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Systems Mapping of Consumer Acceptance of Agrifood Nanotechnology

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Abstract Application of nanotechnology in the agrifood system and the rising number of nanofood products on the market are creating concerns among consumers and other stakeholders. These concerns and other potential barriers to the commercialization of agrifood nanotechnology products may limit the ability to capture its full potential. Understanding the emerging trends and the links between underlying values, expressed attitudes, and actual behaviors involving consumer acceptance of agrifood nanotechnology is important for governance, risk regulation, and the achievement of the full potential of agrifood nanotechnology. The purpose of the study was to use systems mapping to examine and analyze critical links between consumer acceptance of agrifood nanotechnology and factors such as trust, stakeholders, institutions, knowledge, and human environmental health risks. The study used a meta-analysis of the risk perception literature and solicited the opinions of experts to develop the systems map. Factors affecting consumer acceptance of agrifood nanotechnology are dynamic, complex, interactive, and interdependent, and consumer decisions to accept agrifood nanotechnology were found to be the results of complex feedback structure. This study suggests several consumer policy and programmatic levels in the system toward enhancing consumer acceptance of agrifood nanotechnology products where warranted.

Keywords Systems dynamics · Nanofood · Experts' opinion · Trust · Nanotechnology

Researchers interested in the factors responsible for consumer choice, purchase behavior, and acceptance of foods processed by novel and emerging food technologies, such as nanotechnology, biotechnology, ionizing radiation, pulsed electric fields, and ultraviolet laser treatment, face major challenges (Cardello 2003). Enhancing the sensory qualities of these foods has been found to be important to consumer acceptance and their success on the market (Cardello 2003; Siegrist 2008). However, enhanced sensory properties will not be

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the sole assurance for consumer acceptance, as consumer perceptions of food quality do not depend solely on the intrinsic characteristics of the product. Rather, they rely heavily on a host of factors that are extrinsic to the product (Cardello 2003). According to Cardello (2003), variables like contextual, cognitive, social, cultural, and attitudinal factors also matter. In the case of foods that have been processed by novel or emerging technologies, concerns about the nature of the food and the processing technologies influence consumer choice and purchase decisions (Cardello 2003; Cardello et al. 2007). It is generally agreed that consumers' acceptance of new foods is strongly influenced by perceived benefits of the food product as compared to the processing technology (Frewer et al. 2003). However, the acceptance of new food technologies by consumers cannot be reduced to perceived benefits (Siegrist 2008).

Generally, consumers associate more risks with novel food technologies than how they perceive risks of traditional food technologies (Siegrist 2008). The inherent properties and use of a new product may also have strong impact on consumer acceptance. Pharmaceutical and biomedical applications of gene technology, for example, are generally very well accepted, but consumers, especially European consumers, are hesitant to buy bioengineered or genetically modified (GM) foods (Boecker and Nzuma 2007). The price of a product is also an important factor that influences consumer acceptance. Spence and Townsend (2006) have shown that most British consumers will prefer GM foods to traditional foods only if they are relatively cheaper. Perceived naturalness has also been identified as one of the most important factors that have an effect on consumer acceptance of emerging food technologies (Cox et al. 2007; Tenbult et al. 2005).

Public knowledge of nanotechnology and new technologies in general is very limited (Cobb 2005; Hart Research Associates, Inc. 2008; Satterfield et al. 2009). This makes it difficult for most consumers to decide on the possible risk associated with new foods produced with these novel technologies (Siegrist 2008). Consumers therefore tend to depend on trust to ease the complexity of decisions in the absence of adequate knowledge (Earle et al. 2007). Some studies have found that trust in institutions or scientists is an important factor influencing public perception of emerging technologies (Siegrist et al. 2007a). Trust directly influences public perception of risks and benefits and indirectly influences consumer acceptance of, or willingness to buy, GM foods (Siegrist 1999, 2000). Siegrist (2008) has shown that nanofoods exhibit similar relationship. It has also been postulated by Grunert et al. (2003) that consumer reaction towards new food technologies may be rooted in a system of general attitudes and values. Siegrist (2008) stated that assessment of a new food technology depends on the concepts and images that are related to the technology, and consumers use contingently truthful, meaningful, and clearly articulated information for evaluation.

Given the diverse factors and literature, the purpose of the study was to use systems mapping to synthesize, examine, and analyze critical links between consumer acceptance of agrifood nanotechnology and trust, stakeholders, institutions, knowledge, and human environmental health risks. The study used a meta-analysis of the risk perception literature and solicited the opinions of experts to develop the systems map.

From the results of the expert elicitation and the meta-analysis of the relevant literature, a systems map of consumer acceptance of agrifood nanotechnology was developed using system dynamics modeling software called Vensim® (2008). Analysis of the literature suggests a need for a comprehensive qualitative work probing the interactions between underlying values, expressed consumer attitudes, and actual consumer behaviors in relation to agrifood nanotechnologies and novel food technologies in general. Knowledge of how these elements interact is important for a full understanding of public perceptions and consumer acceptance.

This study is the first attempt to our knowledge at trying to examine the links using systems dynamics approach. It is important that further systems dynamics modeling of experts, stakeholders, and consumer perceptions towards nanotechnology and emerging technologies in the agrifood system be undertaken. Systems mapping is a very powerful systems dynamics modeling tool. A systems map can fit into a single page explanation of an entire problem, solution space, and identification of solutions, which could otherwise have taken a lengthy manuscript to put into words (Karsh and Alper 2005). A systems map helps policy makers to understand the overall context of the setting they are working. Such understanding is crucial for consumer policy makers to take consistent and effective action devoid of any unanticipated consequences (Dutta 2001). It is a tool that can help to ensure that the intended outcomes of policy are not diluted or defeated by the feedback of the setting itself to the policy actions (Dutta and Roy 2002). Systems dynamics can help consumer policy makers to gain insights into causal mechanics that determine the behavioral dynamics of consumer decision making (Dutta and Roy 2002).

Below, the literature review and expert elicitation methods are described, followed by a description of the development of the systems map.

Meta-analysis of the Literature

Meta-analysis of the most pertinent literature related to consumer acceptance of novel food technologies with the main emphasis on nanotechnology, but inclusion of other technologies, was done. The meta-analysis of the literature entailed three elements: the initial search for materials, the prioritization of materials, and the aggregation of the relevant factors. For the initial search for materials, literature synthesis was done using text mining to extract technical intelligence from the global nanotechnology, nano-science, and agrifood nanotechnology research literature. In order to simplify the evidence collection process, each identified source was rated according to the quality of the source, the approach to the primary research and the methodology used, and the level to which the source discussed the broader research question (i.e., what influences the public's attitudes towards agrifood nanotechnology?). In order to extract the pertinent evidence from the prioritized literature, a spreadsheet was drawn up with the relevant notes and citations which gave a strong basis for subsequent analysis and aggregation of factors from the information collected. The evidence gathered from this review and results of the expert elicitation conducted in this study informed the construction of the systems map. Factors identified in each study below were incorporated in the systems map generated.

