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Understanding the Diffusion of a Mobile Application for Supply Chain Management: A System Dynamics Approach

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Abstract: - An appropriate information and logistics structure is of paramount importance for the local fresh food supply chain, which is characterized by market fragmentation and little coordination among suppliers and customers. Mobile communication technologies can help meet this goal because of their large diffusion and real time information management. In this context, a System Dynamics model is developed to study the diffusion pattern and the impacts of a new application for mobile devices supporting supply chain operations. To this end, a reference supply chain in Northern Italy has been considered. The base application and the integration of three additional features assisting in the management of product traceability, electronic payments, and time-sensitive deliveries are analyzed. Simulation results provide insights into the dynamics of adoption of the mobile service and help derive business policies to disseminate its diffusion.

Key-Words: - local fresh food, mobile applications, supply chain management, information flow, innovation diffusion, System Dynamics, Bass model

1 Introduction

The introduction of micro-browsers and similar applications in wireless communication devices gives the possibility of having the Internet "in one's pocket" and of performing a variety of activities without being in front of a computer [1, 2]. Mobile devices such as smartphones connected to the Internet can purposefully support supply chain management (SCM), from placing orders to delivering products, as well as making the associated decisions. This is of great value to the logistics industry because the strategic use of wireless and Internet technologies may drive business innovations, increase the customer service level, and eventually secure competitive advantage and long term profits [3, 4].

Some industries, especially those poorly structured and involving a great number of players, are characterized by a scarce control on the information flow among supply chain (SC) partners and sometimes by a lack of an appropriate physical logistics connected to delivery. In such contexts mobile technologies play a significant role because they can improve purchase transactions and the physical distribution process. Also, they can enable the use of electronic communications for more than simply placing orders. Finally, they can support a re-engineering of the logistics process by connecting all the SC members with real time information.

This paper focuses on local fresh food, a sector suffering from the issues just discussed being characterized by a myriad of small producers and retailers that often operate without any kind of SC coordination. The System Dynamics (SD) modeling and simulation approach has been applied to study the benefits and the potential diffusion of a novel mobile application for smartphones and tablets facilitating the SCM from order to delivery. To this end, a reference local fresh food SC based in the city of Torino, Italy, has been considered. The results of the simulation model show the advantages of the application and allow deriving some policies for stimulating its diffusion.

The paper is organized as follows. An overview of the literature forming the theoretical background of this work is presented in Section 2. Section 3 details the methodology, while Section 4 describes the SD model as well as the associated simulation results. Section 5 discusses policy making. Section 6 introduces benefits and limitations of the analysis, implications, and future research directions. Finally, conclusions are given in Section 7.

2 Literature Background

The developed SD model is based on two theoretical pillars: innovation diffusion analysis, with particular regard to the Information and Communication

Technology (ICT) area, and SD applications to diffusion trends and SC issues. They will be discussed in the following sub-sections.

2.1 Analyzing Innovation Diffusion

When studying trends of innovation growth, the S-shaped pattern is very frequently used in order to represent the spread of innovations. At the beginning, a limited number of users, named "innovators", adopt and form that critical mass that will play a key role in the subsequent diffusion process. Then, other users, defined as "imitators", will adopt as a consequence of the social interaction with the innovators and of external factors such as advertising. The demand for the innovation first increases and meets its maximum value and then it decreases and equals zero when the market saturation point has been reached. Therefore, the curve of the cumulated number of adopters grows rapidly when the demand for innovation is rising and then increases at a slower rate while approaching the market saturation [5, 6].

