirements imposed by consumers are transported from FC to modern retailers. These products will be after transported to consumer markets to be sold to end customers at a high price. To reduce the wastes of vegetables, FCs directly sell the NQV in consumer markets at a lower price than HQV.

Modern retailer's benefits directly depend on the quantity of HQV sold in the consumer market. Since the supply of HQV is lower than demand, modern retailers establish a CP to increase the proportion of HQV to be obtained at each farm. By this program, modern retailers assign a skill level to each farmer in function of the proportion of HQV to be obtained in their farms. For example, skill level 0 corresponds to less than 70% of HQV, skill level 1 corresponds to a proportion between 70% and 80%, skill level 2 to proportions between 80 and 90%, and finally, skill level 3 to proportions between 90 and 100%.

Then, retailers can invest to take a farmer to the next skill level. This improvement increases the ability of farmers to buy the latest technology, to apply latest agriculture system and to provide other supporting utilities (Wahyudin et al. 2015), increasing the proportion of harvest to be of high quality.

It is demonstrated that this CP has a positive impact in all members of the AFSC when demand is balanced with supply (Wahyudin et al. 2015). However, it is unknown if these conclusions are applicable to environments in which there is an imbalance between supply and demand. To find out, we propose a MILP model based on Wahyudin et al. (2015) to select the investments to carry out by modern retailers and the product flow through the SC with the following assumptions:

- The quantity of vegetables to be harvested by farmers is known in advance, as well as the proportion of HQV to be obtained at each farm.
- End customers demand HQV. If only NQV are available, we assume that consumers buy them at a lower price.
- If demand is higher than supply, some demand will be rejected. On the contrary, if demand is lower than supply, some product will be wasted.
- Initially, all farmers are at the skill level 0 of the CP. It is known the proportion of HQV to obtain by each farmer if it remains in skill level 0. The improvement of such proportion with each skill level is known.
- The objective of the model is to maximize the profits obtained by the whole AFSC. Economic data for each period, such as distribution costs, production costs, training costs, penalty costs and vegetable selling price, are known. Investments in the CP cannot exceed the available budget.

3 MILP Model Formulation

The model aims to determine if CP positively impact on SC profits when supply and demand are not balanced. Since Wahyudin et al. (2015) assumed that all harvest was sold, their model is extended by including harvest and demand data and by quantifying wastes and rejected demand due to supply and demand imbalances.

The nomenclature used to formulate the model is presented in Table 1 where i refers to farmers, j to FC, k to modern retailers, m to consumer markets, v to vegetables, c to product's quality, t to time periods, and FC_i to the set of farmers i that belong to FC j.

Table 1 Model nomenclature

Parameters			
s_i^{vt}	Quantity of vegetable v produced by farmer i at period t.	dem_m^{vt}	Demand of vegetable v in market m at period t.
p_{ijm}^{vct}	Price of selling one unit of vegetable v of quality c from farmer i through FC j at market m at period t.	pc^{vt}	Penalty cost for overproducing / underproducing one unit of vegetable v at period t.
dij_{ij}^{vt}	Cost of distributing one unit of vegetable v from farmer i to FC j at period t.	r_{ij}^{vt}	Cost of producing one unit of vegetable v by farmer i in FC j at period t.
djk_{jk}^{vt}	Cost of distributing one unit of vegetable v from FC j to modern retailer k at period t.	h_{ij}^{t}	Cost of training the farmer i in FC j at period t for increasing one level in the CP program.
djm_{jm}^{vt}	Cost of distributing one unit of vegetable v from FC j to consumer market m at period t.	dkm_{km}^{vt}	Cost of distributing one unit of vegetable v from modern retailer k to consumer market m at period t.
g_{ij}^{t}	Vegetable's worth when being produced by farmer i in FC j at period t.	α	Percentage of quality improvement with each CP skill level
L	Maximum skill level of the CP.	l_{ij}	Initial skill level of farmer i in FC j
CPB	Available budget for CP investments.		
Decision variables			
q_{ij}^{vct}	Quantity of vegetables v of quality c transported to FC j facilities from farmer i at period t.	qk_{ijk}^{vct}	Quantity of vegetables v of quality c sold to modern retailer k from farmer i in FC j at period t.
qm_{ijm}^{vct}	Quantity of vegetables v of quality c sold to consumer market m from farmer i in FC j at period t.	Q_{ijkm}^{vct}	Quantity of vegetables v of quality c coming from farmer i in FC j sold by retailer k to market m at period t.
w_i^{vt}	Quantity of vegetables v wasted in farmer i at period t due to overproduction.	$rdem_m^{vt}$	Quantity of rejected demand in market m at period t due to scarcity of vegetables v.
SL_{ij}^{t}	CP program current skill level of farmer i in FC j at period t.	F_{ij}^{t}	CP program levels improved by farmer i in FC j at period t.