In a conceptual framework developed by Ronteltap et al. (2007), consumers' actual adoption of innovation in the food area is ultimately determined by their intention to use it. The framework distinguishes between proximal and distal determinants of consumer adoptions. At the proximal level, adoption (intention) is determined by (1) perceived costs and benefits, (2) perceived risk and uncertainty, (3) subjective norm, and (4) perceived behavioral control. They did however contend that these perceptions are affected by a set of more distal determinants, namely, (a) features of the innovation, (b) consumer characteristics, and (c) characteristics of the social system of which the consumer is part. They further explained that whereas innovation and consumer characteristics hold a direct relationship with perceptions of the proximal determinants, characteristics of the social system generically affect the framework. Communication is represented in their framework as an important means linking innovation features to consumer perceptions.

In another study of empirical research and theoretical considerations, Siegrist et al. (2007b) hypothesized that as nanotechnology is a relatively new technology, especially its applications in the food sector and the obvious lack of consumer awareness, affect evoked by nanotechnology products will influence risks and benefits associated with the technology. A previous study by Siegrist (2000) indicated that consumers' perception of risks and benefits influence willingness to buy GM foods. With GM foods, perceived benefits negatively influenced perceived risks (i.e., as perceived benefits increase, perceived risk decreases and vice versa), and Siegrist et al. (2007b) assumed that perceived benefits will negatively influence perceived risks for nanofoods too. However, Siegrist et al. (2007b) proposed that nanotechnology is less familiar, and therefore, additional information will be needed for nanofoods to generate any meaningful effect or associations. Siegrist et al. (2007b) also proposed that trust may have an effect on how additional information is received. Therefore, consumer trust in the agrifood industry likely has a direct impact on the affect evoked by the information about the agrifood nanotechnology.

In an empirical study for the direct and indirect links between trust in regulatory institutions and acceptability of hazards, Bronfman et al. (2009) concluded that trust in regulatory institutions was correlated negatively with perceived risk and positively with perceived benefit and the degree of acceptability. The main finding of this study was that social trust retained a direct as well as indirect causal link (mostly through perceived benefit) with the degree of public acceptability of a hazard. The study also found an indirect relationship between perceived risk and acceptability.

To compare nanotechnology with other technologies and analyze risks and benefits of specific nanotechnology applications, Currall et al. (2008, 2006) specifically presented a method for comparing the risks and benefits of nanotechnology relative to those of other technologies. Their study involved tracking of public opinion and how it shifted overtime due to more information on risks and benefits of nanotechnology in the public domain. The study used a “scorecard” in tracking these shifts. Their findings challenged the general assumption that the public considers applications of nanotechnology only in terms of possible risks. They argued that, although perceived risks is an important factor, consumers use a “complex calculus” in viewing nanotechnology products and applications with perceived risk being one of several factors. Their results showed that consumers' perception of risks or benefits of nanotechnology is not dependent on one another as many studies including Bronfman et al. (2009) and Siegrist et al. (2007b) have shown. Rather, results of their study demonstrated a consistent pattern for both health- and environment-related applications of nanotechnology that perceived benefits manifested more when risks were lower than when risks were high. They concluded that public perception of risks and benefits of nanotechnology is an intricate web of “decision-making calculus” and not as simple as previously assumed. Analysis of their data indicated that nanotechnology is currently perceived as medium risk and moderate benefit. The study predicted two scenarios where over time, public reaction to nanotechnology will swing to either high benefit and low risk or low benefit and high risk. The consumer policy implication of their study is whether the future of agrifood nanotechnology will be determined by rumor and supposition, as it is generally believe to be the case for GMOs or whether it will be accepted base on “sound science and engineering” (Currall et al. 2006, p. 153). They concluded that “education can prevent opinions from becoming polarized on the basis of misinformation” (p. 154).

In a similar study, Siegrist et al. (2007a) adapted the psychometric method to examine public perception of nanotechnology applications. The psychometric approach is commonly used in behavioral studies to understand public perceptions of different hazards and to identify factors that influence perception (Slovic 1987). Siegrist et al. (2007a) found that various nanotechnology applications are perceived differently by the public and suggested that it is problematic to examine general attitudes toward nanotechnology as a whole. They concluded that public reactions to nanotechnology in the short to medium term will depend on how the food industry, governmental and regulatory agencies, and consumer advocacy and environmental groups handle the issue. Siegrist et al. (2007a) explained that applications can be found for which such social amplification process is expected to increase perceived risk, such as those with high levels for dread risk and distrust. Applications in the food or health domains were specifically identified as the most probable to become controversial topics among the nanotechnology applications. The study pointed out that some of the varied array of potential nanotechnology applications may determine how the public perceives the risk of the entire field of nanotechnology. Nanotechnology ammunition, for example, was cited as a source that has the potential to negatively influence the general perception of nanotechnology.

As part of the Siegrist et al. (2007a) study, the weighted rating scales of perceived risks, perceived benefits, and trust were examined to ascertain whether there were differences between that of experts and laypeople. They found out that risk assessments for nanotechnology by laypeople were higher than risk assessments by experts. Another finding from the study was that laypeople had less trust in regulatory and governmental agencies than experts. Contrary to perceived benefits, laypeople and experts perceived similar levels of benefits. The study also confirmed existing findings that confidence is a key factor in risk perception of experts with all emerging technologies (Siegrist and Cvetkovich 2000). The study concluded that risk perception of both laypeople and experts will depend strongly on how nanotechnology is regulated.

Frewer et al. (2003) suggested that acceptance of new technologies is based to a great extent on public perceptions of the associated risks, and that perceptions of risk are influenced by trust in the information and the source which provides it. However, psychological factors such as the strength of prior attitudes towards a particular technology have also been found to limit the impact of trust on attitude change following information interventions (Frewer et al. 1999). There may also be an interaction with the type of information provided. Cox et al. (2007) concluded that the way of communication and the use of proper information about risk can positively transform attitudes and behaviors in terms of raising consumer trust in product innovations.

In an empirical study, Kahan et al. (2009) explored whether greater familiarity with nanotechnology results in positive attitudes. They found that knowing more about nanotechnology and its applications does not always result in more positive attitudes, but rather to split into positive or negative perceptions. In exploring the causes of this split which they termed “polarization effect,” Kahan et al. (2009) showed that exposure to new information about nanotechnology results in more positive perception of nanotechnology by individuals with personal values described as “hierarchical individualist” compared with people holding what they described as “egalitarian-communitarian” values, who showed more negative perceptions after receiving the same information. Currall (2009) explained that values such as hierarchical-individualist and egalitarian-communitarian are symbolic of what Kahan et al. (2009) described as “the cultural-cognition thesis,” which they defined in an earlier study as “the tendency of people to base their factual beliefs about the risks and benefits of a putatively dangerous activity on their cultural appraisals of these activities” (Kahan et al. 2008, pp. 3–5). Kahan et al. (2009) also found out that culture can have a two-sided effect. They explained that exposure to information about nanotechnology is dependent on cultural inclination and that consumers with pro-technology values are likely to learn more about nanotechnology. They further stated that cultural inclination may lead consumers who see nanotechnology in a positive light to become more positive and vice versa as new information about nanotechnology is received.