Numerous models to forecast innovation diffusion do exist, among them the Gompertz, Logistic, Bass, and Fisher-Pry models [7, 8]. In particular, the Bass model [9] has been used in very heterogeneous fields such as retail services, industrial technology, agricultural, educational, pharmaceutical, and consumer durable goods sectors, being it quite intuitive and simple but, at the same time, with a high power of demand forecasting [10]. The Bass model has been extensively applied in the ICT arena too. Its original formulation and subsequent extended versions are suitable to model the timing of the process of the adoption of a technology, tightly dependent on the innovation attitude of each class of potential adopters [11]. The Bass model has been implemented to study the diffusion of mobile telephony and communication infrastructures as well as to forecast the demand of mobile communication services [6, 12, 13]. With the aim of capturing the complex cause and effect relationships among the factors involved in the diffusion of an innovation in the ICT field, some contributions rely on the SD representation of the Bass model provided by [14] to develop frameworks for identifying the economic and socio-cultural determinants affecting the capacity to adopt ICT innovations, defining policies to stimulate the diffusion of ICT solutions, or forecasting the success of products either prior to their launch or during their lifecycle [15, 16].

2.2 Supply Chain Modeling with System Dynamics

SD is a modelling and simulation approach aimed at understanding the behavior of a complex system to support policy design. This methodology enables to graphically represent a system of interrelated stock, flow, and auxiliary variables, define the mathematical equations describing the relationships among them, and perform a computer-based simulation to determine the trends of the investigated variables over a preset period of time. Model validation is performed through historical data and sensitivity analysis [14, 17].

Sterman offers a very detailed SD representation of a SC [14]. Based on his work, contributions focus on several issues affecting both manufacturing and service industries [18, 19, 20]. SD has been applied to capture the interrelation between SC responsiveness and efficiency and to study the effects of strategies to improve them [21, 22]. Furthermore, SD models have been developed to examine instabilities in the SC due to actions addressing the imbalances between supply and demand like price changes, promotions, and the involvement of additional suppliers [23]. SD proved to be beneficial in SC reengineering and to characterize the conditions under which the bullwhip effect can occur [24]. Finally, SD models have been extensively used to evaluate the operational and economic performance of SCs [25, 26].

3 Methodology

In order to understand both the methodology and the proposed model it is beneficial to briefly explain the basic characteristics of the mobile application at issue. The application has two main functionalities, namely assisting SC operations and supporting vehicle routing. It enables online order placement, inventory control, dispatching and receiving management. All users share product, order, inventory, and shipment information and are charged a fee for receiving orders or dispatching deliveries by using the application. Moreover, the application can feature three optional services respectively assisting in product traceability management, payments, and "time sensitive" delivery management. The adjective "time sensitive" refers to deliveries whose time window can be changed by the customer even shortly before the planned execution time.

The study has been carried out through a phased approach [27]. First, semi-structured interviews are

conducted with consumers, retailers, and producers, who will be named farms hereinafter, to create a knowledge base on the industry processes. The interviews also identify a clear willingness of the SC players to adopt the service and provide quantitative data for running simulations. Then, a simple SD model is designed to capture the most important flows, state variables, and feedback loops. Finally, a detailed SD model is calibrated and simulation results are analyzed. Comparisons between the diffusion trends of the base application and those resulting from also adopting the optional features are made. The Bass model has been used given its suitability to represent the dynamics of diffusion of ICT-based and mobile services.

The reference market is composed of producers, retailers, and consumers of fresh food in a target urban area of 1.5 million population in the greater Torino area, Italy.

4 Model Development and Simulation
This section details the SD model and the simulation results. Due to space constraints, only selected parts of the model will be discussed. The complete model including all the associated equations is available from the authors.

4.1 The System Dynamics Model
The SD model is structured into ten interconnected sub-models concerned with the diffusion of the base application among consumers, retailers, and farms, order issuing, inventory management, user satisfaction, the revenue for the service provider company, and the diffusion of the three optional features (Fig.1). The studied SC includes those actors relying on the mobile service for both placing orders upstream and delivering goods downstream.
The model is based on Sterman's [14] representations of the Bass model and of a manufacturing SC and has been developed using the Vensim DSS software package. The simulations have been performed with Euler integration, with one-day time intervals and a simulation horizon of 156 weeks corresponding to about 3 years.
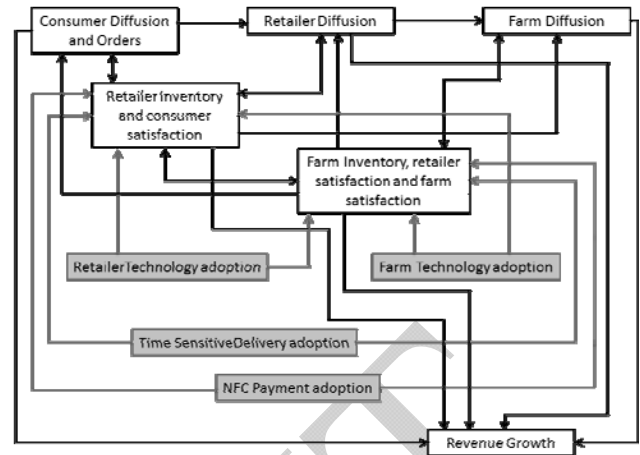