The MILP model of the addressed problem can be presented as follows:

$$\begin{aligned}\max\ Z = &\sum_v\sum_c\sum_i\sum_{j\in FC_i}\sum_m\sum_t\left(\sum_k Q_{ijkm}^{vct}+qm_{ijm}^{vct}\right)\cdot cp_{ijm}^{vct}-\sum_v\sum_c\sum_i\sum_{j\in FC_i}\sum_t q_{ij}^{vct}\cdot\left(dij_{ij}^{vt}+r_{ij}^{vt}\right)\\ &-\sum_v\sum_c\sum_i\sum_{j\in FC_i}\sum_k\sum_t qk_{ijk}^{vct}\cdot djk_{jk}^{vt}-\sum_v\sum_c\sum_i\sum_{j\in FC_i}\sum_m\sum_t qm_{ijm}^{vct}\cdot djm_{jm}^{vt}\\ &-\sum_v\sum_c\sum_i\sum_{j\in FC_i}\sum_k\sum_m\sum_t Q_{ijkm}^{vct}\cdot dkm_{km}^{vt}-\sum_v\sum_t\left(\sum_i w_i^{vt}+\sum_m rdem_m^{vt}\right)\cdot pc^{vt}\\ &-\sum_i\sum_{j\in FC_i}\sum_t F_{ij}^{t}\cdot h_{ij}^{t}\end{aligned} \tag{1}$$

Subject to:

$$s_i^{vt} = \sum_{j \in FC_i} \sum_c q_{ij}^{vct} + w_i^{vt} \qquad \forall i, v, t \tag{2}$$

$$q_{ij}^{vct} \leq s_i^{vt} \cdot \left(g_{ij}^t + \alpha \cdot SL_{ij}^t\right) \qquad \forall i, j \in FC_i, v, c = 1, t \tag{3}$$

$$q_{ij}^{vct} \leq s_i^{vt} \cdot \left(1 - g_{ij}^t - \alpha \cdot SL_{ij}^t\right) \qquad \forall i, j \in FC_i, v, c = 2, t \tag{4}$$

$$q_{ij}^{vct} = \sum_k qk_{ijk}^{vct} \qquad \forall i, j \in FC_i, v, c = 1, t \tag{5}$$

$$qm_{ijm}^{vct} = 0 \qquad \forall i, j \in FC_i, k, v, c = 1, t \tag{6}$$

$$q_{ij}^{vct} = \sum_m qm_{ijm}^{vct} \qquad \forall i, j \in FC_i, v, c = 2, t \tag{7}$$

$$qk_{ijk}^{vct} = 0 \qquad \forall i, j \in FC_i, k, v, c = 2, t \tag{8}$$

$$qk_{ijk}^{vct} = \sum_m Q_{ijkm}^{vct} \qquad \forall i, j \in FC_i, k, v, c, t \tag{9}$$

$$Q_{ijkm}^{vct} \leq qk_{ijk}^{vct} \qquad \forall i, j \in FC_i, k, m, v, c, t \tag{10}$$

$$\sum_i \sum_{j \in FC_i} \sum_k \sum_c Q_{ijkm}^{vct} + \sum_i \sum_{j \in FC_i} \sum_c qm_{ijm}^{vct} + rdem_m^{vt} = dem_m^{vt} \qquad \forall m, v, t \tag{11}$$

$$\sum_i \sum_{j \in FC_i} \sum_t F_{ij}^t \cdot h_{ij}^t \leq CPB \tag{12}$$

$$\left(g_{ij}^t + \alpha \cdot SL_{ij}^t\right) \leq 1 \qquad \forall i, j \in FC_i, t \tag{13}$$

$$SL_{ij}^t = l_{ij} + \sum_{t_1 = 0}^{t} F_{ij}^{t_1} \qquad \forall i, j \in FC_i, t \tag{14}$$

$$SL_{ij}^t \leq L \qquad \forall i, j \in FC_i, t \tag{15}$$

$$F_{ij}^t,\ SL_{ij}^t \quad INTEGER,$$

$$q_{ij}^{vct},\ qk_{ijk}^{vct},\ qm_{ijm}^{vct},\ Q_{ijkm}^{vct},\ w_i^{vt},\ rdem_m^{vt} \quad CONTINUOUS \tag{16}$$

The objective of the model (1) is to maximize the profits obtained by the AFSC. The first term of the equation represents the profit obtained when selling HQV or NQV. The rest of the equation expresses the different costs of the AFSC: production and distribution costs, penalty costs (rejected demand and vegetable wastes), and investments in the CP.

Constraint (2) states the vegetables balance at farmers. Constraints (3) and (4) establish the minimum quantity of HQV or NQV being transported from farms to FC. Constraints (5) and (6) indicate the flow to be followed by HQV, allowing them to be transported from FC to modern retailers but not allowing them to be directly transported to consumer markets. Similarly, constraints (7) and (8) establish the flow of NQV, only allowing them to be transported directly from FC to consumer markets. Constraints (9) and (10) state the vegetables balance at modern retailers. Constraint (11) defines the vegetables balance in consumer markets. Constraint (12) ensures that the total investment made for training farmers do not exceed the budget. Constraint (13) establishes that the maximum proportion of vegetables being HQV is equal to 1. Constraint (14) calculates the current skill level of a farmer at each period. Constraint (15) ensures that the skill level of each farmers does not exceed the maximum number of levels available at the CP program. Finally, constraint (16) states the definition of variables.