Scheufele et al. (2009) conducted a study to investigate how perceptions of nanotechnology are influenced by personal values, attitudes, and the way information is processed: They explored the possible impact of religious beliefs (that is, the value to which one attributes “religious guidance”) on the value system that consumers use when deciding on the acceptability of emerging technologies. One of the major findings of their study was that increased levels of religiosity were negatively correlated with acceptance of nanotechnology as moral. This correlation still held when they controlled for other factors such as trust in scientists and regulatory agencies, knowledge about nanotechnology, influence of advocacy groups, and media coverage of science. Their findings also held true for both individual- and country-level analyses, despite the substantial religious differences across the USA and Europe.

On a very different approach, Pidgeon et al. (2009) organized workshops on different applications of nanotechnology in the UK and the USA to explain the impact of issues, such as institutional and regulatory factors on public reactions. Participants with very little knowledge of nanotechnology were deliberately chosen to provide an opportunity to explore the reasons for different reactions to nanotechnology. There were clear differences between the participants from the UK and the USA. The UK participants were more concerned about community, national, and international implications of nanotechnology, whereas the US participants demonstrated more consumerism and confidence in nanotechnology applications. Pidgeon et al. (2009) made a recommendation, similar to that made by Siegrist et al. (2007a) and Currall et al. (2006), that further studies examining specific nanotechnology applications and products, as opposed to nanotechnology in general, should be pursued.

There is very low awareness of nanotechnologies, particularly in relation to food (GSS 2006). Despite this, various surveys on public attitudes have shown that views in general are fairly positive, if a little uncertain (Cobb and Macoubrie 2004; Gaskell et al. 2006). There is less enthusiasm for food applications than other areas in which nanotechnologies might be used however, and attitudes towards food are slightly more negative (Siegrist et al. 2007a). This is in part explained by the fact that, although concerned about the risks of nanotechnology in all its forms, the public sees fewer potential benefits for food applications (IOM 2009).

Satterfield et al. (2009) conducted a meta-analysis on 18 independent surveys focusing on risk perceptions (reported in the literature between 2004 and 2009) and with the objective of characterizing the public response to nanotechnology. They concluded from their analysis that the general pattern across the various survey studies indicate that the public currently perceive nanotechnology as “resulting in more benefits than risks, and familiarity with this new technology does correspond to positive evaluations of its applications” (Satterfield et al. 2009, p. 757). They therefore recommended that “the very malleability of risk judgments here and now calls for intentional (and logically defended) framings in survey design and better use of intercepting independent variables and contextual descriptions, as a flawed but best proxy available for anticipating the perceived risk of nanotechnologies” (p. 756).

The literature reviewed highlight a range of factors that may shape public opinion and influence consumer acceptance of agrifood nanotechnology, including trust, experience of previous technological innovations, perceived risks and benefits, a sense of control, religiosity, cultural outlook/worldview, and the source from which consumers receive information about agrifood nanotechnology—all of which impact on people's affective responses.

Expert Elicitation

Experts' opinions were elicited on factors that may influence consumer acceptance of agrifood nanotechnology. Of the 70 potential experts contacted, 21 experts (30% response rate) participated in the study. Four experts initially agreed to participate but later declined due to scheduling conflicts, 18 experts declined either due to lack of interest in the study or do not consider themselves as experts, and 27 experts did not respond to requests to participate. Experts were given the option to participate in the electronic survey or the phone interview, or both. Of the 21 experts that participated, nine participated in both an electronic survey and a phone interview, 11 participated in only the electronic survey, and one gave qualitative answers to the electronic survey. The experts were asked to indicate their level of involvement (e.g., expertise, following developments in field, using or making products, overseeing products, and policy studies or making) in agrifood nanotechnology. Of the 21 experts that participated, 45% said they were involved, and 30% said they were very involved.[1]

The sole dependence on experts' opinion and the literature for the systems map may be seen as a limitation of this study. Consumer acceptance for agrifood nanotechnology was not directly assessed through consumer surveys; however, an extensive and detailed meta-review of the literature including previous consumer surveys was conducted. The number of experts ($n=21$) is small as compared to approximately 80 people that can be identified as experts on agrifood nanotechnology; however, our number ($n=21$) falls well within other expert elicitation studies, for example, 5–20 (Kuzma et al. 2009; Morgan and Henrion 1990). Thirteen of the 21 experts come from academe, which is another limitation, although this is not surprising given the nascent nature of agrifood nanotechnology and with most of the public activities taking place at the universities.

Materials developed for the expert elicitation process included a brief project description and introduction to the questionnaire in an email, Institutional Review Board approval statement for the study (provided to the panelists prior to agreeing to participate in the expert elicitation process), and the elicitation questionnaire. The email and the brief project description stated the reason for conducting an expert elicitation and the expectations of the experts. Selection and preparation of questionnaire was to elicit experts' opinion regarding the attributes that affect consumer attitudes toward agrifood nanotechnology products and applications. For the electronic survey, six questions were asked eliciting responses using both ranking and Likert's scale.[2]

From the content analysis of the literature on emerging technologies, ten potential barriers to the commercialization of agrifood nanotechnology products that may limit the ability to capture its full potential were identified. Experts were then asked to rank according to what they believe to be the most significant potential barrier to the commercialization of agrifood nanotechnology products and applications. Experts were given the option to add any potential barriers that they believe to be important and rank them under "Others."

Majority of experts were of the view that "public attitudes and perceptions and consumer acceptance" are the most significant barrier to the commercialization of agrifood nanotechnology followed by "regulatory uncertainty," "health and safety," and so on, as shown in Table 1.

Nine factors that are likely to affect consumer acceptance of agrifood nanotechnology products were identified from the literature, and experts were asked to indicate their opinions how likely the factors affect (positively or negatively) consumer acceptance

[1] See Appendix 2 for the list of experts and their affiliations/expertise.

[2] Please see Appendix 1 for survey questions.

Table 1 Ranking of barriers and potential barriers to commercialization

Factor	Number of respondents	Average weighted score	Ranking
Public attitudes and perceptions, and consumer acceptance	20	2.65	1
Regulatory uncertainty	20	3.20	2
Health and safety	20	4.30	3
Standards	20	5.30	4
Market readiness	19	5.53	5
Capital	18	6.17	6
Manufacturability	16	6.50	7
Workforce readiness	18	6.89	8
Infrastructure	18	7.28	9
Nomenclature	18	7.33	10

NB. 1=most important factor

(willingness to buy or consume) agrifood nanotechnology products on a five-score Likert scale from "very likely" to "not at all likely." The results obtained are shown in Table 2.

On a five-score Likert scale from "very aware" to "not at all aware," experts were asked to indicate the level of public awareness of agrifood nanotechnology. Fifty-five percent of the experts responded that the public is "not very aware," and 45% said the public is "not at all aware."