Fig.1 Model Overview

The SD model presents many feedback loops among variables. For example, a growth in the number of consumers adopting the mobile application increases the order rate to retailers and how successful these players are in fulfilling the augmented orders determines the consumer satisfaction. Satisfaction, in turn, influences the growth of adopting consumers' population through the "word of mouth" effect. A similar situation can be observed for retailers and producers. Also, all the other variables remaining equal, a growing number of orders to the farms make the order rate to each single farm go up. The possibility of increasing the business volume with the use of the new application is perceived by the retailers that are stimulated to adopt. Furthermore, the more the adopting farms, the more the products available for retailers, and the higher the retailers' satisfaction. This, in turn, increases the number of adopting farms thanks to the interaction between these two SC echelons.

4.1.1 Consumer Diffusion and Orders
Fig.2 shows that the stock variable "Potential Consumers" is decreased by the flow of the consumers adopting the application, represented by the variable "Consumer Service Adoption Rate". The latter in turn increases the stock variable "Consumers", that indicates the number of adopters of the base application.

Consumers may adopt as a consequence of either advertising or "word of mouth". Advertising is performed by both the suppliers that have already adopted the mobile application, through verbal persuasion of their customers to use it because of its efficiency and easiness of use, and the service provider company, by means of formal campaigns. "Word of mouth" is pursued by adopting customers

towards their suppliers and between members of a same SC echelon.

The number of adopting consumers, together with the average number of orders per consumer in each single time step, determines the "Consumer Order Rate" which feeds the stock "Consumer Orders". The SD model is based on a standard order composition and does not consider the variability of the products that form an order.

The key equations of this sub-model are:

Potential Consumers = INTEG (− Consumer Service Adoption Rate, Total Consumer Population) (1)

Consumer Service Adoption Rate = max (0, Consumer Service Adoption from Advertising + Consumer Service Adoption from Word of Mouth) (2)

Consumers = INTEG (Consumer Service Adoption Rate, 1) (3)

Fig.2 Consumer Diffusion and Orders

4.1.2 Retailer Inventory and Consumer Satisfaction

As far as the inventory management of the retailer is concerned (Fig.3), the stock variable "Single Retailer Inventory" is augmented by the flow of orders received from farms by each single retailer ("Single Retailer Receiving Rate") and diminished by the flow of orders shipped to consumers ("Single Retailer Shipment Rate") according to equation (4).

Single Retailer Inventory= INTEG (Single Retailer Receiving Rate-Single Retailer Shipment Rate, 40) (4)

The consumer demand determines both the shipment rate, according to the number of orders

that can be fulfilled from the stock, and the orders to the farms based on a forecast of future consumer orders modelled as a first-order exponential smoothing of the present order rate.

Fig.3 Retailer Inventory Management

In order not to excessively complicate the model, consumer satisfaction has been calculated as a global value taking into account both those consumer adopting the base application and those ones also using the additional features. In the case of consumers, just the payment management service relying on the Near Field Communication (NFC) technology applies (Fig.4). Thus, consumer satisfaction is determined as per equation (5):

*Consumer Satisfaction = Consumer Receiving Service Level * (1-Weight of Pricing) + Consumer Sensitiveness to Pricing * Weight of Pricing* (5)

The service level associated with the use of the mobile application ("Consumer Receiving Service Level") is defined by "Consumer Order Fulfilment Ratio", which measures how many orders are fulfilled in every time step, "E-Order Service Reliability", which assesses the degree of reliability and security of the electronic system to place orders, and "Consumer Receiving Timeliness and Efficiency", which evaluates the efficiency of receiving goods with the support of the mobile SC service. The contribution of the payment management service depends on the number of retailers adopting such payment system. Also, the more the consumers actually using it, the more the influence on the global degree of satisfaction.