4 Discussion of Results

The model was implemented in MPL® 5.0 and solved by using the solver Gurobi^{TM} 6.0.4. Input data and values that decision variables acquire once solved the model were stored in a Microsoft Access Database. The computer used for solving different scenarios has an Intel® Xeon® CPU E5-1620 v2(C) @ 3.70GHz processor, with an installed capacity of 32.0 GB and a 64-bits operating system.

First, the model is solved for the instance proposed by Wahyudin et al (2015) for three scenarios: i) demand < supply, ii) demand = supply, and iii) demand > supply. For scenarios in which demand is higher or lower than supply, the initial demand is augmented or reduced a 40%, respectively. Results (Fig 1) show that the same quantity of HQV is sold before and after implementing CP in all scenarios. This is because the temporal horizon is not broad enough to obtain a return of the retailers' investments. In cases in which demand is higher than supply, some demand will be rejected. When demand is lower than supply, only NQV will be wasted.

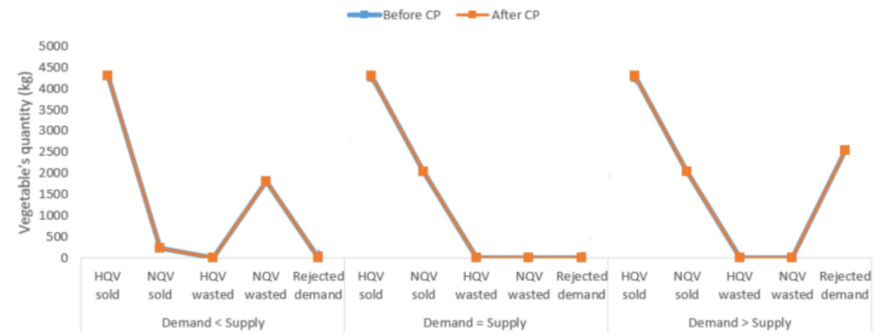

Fig. 1 Results for the two periods of time instance (Wahyudin et al. (2015) instance)

Since the previous instance considers a two periods of time horizon the model is solved for a new instance with a 120 periods of time horizon. For that, data used in the previous instance is replicated for the 120 periods of time. Results presented in Fig 2 show that the quantity of HQV sold after implementing CP increases in all scenarios while the quantity of NQV sold decreases. When wasting vegetables, only NQV are thrown away. Demand is only rejected in the scenario in which demand is higher than supply.

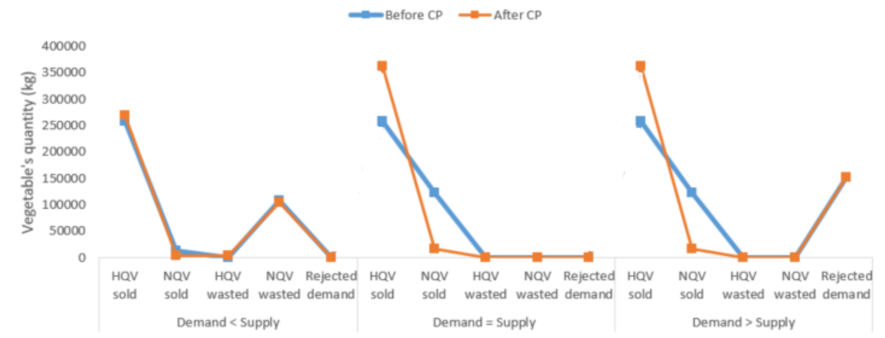

Fig. 2 Results for the 120 periods of time instance

Total AFSC profit has increased in all scenarios for the second instance: 2% when demand is lower than supply, 2,4% when demand is equal to supply, and 30,2% when demand is higher than supply. Similarly, the quantity of HQV sold have increased in 4,1% when demand is lower than demand, and 40,7% when demand is equal to or higher than supply. Modern retailers have invested in increasing three skill levels of a farmer when demand is lower than supply and spent all the CP budget when demand is equal to or higher than supply.

5 Conclusions and Future Research Lines

An extension of the MILP model proposed by Wahyudin et al. (2015) is presented to prove the validity of their conclusions for cases where demand and supply are not balanced. Results show that it is profitable to invest in farmer's empowerment in situations with an imbalance between supply and demand provided that the considered time horizon allows the return of investments made.

The model can be employed by modern retailers as a tool to select which investments to carry out depending on the increase of profit that such investments would produce. It is also useful to determine the flow of products among the AFSC actors to optimize the whole AFSC profits.

The proposed model could be more extended for contemplating in a more realistic way the AFSC behaviour. In real AFSCs, not all consumers are willing to buy a NQV, even if it has a low price. In such cases, some demand will be rejected while NQV will be wasted. This situation will reinforce the need of improving the skills of farmers to increase the quality of harvested products. The benefits of employing CP for that could be analysed by extending the proposed model.

Finally, several parameters could be modelled as uncertain to represent the real behaviour of agri-food sector, namely the consumer demand, economic data, the quantity of harvested vegetables, the HQV proportion to be obtained during harvest at each farm, and the improvement of such proportion with each skill level.

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