On how likely identified sources of information from the literature help improve public awareness of agrifood nanotechnology, National Government and regulatory agencies were identified as "very likely" as shown in Table 3.

Table 4 shows how likely the above sources of information about agrifood nanotechnology will be trusted by the public. Experts were given the option to add any other sources that they think will be trusted by consumers under "Others." Two experts ranked the news media as the "very likely" trusted source by consumers in the column provided for "Others." Incidentally, in the survey questions, the media was advisedly omitted based on the reason that the media is only a medium used by any of the sources

Table 2 Percentages of experts in each category for factors likely to affect consumer acceptance of agrifood nanotechnology products

	Very likely	Likely	Somewhat likely	Not very likely	Not at all likely
Perceived risk	65	25	10		
Perceived benefits	65	25	5	5	
Trust in ANT associated industries	50	35	15		
Trust in regulatory agencies	40	35	25		
Relative price of ANT products	25	35	30	10	
Influence of advocacy groups	20	30	45	5	
Scientist in ANT academic institutions	20	20	25	30	5
Cultural beliefs	10	25	25	35	5
Religious beliefs	5	25	20	40	10

Table 3 Experts' opinion on how sources of information help improve public awareness of agrifood nanotechnology

	Very likely	Likely	Somewhat likely	Not very likely	Not at all likely
Intergovernmental agencies	30	40	15	15	
National government	40	25	35		
Regulatory agencies	40	25	30	5	
Environmental organization	15	50	25	10	
Consumer organization	20	45	20	15	
Businesses and industries	5	35	35	20	5
Friends and family	15	10	35	25	15
Scientists	10	20	40	20	10

identified and is not the primary source of information. However, it must be acknowledged that "investigative journalism" can be categorized as a primary source of information.

Public attitudes, perceptions, and consumer acceptance; regulatory uncertainty; and health and safety are the most identified barriers in the literature, and the results obtained from the value elicitation from experts compared favorably with evidence from the literature.

Experts' recognize regulatory agencies, national governments, and to some large extent, intergovernmental agencies as the most likely sources of information that could help improve public awareness of agrifood nanotechnology followed by consumer organizations, environmental organizations, and friends and family. However, experts' identified regulatory agencies and environmental organizations as the most likely sources of information on agrifood nanotechnology that will be trusted by the public followed by consumer organizations.

Systems Mapping of Consumer Acceptance

In order to find and analyze the key policy and programmatic intervention points in agrifood nanotechnology systems that can be leveraged to facilitate consumer acceptance of agrifood nanotechnology products where warranted, a systems map was constructed. The systems map constructed for this study is an influence diagram based on a system dynamics modeling framework. The goal of this model is to capture an analysis of consumer

Table 4 Experts' opinion on how sources of information is trusted by the public

Sources of information	Very likely	Likely	Somewhat likely	Not very likely	Not at all likely
Environmental organization	45	45	10		
Regulatory agencies	45	40	15		
Consumer organization	10	65	15	10	
National government	20	45	35		
Friends and family	20	45	20	15	
Scientists	20	45	20	15	
Businesses and industries	20	45	20	15	
Intergovernmental agencies	5	25	45	20	5

acceptance at rational, process, and transactional levels (Elias and Cavana 2005); major stocks and flows as identified by the experts and evidence from literature; interactions between stocks and flows, stakeholders, processes, and institutions; and policy leverage points as suggested by historical experience with other emerging technologies in agriculture and food.

System dynamics modeling is a tool that can account for complex and dynamic features of systems. It is in its infancy for addressing policy questions related to science and technology, yet it has been shown to be a powerful and enlightening tool for business decisions. System dynamics is an approach that allows for the understanding of complex systems over time. Whereas most models are linear with beginning and end points, system dynamics sees the world as it is, with non-linear and interacting parts that feedback to and affect each other. It uses basic concepts like "stocks" (levels of quantities that change over time and need to be tracked) and "flows" (rates of change). System dynamics modeling is a tool which addresses complexity and incorporates feedback loops in systems, and the results of system dynamics models have shown to be valuable in identifying factors that affect outcomes of processes, programs, and decisions (Sterman 2001). The first use of system dynamics modeling dates back to 50 years ago for "industrial dynamics" or decisions about businesses, workforce, and product markets (Forrester 1958). Since then, system dynamics has been used to predict outcomes of medical treatment, land, economic, housing, and environmental policy. In several instances, investigators have been able to accurately predict unintended consequences of public policies through using system dynamics thinking, mapping, and models, such as the unanticipated impact that low cost housing programs increases unemployment (Forrester 1969). Many groups are using system dynamics to develop systems models collaboratively with the multiple goals of bi-directional communication and learning, public engagement, and better depictions of real-world system (Stave 2002).

The agrifood sector extends from input supply industries and agriculture to food processing, food distribution, and retail (Porter 1998). In the flow of products throughout the value chain, the sequence of different stages of sourcing, production, processing, and distribution involved in the provision of food to consumers and the interrelationships between the actors constitute a classical "system dynamics" environment, which is characterized by processes that incorporate feedback loops as well as sequences of causes and effects with possible time delays in between (Fritz and Schiefer 2008a). The interrelationships span food supply chains where they might remain stable due to contracts or customs, or food supply networks where interrelationships develop dynamically through changing trade relationships from within a network of different enterprises that are active at each one of the stages of the value chain (Fritz and Schiefer 2008b). The network scenario, which is dominant in most of the sector, poses a specific challenge to initiate and support the necessary innovation and to assure product characteristics like food safety, food quality, or food origin at the consumers' end (Thompson et al. 2007). These dynamics become even more interrelated when one considers the multidisciplinary nature of nanotechnology and its applications in the agrifood system.

The application of systems dynamics modeling in the agrifood systems in a context of consumer attitudes towards emerging technologies like food nanotechnology is novel. It must be noted that the model developed in this study is a draft which will need further development. It is, however, a very important start for any future study.

This study uses mapping and modeling interchangeably because it is a very fundamental model and work in progress which does not entail all that is required in a full systems dynamics model. However, this is not the first time mapping or modeling has been used interchangeably in a systems dynamics study (Andersen et al. 2004). A study involving 25 researchers from eight institutions (Syracuse University, TECNUN at University of Navarra, CERT/CC at Carnegie Mellon University, University at Albany, and Agder University College) and a variety of disciplines (computer science, information security, knowledge management, law enforcement, psychology, organization science, and system dynamics) described systems dynamics mapping as “a fairly detailed system dynamics model with the basic structure of the problem” (Andersen et al. 2004, p. 7). Their study included stakeholder analysis, expert presentations, and reviews to produce preliminary system dynamics models of insider and outsider cyber attacks. The study developed several systems map. The one which was of interest to the current study was the systems mapping of trust and deterrence. The map explored the numerous linkages around the issues of trust and deterrence.