The variable "Consumer Sensitiveness to Pricing" compares the price expected by consumers

with the actual one. In addition to the "Receiving Unit Fee" and the "Dispatching Unit Fee", each SC member is charged with the "WebApp Unit Price" in order to download the application allowing using the services.
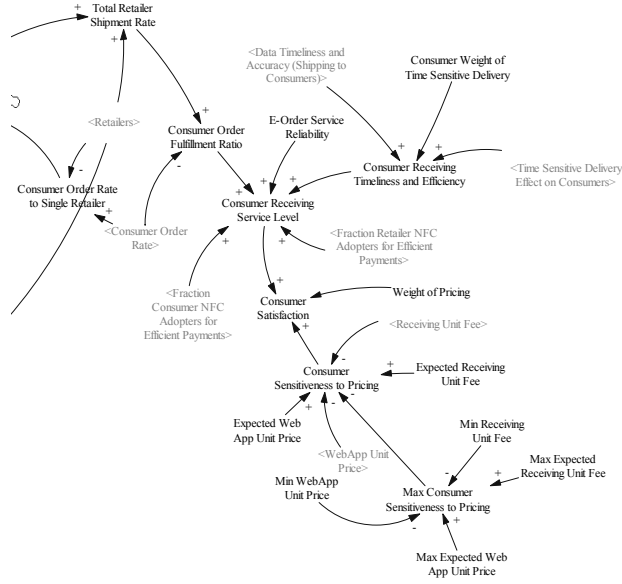

Fig.4 Consumer Satisfaction

4.1.3 Retailer Technology Adoption
This sub-model explains the dynamics of the diffusion of the optional feature concerned with product traceability among retailers. Such additional service offered by the application is based on a traceability system relying on Radio Frequency Identification (RFID) technology. Also, the service is intended for SC players managing an inventory, that is retailers and farms.

The more retailers adopt the product traceability system the more the quantity of information available real time in the SC, due to the acquisition of the information contained in the RFID tags that enables a more efficient warehouse management [28]. The increase in the level of information creates a number of benefits, such as a reduction in the order fulfillment time, a decrease in the inventory counting time [29], less time spent on receiving goods [30], and a reduced probability of stock-out. A lower probability of stock-out brings as a consequence a lower level of safety stock [29]. Such aspects reflect on a better inventory management, as it can be seen in Fig.3. This positively influences the consumer satisfaction which in turn stimulates new retailers to adopt the application and the product traceability management feature, thanks to the "word of mouth" effect. The positive adopting trend thus created is counterbalanced by the retailers' aptitude to technology investment, which basically

depends on the infrastructural costs of introducing an RFID-based product traceability system: the more such costs the less the adoption of the application feature.

4.1.4 Time Sensitive Delivery Adoption
This sub-model refers to the farms' and retailers' adoption of the application option managing time sensitive deliveries. Of course, consumers do not perform deliveries, so there is no need for using this feature. However, they can still benefit from time sensitive deliveries by retailers.

The adoption of the option by farms or retailers depends on the level of satisfaction of their customers, retailers or consumers, with time sensitive deliveries offered by other players. The more their satisfaction the more they will try to convince new farms or retailers to adopt this kind of delivery. Also, the more the players offering time sensitive deliveries, the more their customers will be able to take advantage of such service (variables "Delivery Time Sensitive Effect on Retailers / Consumers"), thus increasing their degree of satisfaction with the application. Adoption is modelled as per equation (6) in the case of retailers, where T indicates the current time period:

*Retailer Time Sensitive Delivery Adopters = Retailer Time Sensitive Delivery Adopters (T-1) + ((Retailers (T-1) -Retailer Time Sensitive Delivery Adopters (T-1)) + (Retailers-Retailers(T-1))) * Retailer Time Sensitive Delivery Adoption Fraction*

(6)

Fig. 5 shows the retailers' portion of the sub-model. Similar considerations can be done for farms.
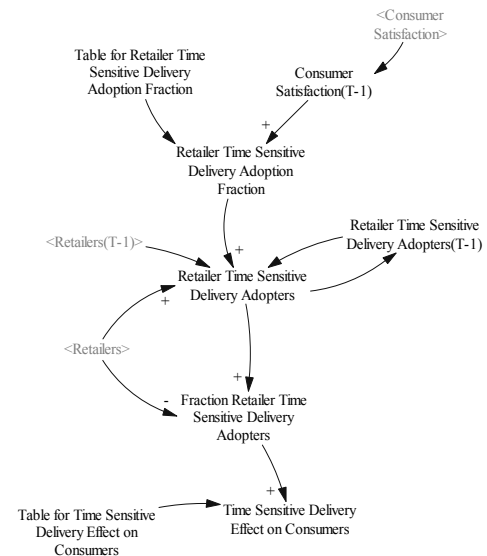

Fig.5 Retailer Time Sensitive Delivery Adoption

4.1.5 NFC Payment Adoption

The sub-model represents the adoption of the application option supporting payments via NFC by farms, retailers, and consumers. Their adoption in each time period is conditioned by their level of satisfaction in the previous period. Let us consider again the example of retailers, the more the retailer satisfaction with the use of the feature, the more they will encourage new retailers to adopt the application together with the payment option. Moreover, it is assumed that payments via NFC technology are completely reliable: all transactions are successful and generate satisfaction. For this reason the level of satisfaction is assumed to be proportional to the fraction of the optional service adopters.

NFC payment adoption is described by equation (7) in the case of retailers:

Retailer NFC Adopters for Efficient Payments = Retailer NFC Adopters for Efficient Payments (T-1) + ((Retailers(T-1)-Retailer NFC Adopters for Efficient Payments(T-1)) + (Retailers-Retailers (T-1)))*NFC Retailer Payment Fraction (7)

Fig. 6 presents the retailers' portion of the sub-model. Similar considerations can be done for farms and consumers.
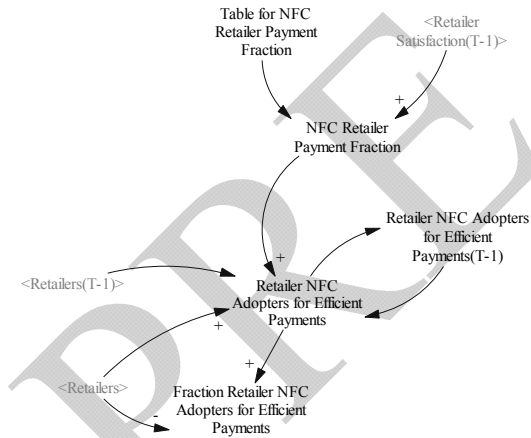

Fig.6 Retailer NFC Payment Adoption

4.2 Analysis of Results

The SD model was calibrated by using the data from the interviews and simulated over the predefined time horizon. Both the adoption of the base application and the adoption of the additional features have been analyzed.

A first result is that the availability of the optional services has a positive influence on the diffusion of the base application because it shortens its market saturation time. When no optional features are available, all the farms, retailers, and consumers in the reference SC adopt the application in respectively 82.4 weeks, 9.4 weeks, and 12.6 weeks. When the optional services are available, they adopt the base application in 79.6 weeks, 8.8 weeks, and 11.6 weeks respectively. The reduced improvement in the adoption period is due to an already quick diffusion of the base application because of its characteristics that are innovative in the analysed SC.

