Available online at www.centmapress.org

Int. J. Food System Dynamics 9 (4), 2018, 321-330

DOI: http://dx.doi.org/10.18461/ijfsd.v9i4.943

INTERNATIONAL JOURNAL ON FOOD SYSTEM DYNAMICS

On Consumers' Acceptance of Nanotechnologies: An Italian Case Study

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Received August 2017, accepted May 2018, available online August 2018

ABSTRACT

Nanotechnology represents a new frontier in food science with a great potential for many food sectors. Several studies have examined public's benefits and risks perception of nanotechnology, but the literature on the factors influencing the public's attitudes toward nanotechnology is rather limited. We investigate the willingness to buy for nanotechnology foods, and the role of risks and benefits perceptions. We use a structured questionnaire was submitted to consumers and Principal Component Analysis, followed by Structural Equation Model, were performed. We estimate the consumer willing to buy nanotechnology food for four nanotechnology applications, and conclude on a positive role of trust in institutions on willingness to buy food with nanotech applications, and on the (relatively lower) importance on consumers' attitudes toward health and innovations. Policy implications are also provided.

***JEL**: D12, P36, Q11, Q18*

***Keywords**: Consumers trust, Consumers perceptions, Food Risks, Nanotechnologies, Nano-inside*

1 Introduction

Innovations in the food industry are numerous, and growing in number, and the development and application of agrifood technologies play a key role to foster a sustainable growth of agricultural production (Frewer, 2017). Among them, nanotechnology represents a new frontier in food science with a great potential for many food sectors. For instance, nanotechnology may help improving sensory characteristics, health and food safety (Graveland-Bikker and de Kruif 2006; Takhistov, and McClemeents 2006). Due to the novelty of the introduction of nanotechnology in the food industry, few studies have analyzed the interaction between this new technology with human population and the environment. In particular, the potential hazards of nanotechnology applications are quite unknown, and the benefits that may be provided are not sufficiently understood. A number of studies have examined, or reported,the public's benefits and risks perceptions of nanotechnology as well as public attitudes toward nanotechnology in the US and in Europe (e.g., Bainbridge, 2002; Cobb and Macoubrie, 2004; Gaskell et al., 2004; Lee et al., 2005; Scheufele and Lewenstein, 2005; Nerlich et al., 2007; Kjølberg, 2009; Frewer et al., 2014; Giles et al., 2015; Santeramo et al., 2018). Recent studies are worth mention. In particular, Souza et al. (2016) reviewed applications of nanoparticles in food packaging and emphasized the great potential of nanotechnologies to improve food packaging, and the absolute necessity to increase the research on this field. Moreover, O'Callaghan et al. (2016) analyzed consumers attitudes toward smart packaging that include nanotechnologies: they found a positive attitude toward the use of nanotechnology to extend the shelf life, but argue that a large heterogeneity in consumers' attitude is due to the type of technology adopted. Such a large heterogeneity calls for further research.

Limited research has been conducted on consumer's attitudes in Italy and limited knowledge exist on the factors influencing the public's attitudes toward nanotechnology. In addition, the vast majority of studies has investigated the differences of consumers' attitudes toward two different types of innovations: outside and inside nanotechnologies applications (Santeramo, 2018). Most of potential nanotechnology applications in the food sector are still at the early stage of product development, and only a limited number of "nano-outside" applications are already commercially available in some countries (Handford et al., 2014; Ranjan et al., 2014; Pathakoti et al., 2017; Basu et al., 2017), even though it is really difficult to make a complete inventory of nanotechnology food applications already commercialized in the global market.

Given the scant attention that has been devoted to analyzing consumers' attitudes toward nano-inside applications, our research is specifically focused on these aspects. In particular, we investigate the willingness to buy for nanotechnology foods, and analyze how perceived risks and perceived benefits influence stated preferences for different nanotech products. Our contribution is twofold: we deepen on four "inside" nanotechnology applications in the food sector and conclude on a positive role of trust in institutions on willingness to buy food with nanotech applications, and on the (relatively lower) importance on consumers' attitudes toward health and innovations; furthermore we deepen on implications for policymakers.

Increasing consumers' awareness of the benefits and of risks in applying nanotechnology is an important goal. Communicating in the right way the potential risks, and thus avoid exacerbating the perceptions of risks is also very important. Regulations, public education and a clear communication program should be strengthened.