The systems map of Figure 1 provides a synopsis of the key components, stages, and the links between underlying values, expressed attitudes, and actual behaviors involving consumer acceptance of agrifood nanotechnology. The influence diagram is introduced to capture the dynamics of consumers at rational, process, and transactional levels (Elias and Cavana 2005; Freeman 1984) through mental and conceptual modeling of experts' opinion and the evidence from literature. Agrifood nanotechnology will affect the interests of different stakeholders in different ways. Understanding the stakeholders and analyzing their interests will help in understanding consumer acceptance. The rational level of stakeholder analysis starts with the development of a stakeholder map (Elias et al. 2002). The process level of analysis was to understand links between underlying values, expressed attitudes, and actual behaviors involving consumer acceptance of agrifood nanotechnology. The transactional level analysis was to understand the set of transactions or bargains between processes, institutions, and consumers.

The systems map is a way to represent the components of the dynamic and nonlinear behavior of consumer acceptance (Cloutier and Boehlje 2001). It is a basic structural portrayal of archetypical effects within the system of interest. Influence diagrams are specifically used as “blue print” for the quantitative development of models (Andersen et al. 2004). The model as developed could be simulated quantitatively in future work. To do that

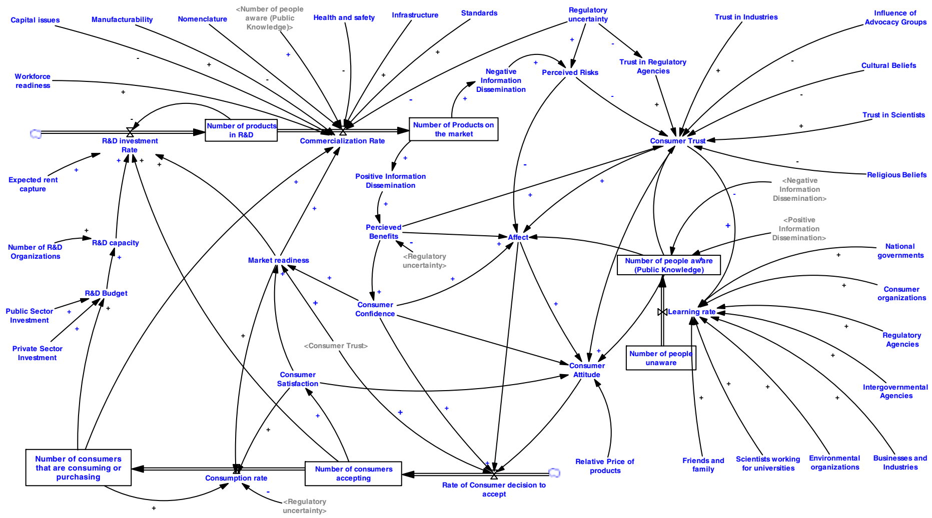

Fig. 1 A systems map of consumer acceptance of agrifood nanotechnology

will mean the initial conditions of critical coefficients and decision factors would have to be quantified from information gathered from published sources, industry representatives, experts, and even historical precedents (Fisher et al. 2000).

The major implications drawn from this systems mapping exercise are that

- It is clear that factors affecting consumer acceptance of agrifood nanotechnology are dynamic, complex, interactive, and interdependent. This also implies that simplification, linear conceptual structuring, and linear thinking are restrictive and can create as many problems as they find solutions to others. The main lesson here is that systems dynamics mapping exercise as in this study creates the platform that is required by policy makers to comprehend and understand the relationships within the system.
- Consumer decisions to accept agrifood nanotechnology are the results of complex feedback structure.
- Consumer trust is dynamic and varies depending on which effect dominates among the several factors. Perceived risks and benefit seem to be the dominant factors with all things being equal.
- The learning rate leading to stock of public knowledge of agrifood nanotechnology is likely influenced by the combinatory effects of several factors.

From the analysis of the literature and experts value elicitation, the most important stocks identified included number of consumers accepting agrifood nanoproducts, number of consumers that are purchasing or consuming nanoproducts, number of products in research and development, number of nanoproducts on the market, number of people unaware of nanotechnology, and number of people aware (public knowledge). The flows from these stocks include consumption rate, research and development (R&D) investment rate, commercialization rate, learning rate, and rate of consumer decision to accept.

The essence of application of systems mapping in this study is to develop the links and determine the possible causal and feedback loops qualitatively. Causal loop diagrams play two important roles in systems dynamics: (1) they serve as fundamental construct of causal hypotheses during model development and (2) they help to simplify how a model is represented (Georgiadis et al. 2005). With respect to level of consumer acceptance, as many as 71 different causal and feedback loops can be generated by the model. The principal feedback loops included are described using Figure 2. Figure 2 is part of the main systems map shown in Figure 1 and makes the description of the principal feedback loops included in the main systems map clearer.

As depicted in Figure 2, increase number of products in research and development will lead to increase in number and variety of agrifood products on the market, and depending on how information on the products are disseminated and received, may lead to increased in perception of risks or perception of benefits. Increase in either perception will have an effect on consumer trust. Increased in risk perception will create a balancing loop (−), whereas increase in perception of benefits will create a reinforcing loop (+). Increase in consumer trust will increase the number of consumers accepting agrifood nanoproducts which will enhance the consumption rate and hence increase the number of consumers that are purchasing or consuming agrifood nanotechnology products. Increase number of consumers that are purchasing or consuming agrifood nanotechnology products will ultimately lead to increase R&D investment rate, more products in R&D, increase in the rate of commercialization, and more agrifood products on the market.

It must be noted that several other exogenous factors come to play, some of which are shown in the main systems map. For example, several factors contribute to consumer trust

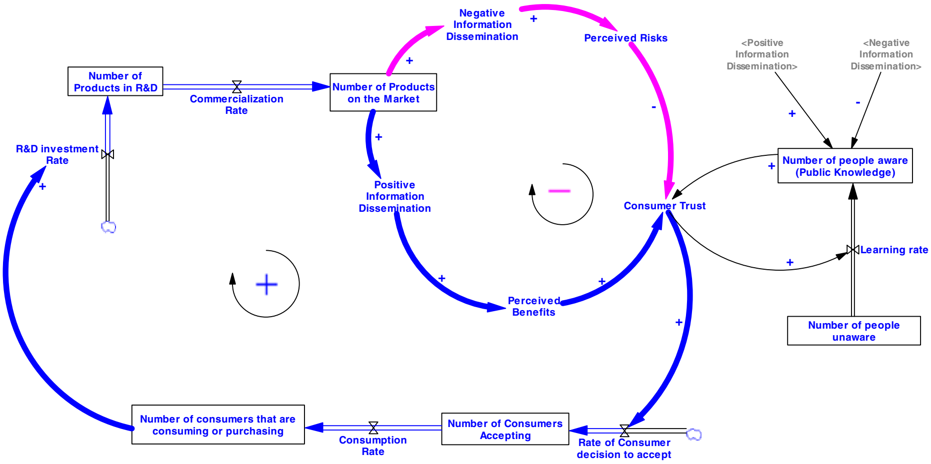

Fig. 2 Main feedback loops of consumer acceptance of agrifood nanotechnology in the systems map

as can be seen in the "causes and uses tree" diagrams generated from the systems map (Figs. 3 and 4). There are others which are not shown in the map such as patents and other intellectual property rights factors. The public, for example, may not be certain that the values of the food industry are the same as theirs but still assigns know-how to the food industry (Siegrist 2008). For this reason, a lack of trust may hinder efforts to inform consumers about the benefits of agrifood nanotechnologies. The causes and uses trees play two important roles: (1) They are used to breakdown wide systems map into finer levels of detail for particular stock of interest as used in this study for "consumer trust." Developing the tree diagrams helps move thinking step-by-step from the various factors that flow into the stock of interest and factors that flow out of the stock (Tague 2004). (2) The tree diagrams also help in debugging the entire model (Dutta and Roy 2002).