Another interesting outcome is that the diffusion processes of the optional features are very similar to the diffusion process of the base mobile application, for all the three SC echelons. As an example, Fig.7 compares the evolution overtime of the consumers adopting the base application (blue line) with the growth in the number of consumers also adopting the payment management feature (red line). This witnesses the great appeal the three offered options have on the potential users.
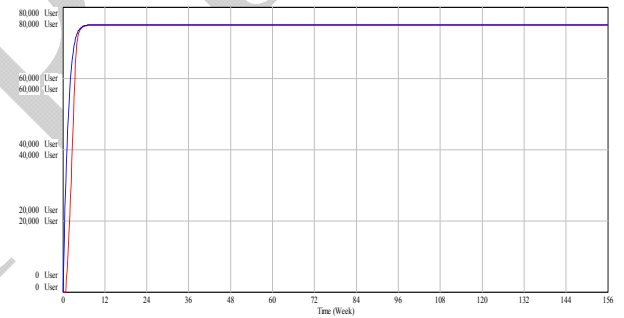

Fig.7 Diffusions among Consumers

Additionally, simulations show how the diffusion of the optional services drives the diffusion of the base application. Taking again the case of consumers, Fig.8 represents the dynamics of the diffusion of the base application under different adoption rates of the three additional features. In particular, the diagram contrasts the diffusion when no additional services are offered (blue line) and when they are available and characterized by a normal adoption rate (grey line), a low adoption rate (green line), and a very low adoption rate (red line). As it can be seen, the slower the adoption process of the optional features, the slower the diffusion of the mobile application.
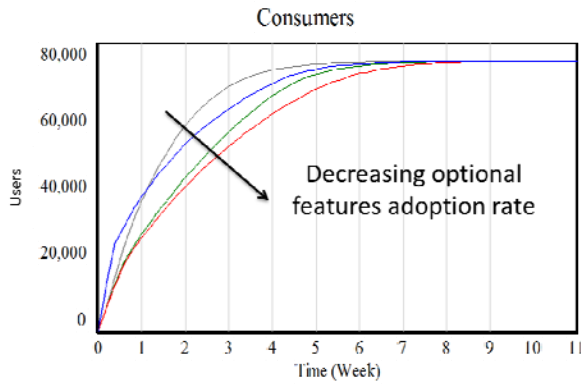
Fig.8 Consumer Diffusion of Base Application

The diffusion of the optional features among users, and in particular the one associated with product traceability management, has also a positive impact on the inventory management and ultimately on the revenue from the application services for the service provider company. As a matter of fact, the increased availability of real time information allows operating with a lower inventory level. Since the demand for the kind of product at issue can be considered steady, this means that SC players will issue orders more frequently. Such increase in the order frequency implies more online information exchanges by means of the mobile application and thus more revenue for the company providing the service. In fact, as mentioned in Section 3, a fee is charged for each dispatching and receiving transaction managed by the mobile application. In order to quantitatively understand the effect of reduced inventory levels on the service provider's revenue, a scenario analysis was carried out. In Fig.9 the situation when no additional services are available (blue line) is compared with the situation when they can be adopted. Three scenarios were considered for the latter: 10% (grey line), 30% (green line), and 50% (red line) increases in the order frequency. As it can be seen, the increase in the revenue is quite significant.
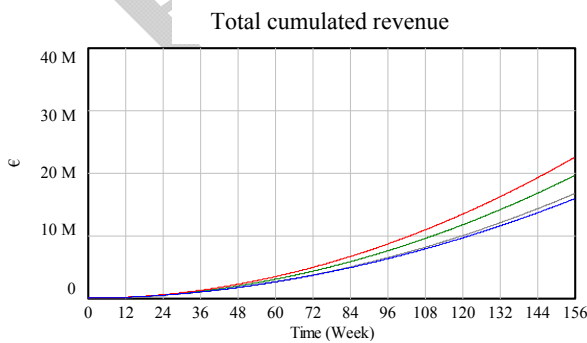

Fig.9 Service Provider's Revenue

Sensitivity analysis was also performed on the model and its results gave interesting insights for policy making.