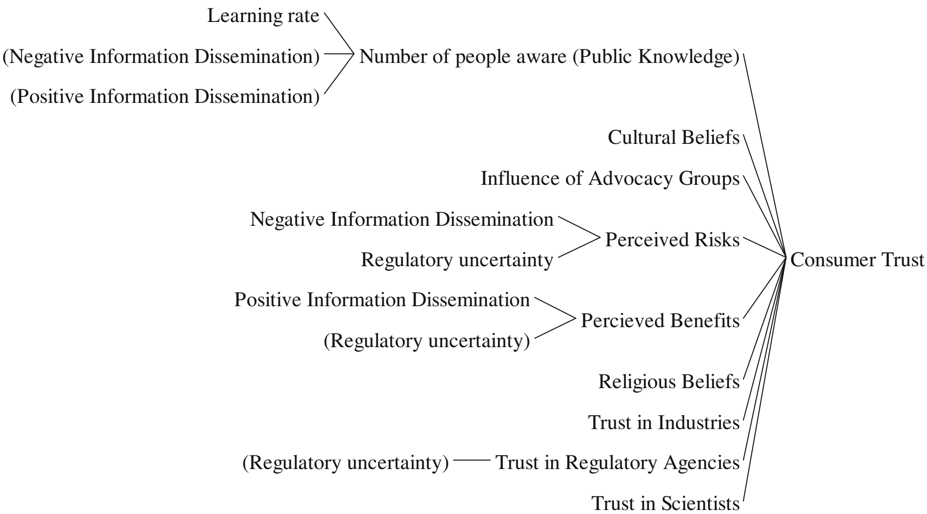

Fig. 3 "Causes Tree" diagram for consumer trust as generated from the systems map

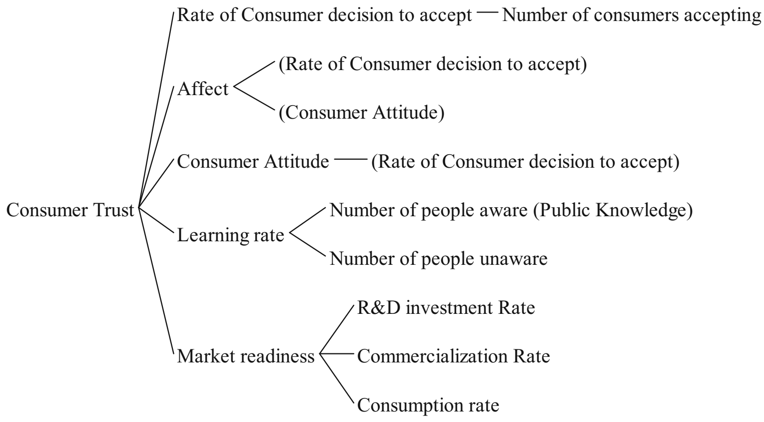

Fig. 4 "Uses Tree" diagram for consumer trust as generated from the systems map

As the elicitation results showed (Table 2), these factors differ in magnitude. The effects of perceived risks and perceived benefits on trust are greater than say the effect of religious beliefs, according to the experts surveyed. Although the remaining attributes appear to have been of much less importance than perceived risks and benefits, they still evoke some influence on trust and ultimately product acceptance. Depending on future scenarios, some of these attributes can become very important and thus affect the dynamics of the whole system. For example, a recall of an agrifood nanoproduct by industry can make trust in industry a huge factor. This is what makes systems dynamics an important tool for studying the uncertainty in consumer acceptance.

Trust is a key factor in affective responses to science and technology (Priest et al. 2003), and this is shown in the systems map in Figure 4. Along with negative emotions, trust can significantly influence both perception of risks versus benefits of new technologies and public acceptance of new technologies (Finucane et al. 2000; Priest 2001). It has also been found that most consumers evaluate new technologies by relying on general attitudes (Siegrist 2008). Consumer confidence in the safety of agrifood nanotechnology might be dependent on the level to which consumers trust various actors with the task of ensuring food safety (de Jonge et al. 2008).

There is little evidence from the literature with regards to the relation between trust and affect supporting the claim that it has hardly been investigated (Visschers and Siegrist 2008). Understanding this relation is crucial to understanding consumer acceptance. Siegrist et al. (2007b) examined both social trust and affect toward nanotechnology food products and associated these directly with each other and with risk perception, perceived benefits, and willingness to pay. The systems map shows these relationships between consumer trust, consumer attitude, perceived risks and benefits, and consumer confidence.

Public knowledge is an important stock identified in this systems map. The role of information in consumer acceptance is still not clear. In some respects, the arrows from consumer trust to learning rate and from public knowledge to consumer trust can all carry dual polarity. This is in line with evidence from literature. Some studies have found negative influences, while others have found positive influences (Cardello 2003; Hansen et al. 2003; Scholderer and Frewer 2003; Wilson et al. 2004). Past literature suggests that if information on benefit comes from a trusted source, then positive reactions are possible (Hansen et al. 2003). This observation was also corroborated by the experts' elicitation.

In any model such as presented in this study, where the inputs are mostly facts with some level of uncertainty, and experts' opinions with unknown values and functional forms, no quantitative conclusions can be drawn without experimental or further empirical research. The systems map as presented indicates how broad based models of consumer attitudes towards agrifood nanotechnology can be created and how certain conclusions can be drawn by simple inputs and historical antecedents. Furthermore, the model is suggestive of ways in which governance of agrifood nanotechnology, through policy, could affect changes. This systems map incorporates the various conceptual models and can be used to guide policy making, although the quantification will be needed for predictive capabilities.

Policy Implications of Study Results

System dynamics models can act like "vehicle dashboard" that consumer policy and decision makers may use as a practice environment. Systems models give the chance for experimentation and reflection and thus facilitate the complete understanding of the complex environment in which policy makers' work (Fisher et al. 2000). Consumer acceptance of agrifood nanotechnology involves a high level of complexity in which to model and to understand how decisions are formed. The complexity exists, partly due to the uncertainty of risks and benefits of using nanotechnology in the food supply. Stakeholders of the agrifood system learn about the benefits through feedback within the system. Learning about the benefits and risks of agrifood nanotechnology influences the consumer acceptance process. Through system dynamics, policy makers and other stakeholders in the agrifood sector may gain insight into the causal factors influencing consumer acceptance. Knowledge of how causal factors influence public perception and consumer acceptance patterns may assist industry, academics, and policy decision makers in strategic planning.

This study has used systems mapping to examine and analyze critical links between consumer acceptance of agrifood nanotechnology and other factors such as trust, stakeholders, institutions, knowledge, and perceived human environmental health risks. The study used meta-analysis of the literature and experts' opinion in developing this systems map. The critical links were derived from the expert elicitation and the literature. The overriding major issue is whether stakeholders in the agrifood system can cooperate and take specific steps toward increasing consumer acceptance (where warranted) of nanotechnology innovation in food systems.

The broader consumer policy issues identified in this study, as derived from the meta-analysis of the literature, empirical results from expert elicitation, and systems mapping, include needs to address

- Building the trust of consumers in the other stakeholders of agrifood nanotechnology system especially those with responsibilities to ensure the safety of nanofood products;
- Addressing public risk perception and consumer acceptance of agrifood nanotechnology;
- Handling public education of different stakeholder groups, public engagement in the governance and regulatory process, and involvement of consumers in proactive debate on risks and benefits of agrifood nanotechnology;
- Communicating the risks and benefits of agrifood nanotechnology in relation to both scientific and non-scientific communication;
- Studying how these issues will impact the governance of agrifood nanotechnology research, development, and commercialization;

- Striking appropriate balance between benefits and risks to determine the correct level of precaution in the applications of nanotechnology in the food supply;
- Assessing the impact of nanotechnology on economy, trade, farming and farm families, and employment at federal/state or local level;
- Increasing access to information on nanotechnology in the food supply.

The current state of low public awareness of agrifood nanotechnology, in concert with limited knowledge about the risks of some of the applications, regulatory uncertainty, and lack of clear governance framework, increase the risk of public rejection of beneficial food nanoproducts. Efforts to improve consumer awareness and public engagement through initiatives on education are important, but are counterproductive when policies are formulated with the sole purpose of getting the public on board, without considering the causal feedback loops identified in the systems map. Again, evidence from literature and some experts' opinion are varied on the role of information: Some suggest that having more information is not at all or only slightly correlated with support for the technology (Gaskell et al. 2004), while others argue that support for nanotechnology may be correlated to higher levels of information (Lee et al. 2005; Priest 2006; Kahan et al. 2007). This gives credence to the outcome of the systems mapping exercise that there are combination of factors at work to explain how agrifood nanotechnology is perceived or will be perceived. As can be seen from the systems map, public knowledge is only one of several factors affecting consumer attitude, consumer trust, and affect.

Public engagement is important if the critical issues of risk management, public risk perception, governance, and regulatory concerns of agrifood nanotechnology are to be effectively addressed. The public should be seen both as unambiguous stakeholders interested in agrifood nanotechnology and the larger public, being citizens and consumers (Mantovani et al. 2009). Public engagement is a key factor in finding out the level of consumer acceptance and can also be as important to agrifood nanotechnology development as the core technical, scientific, political, and economic challenges (Mantovani et al. 2009). Public engagement has a dual role in consumer acceptance of agrifood nanotechnology:

- Public engagement will lead to increased consumer awareness which will enable consumer acceptance or rejection of agrifood nanotechnology to be based more on facts than on suspicions or speculative claims.
- Engaging the public will enhance the depth of interaction and confidence and trust among those involved in the research, development, governance, and regulation of agrifood nanotechnology, the public, and NGOs (Mantovani et al. 2009). This is crucial if satisfactory trade-offs of risks and benefits of agrifood nanotechnology are to be defined appropriately.

Building trust and confidence in an industry, especially an industry that may involve significant risks like the agrifood nanotechnology industry, governance systems, especially regulatory aspects of governance systems, are the key building blocks (Paddock 2006). They do not only set management standards and penalize illegal conduct, they help build public confidence in an industry (Paddock 2006). Historical precedents of transformational technologies and innovations can assist with the development of parallel frameworks for understanding and anticipating public reactions (Guston and Sarewitz 2002) to agrifood nanotechnology developments and innovations. As this study and evidence from literature have established, research and commercialization of agrifood nanotechnology can be strongly influenced by consumer acceptance and patterns of public attitude in general. It is important, therefore, to have knowledge about past examples on how societal responses to transformational innovations of other emerging technologies were handled. The reaction of the public to the introduction of GM foods for example can help anticipate consumer concerns and public reaction to agrifood nanotechnology (Kuzma et al. 2009). The question that arises as to what the results of current study would have been for biotechnology in its early years. As can be seen from the systems map, consumer acceptance is dynamic, and as a result of what happened with the introduction of GM foods, consumer attitudes towards emerging technologies have somehow changed. Therefore, the results would not likely be the same. Depending on the jurisdiction, there has either been a certain level of increase in trust and confidence in regulatory agencies and governments or the reverse. Moreover, due to how consumer and environmental groups were allowed to frame GM foods, lessons have been learned, and governance issues are being handled differently. Another clear difference is how nanofood products are being introduced into the market by industry. Due to fear of backlash, there has been a cautious approach to the introduction, and even how information on nanofood R&D is being handled by industry is different. This was not the case with biotechnology.

Some of the evidence from the literature assumes the building of trust and the consequent consumer acceptance of agrifood nanotechnology can be achieved through informing and educating the public about scientific and technological developments (Ebbesen 2008; Paddock 2006). However, the resulting systems map gives an indication that public attitude towards agrifood nanotechnology will not be shaped only by information, education, openness, and debate about science but also by risk and benefit perception and combination of other factors (such as culture and affect) as it was with biotechnology. This study has shown that public information on agrifood nanotechnology should cover political, sociological, technical, and ethical sides to meet public expectations. This is because trust can be seen as a political issue. In a study by Macoubrie (2005a, b), lack of trust in regulatory agencies in the USA seemed to be a result of lack of trust in the US Congress and the White House.

Another important priority for policy makers on the issues raised by agrifood nanotechnology is to explore, develop, and provide the necessary support to institutions and facilitate the processes that would allow the public to exercise actual power in relation to trajectories or developmental path of agrifood nanotechnology applications. An apparent consumer policy issue that should be investigated in this situation concerns the comparative advantages of the diverse forms of “deliberative” processes, such as citizens' juries, deliberative polling, and consensus councils, as means whereby ordinary citizens might make informed choices about the complex scientific and social problems associated with agrifood nanotechnology (Ebbesen 2008). Public perception and confidence, consumer trust and acceptance, and regulatory uncertainty are likely to be the predominant factors that will determine the success or failure of nanotechnology applications for the agrifood sector. There is suspicion in some quarters that the major food industries are covertly using nanotechnology in their products (Food Chemical News 2007). Industry will need to be proactive in engaging stakeholders directly by informing, engaging, and consulting consumers at this nascent stage of agrifood nanotechnology lifecycle (Chaudhry et al. 2008; Kuzma et al. 2008).