The authors studied how the diffusion of the mobile application changes when the model parameters associated with the efficiency and reliability of its service change. The outcomes demonstrate how these characteristics mostly affect the adoption by farms and consumers, while it seems that retailers' adoption is not much influenced by efficiency and reliability. This is shown in Fig. 10, where diagrams present the confidence bounds within which the output variable ("Farms" or "Consumers") can be found with a probability of 50%, 75%, 95%, and 100% as efficiency and reliability vary.
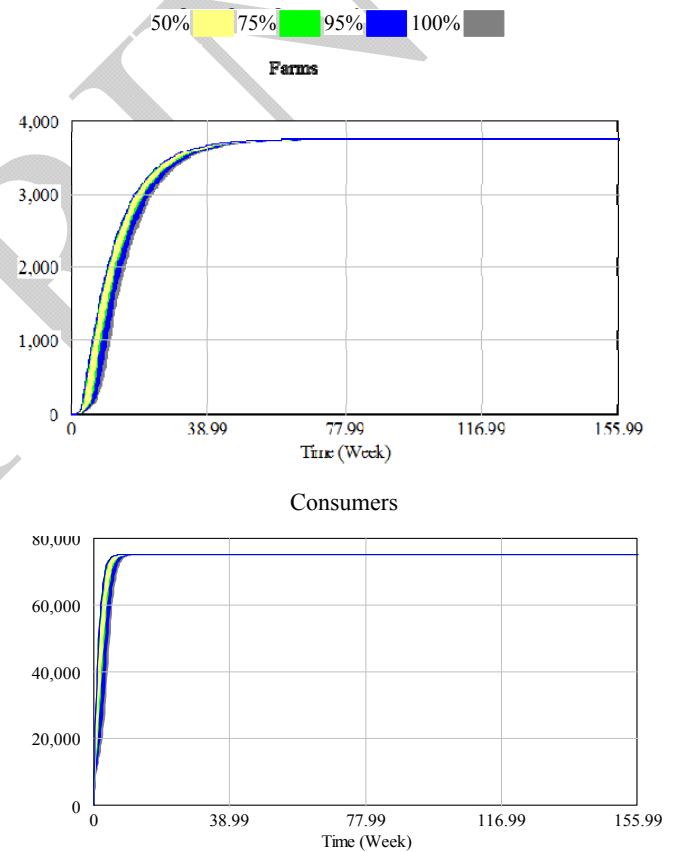

Fig.10 Sensitivity to Efficiency and Reliability

As far as pricing is concerned, the sensitivity analysis revealed that farms, retailers, and consumers do not base their adoption decisions either on the price of the mobile application or on the unit fee for receiving and dispatching services. Changes in these values do not significantly affect diffusion as displayed in Fig.11 for the case of consumers. Similar trends were obtained for farms and retailers. Therefore, users are willing to pay

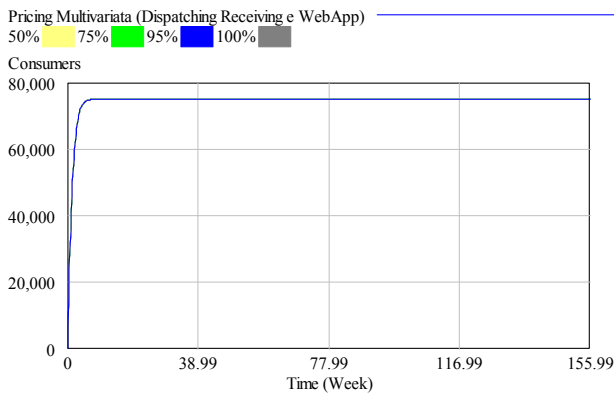even a slightly high price in order to get efficient and reliable services.

Pricing Multivariata (Dispatching Receiving e WebApp)

50% ▢ 75% ▢ 95% ▢ 100% ▢

Consumers

Fig.11 Consumer Sensitivity to Prices

5 Policy Making

The analysis of the outcomes of the SD model suggested some key policies in order to stimulate the diffusion of the mobile application and the associated optional features.

First, given the importance of the adoption of the additional services to both the diffusion of the mobile application and the service provider's revenue, it is highly recommended conducing campaigns to make all the SC echelons aware about the advantages of implementing product traceability systems, electronic payment systems, and time sensitive deliveries. Also, the benefits of managing them through the mobile application should be clear to the potential users. Therefore, the service provider's advertising action should be focused on such topics.

Second, the efficiency and reliability of the mobile application designed for placing and managing orders and for tracking and assisting routing of deliveries prove to be determinant aspects to catalyze and speed up its adoption. Thus, a considerable level of efficiency and reliability of the offered services should be ensured in order to stimulate its diffusion, especially among farms and consumers. In fact, they are the players whose adoption is more affected by changes in these characteristics. To this end, the service provider should for example increase the reliability of data transmission through the 3G and 4G networks. Adopting farms would activate persuasion upon retailers and, at the same time, satisfied consumers would facilitate adoption from "word of mouth" by additional retailers. In a similar way, the retailers will in turn act to increase the communities of adopter farms and consumers and also make their own adopter community growth.

Finally, the pricing policy results not to be determinant in addressing the dynamics of adoption by the SC players because the cost of the application is perceived to be rather inexpensive for the kind of service that is offered and to provide a large potential for economic return from accrued business growth. As a consequence, the service provider company can adjust its pricing policy according to the expected dynamics of revenue growth.

6 Discussion

An appropriate information and logistics structure governing the SC activities is of paramount importance for the local fresh food industry, which is characterized by market segmentation and little coordination among suppliers and customers. Additionally, increasing the quantity of information about the products and the different transactions involving them satisfies the final consumers' need to know the origin and the "history" of what they buy. Mobile communication technologies can help to meet these goals because of their large diffusion and the possibility of managing information real time. The present work develops a SD model to evaluate the diffusion of a mobile application supporting the management of SC operations.

The proposed approach provides a reference methodology to study the impacts of new SC solutions on the key stakeholders and to formulate business policies. Being comprehensive in nature, it also allows an analysis that captures all the different dimensions of the problem. Additionally, by integrating the Bass diffusion model with the SC model, it allows to study the innovation adoption not only from a commercial perspective but also from an operational one, by investigating its effects on SCM activities. Finally, the flexibility of the SD methodology enables not only quantitative but also qualitative evaluations according to the availability of information.

The developed SD model has both a theoretical and a practical value. From an academic point of view it stimulates the combination and adaptation in the area of SCM of literature-based SD models addressing the topic of innovation diffusion. From a practitioners' point of view, the proposed approach offers a roadmap to identify the key enabling factors of the diffusion of mobile technology in the fresh food sector and to simulate their impact overtime. This can purposefully complement feasibility studies and marketing investigations when either introducing new services or upgrading existing ones. Also, it may support decision making about specific business policies.

Of course, some limitations can be recognized in this work. First of all, in the attempt to be as much comprehensive as possible, the SD model is quite large and so, in order not to excessively complicate it, a number of simplifications were introduced. For instance, some variables such as those related to satisfaction and inventory levels are sort of average values that takes into account both the users adopting the base application and the users adopting the additional features. Second, just one reference SC in the fresh food sector has been analysed, although involving a significant number of players. Further investigations on different SCs would be needed in order to generalize the results. Third, the approach requires a strong interaction with potential users, which might not be possible in some situations depending on the degree of stakeholders' commitment. Finally, the present research has just focused on the economic impact the diffusion of the mobile application has on the company providing the service, without analysing the effects on the profit margins of retailers and farms.

Future research efforts will be directed towards applying and adapting the SD model to other SCs in the fresh food sector in order to validate its results. Moreover, underlying simplifying assumptions will be removed by developing separate SD models if required. Finally, it would be interesting to investigate how the advantages brought by using the application can affect the profit margins of retailers and farms.

7 Conclusion

The work develops a SD model to study the diffusion pattern as well as the SC impacts of a new mobile application supporting SCM operations in the fresh food industry. The possibility of integrating optional features in the application has been explored. Business policies to stimulate the adoption have been derived from simulation outcomes. The model will be applied to different SCs in order to validate the results and extended to include the implications of the use of the application on profit margins of the different partners.

Acknowledgements

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