It is also in the common interest of all stakeholders in the agrifood nanotechnology system to be proactive in integrating societal concerns into the R&D process, exploring real benefits, risks, and deeper repercussions for society as a whole (EU 2004). This needs to be done as early as possible and not simply anticipate acceptance post-facto as the major food industries are allegedly doing. In this respect, the complex and emergent nature of agrifood nanotechnology presents a challenge for science and risk communicators. Due diligence must be taken on issues associated with traditional risk assessment, which were critical components of the consumer acceptance process of previous emerging technologies, but may or may not work for agrifood nanotechnology. However, there is the need to avoid an over-emphasis on risk, rather than benefit, which may rather increase the level of perceived risks of agrifood nanotechnology by consumers. The concept that all food poses a balance between risk and benefit should therefore be well communicated (FAO 1999).

Several leverage and programmatic intervention points have been identified in this study that need the attention of consumer policy makers in dealing with consumer acceptance. The key ones are regulatory uncertainty, public knowledge and public engagement, communication about risks and benefits, and consumer trust. As can be seen from the systems map, regulatory uncertainty increases the level of perceived risks and reduces consumer trust. It also influences consumer trust in industry and regulatory agencies. Public knowledge is also important in this regard.

The Way Forward

Future research should strive to improve upon and quantify the parameters in the systems map. It could also explore systems dynamics to understand possible effects of public participation methods on risk perception and consumer acceptance. The public should be informed about the risks, benefits, and applications of agrifood nanotechnology, and this information should be from a trusted source (Siegrist 2008). Where the potential benefits are significant, the associated hazards should be identified, and appropriate polices to encourage research and measures to eliminate unacceptable risks should be implemented.

The systems dynamics approach and the resulting systems map have important implications in respect to consumer acceptance of agrifood nanotechnology. The system dynamics modeling approach and the resulting systems map in this study are expected to help explain what influences consumer attitudes towards agrifood nanotechnology and find leverage points which seem important to policy makers as well as researchers. The broad scheme for dynamism of systems and the results of this study would perhaps provide some leads and ideas for future study to fill data gaps. Although the goal of the model was not the accurate quantitative estimation for forecasting consumer acceptance of agrifood nanotechnology, it enhances the understanding of the mechanism of consumer acceptance of agrifood nanotechnology as a system. The information provided in this paper should thus be a starting point for engaging consumers, stakeholders, and where appropriate, promoting consumer acceptance of agrifood nanotechnology. It also will assist consumer policy makers who are looking for leverage points to be considered for the better practices that could lead to consumer acceptance. However, the model as currently presented in this study will need to be refined and expanded through the identification and analysis of empirical relationships of more variables and factors.

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Appendix 1

Electronic Questionnaire for Expert Elicitation

1. There are several potential barriers to the commercialization of agrifood nanotechnology products that may limit the ability to capture its full potential. Ten of such barriers have been identified below from the literature on emerging technologies. Please indicate what you believe to be the most significant potential barrier with a "1;" what you believe to be the second most significant potential barrier with a "2;" and so on. You may add any potential barriers that you believe to be important and rank them under "Others." Also, if you believe that something already on the list is not a barrier at all, you may leave the ranking blank.

Barriers and potential barriers to Commercialization			Ranking
i.	Capital issues		
ii.	Market readiness		
iii.	Regulatory uncertainty		
iv.	Health and safety		
v.	Workforce readiness		
vi.	Public attitudes and perceptions, and Consumer acceptance		
vii.	Infrastructure		
viii.	Standards		
ix.	Nomenclature		
x.	Manufacturability		
xi.	Others (Please specify)		

2. How likely are the following to affect (positively or negatively) consumer acceptance [willingness to buy or consume] of agrifood nanotechnology products? (assume that the consumer has knowledge that nanotechnology is used for the products that they are making decisions about whether to purchase or consume) (Mark box with an "X").

Factor		Very Likely	Likely	Somewhat Likely	Not very likely	Not at all likely
Perceived Risk						
Perceived Benefits						
Trust in Regulatory Agencies associated with agrifood nanotechnology						
Trust in Industries associated with agrifood nanotechnology						
Trust in Scientists in Academic Institutions associated with agrifood nanotechnology						
Relative Price of products						
Influence of Advocacy Groups						
Cultural Beliefs						
Religious Beliefs						
Others (Please Specify						

3. In your opinion what is the level of public awareness of agrifood nanotechnology? (Mark box with an "X").

Very Aware	Aware	Somewhat Aware	Not very Aware	Not at all Aware

4. In your opinion how likely will the following sources of information help improve public awareness of agrifood nanotechnology?

Factor		Very Likely	Likely	Somewhat Likely	Not very likely	Not at all likely
Consumer organizations						
Environmental organizations						
Friends and family						
Scientists working for universities						
Businesses and Industries						
National governments						
Regulatory Agencies						
Intergovernmental Agencies e.g. FAO, WHO etc						
Others (Please Specify						

5. In your opinion how likely will the following sources of information about agrifood nanotechnology be trusted by the public?

Factor		Very Likely	Likely	Somewhat Likely	Not very likely	Not at all likely
Consumer organizations						
Environmental organizations						
Friends and family						
Scientists working for universities						
Businesses and Industries						
National governments						
Regulatory Agencies						
Intergovernmental Agencies e.g. FAO, WHO etc						
Others (Please Specify						

6. What is the level of your involvement (e.g., expertise, following developments in field, using or making products, overseeing products, policy studies or making, etc.) in agrifood nanotechnology?

Very Involved	Involved	Somewhat Involved	Not very involved	Not at all involved

7. Any other Comments:

Appendix 2

Table 5

Table 5 List of experts and affiliations/expertise

Affiliation	Discipline	Highest degree
Academic[a]	Communication Studies/Film/English, Professor of Nanoscience and Technology Studies	PhD
Academic	Agricultural Engineering and Resource Economics	PhD
Academic[a]	Communication Studies	PhD
Academic	Food Marketing and Consumer Economics	PhD
Academic[a]	Applied Anthropology	PhD
Academic[a]	Sociology	PhD
Academic	Agricultural Engineering	PhD
Academic	Philosophy and Agricultural Economics	PhD
Academic	Philosophy	PhD
Academic	Chemical Engineering	PhD
Academic[a]	Communications	PhD
Government	Anthropology	PhD
Government	Agrifood Marketing	MS
Government	Veterinary Medicine	PhD
Industry	Attorney at Law	JD
International[a] (government)	Psychology and Law	PhD
International[a] (academic)	Food Safety and Consumer Behavior, Applied Psychopharmacology	PhD
International (academic)	Psychology, Economics, and Mass Communication	PhD
International[a] (academic?)	Food Science	PhD
NGO[a]	Communication	MS
NGO	Archaeology	PhD

[a] Experts who participated in the semi-structured interviews

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