2 Nanotechnologies in the food industry: an overview of current knowledge

Nanotechnology is one of the most promising advancement in food science and technology with the potential to drive the future development of the global food sector (Casolani et al., 2015; Santeramo et al., 2018; Sodano et al., 2016a. 2016b). Nanotechnology focuses on the use of engineered materials and structures with nanoscale dimensions, usually in the range of 1-100 nanometres (one-billionth of a metre). This small size, in combination with the chemical composition and surface structure, gives engineered nanoparticles its unique features and makes them suitable for many applications. In particular, a number of engineered nanoparticles have been already developed for a variety of applications in the food sector and they are expected to provide a range of important benefits including sensory improvements, increased absorption of nutrients, stabilization of bioactive compounds, extended product shelf-life, quality and safety monitoring(Dasgupta et al., 2015; Handford et al., 2014; Pathakoti et al., 2017; Ranjan et al., 2014; Rossi et al., 2014). Two main types of nanotechnology food applications are distinguished: "nano-inside" applications when nanoparticles are incorporated into the food product, and "nano-outside" applications when nanoparticles are incorporated into the food contact materials like packaging (Handford et al., 2014; Pathakoti et al., 2017).

The most important factor that limits the diffusion of nanotechnology applications in the food market is the relatively limited knowledge of the potential risks for human health and environment. More precisely, while toxicology studies are providing increasing evidence that engineered nanoparticles may have adverse effects on human healthand environment (He et al., 2014; León-Silva et al., 2016; McShan et al., 2014; Nikodinovska et al., 2015), the knowledge on the implications for humans and the environment due to repeated exposure to engineered nanoparticles is still limited (Pathakoti et al., 2017; Ranjan et al., 2014). In addition, because toxicity is specific for different nanoparticles, a safety and environmental assessment must be performed on a case-by-case basis (Handford et al., 2014). Recent evidence do not allow to build a sound science-based regulatory framework, and thus there are currently no specific regulations on nanotechnology food applications either in EU, USA or elsewhere (Coles & Frewer; 2013; Magnuson et al., 2013). In addition, there is a lack of universal guidelines specifically developed for the safety and environmental assessment of nanotechnology food applications, even thoughexperts from around the globe are working in bringing an international dimension and harmonization to "nanometrology" and standardization of approaches (Magnuson et al., 2013; Schoonjans & Chaudhry, 2017). However, the current lack of a clear governance framework and consequent regulatory uncertainty makes it difficult for developers and manufacturers to know what, if any, regulations should be complied with, and what risk assessments, if any, are appropriate.

Another potential barrier to the commercialization of food nanotechnology products is related to public concerns about the use of such novel and unfamiliar technology with consequent uncertainty of consumers' acceptance. Several studies have been carried out in different countries (Bieberstein et al., 2013; Chen et al., 2013; Cook & Fairweather, 2007; Farshchi et al., 2011; Matin et al., 2012; Schnettler et al., 2013; Stampfli et al., 2010) to investigate public awareness and attitude toward food nanotechnologies. Results of these studies show that public knowledge on food nanotechnology is quite limited, and attitude varies across individuals. As expected, the attitudes towards nanotechnology food applications are influenced by the associated perceived benefits and perceived risks (Chen et al., 2013; Siegrist et al., 2008; Stampfli et al., 2010). Consumers' perception of risks and benefits is, in turn, mainly determined by the general attitude toward new technologies (neophobia/neophilia), nanotechnology knowledge, and social trust (i.e. trust in scientists, regulatory agencies, food industry and retail) (Chen et al., 2013; Cook and Fairweather, 2007; Matin et al., 2012; Stampfli et al., 2010). Specifically, positive attitude toward new technology (neophilia), deep knowledge on nanotechnologies, and higher social trust tend to increase consumers' perceived benefits and to reduce consumers' perceived risks of nanotechnology applications. Finally, consumers' acceptance of food nanotechnologies varies across different applications: it tends to be greater for "nano-outside" applications as that the lack of ingestion is perceived as a minor exposure to potential hazards (Siegrist et al., 2008; Stampfli et al., 2010).

The successful introduction of nanotechnology applications into the food market is strictly related, on one hand, to the graduality of the process that should follow the advancement of toxicology research and the consequent construction of a sound science-based regulatory framework, and, on the other hand, to the increasing public knowledge, the awareness and the trust.All these aspects must be bear in mind in order to avoid the excess of precaution that has severely limited the introduction and diffusion of GMOs in Europe (Lofstedt, 2014; Tosun and Shikano, 2016). In particular, it is necessary to deepen the understanding of objective risks and objective benefits derived from the introduction of nanotechnologies applications in the food industry. On the other hand, a careful comprehension of beliefs and subjective perceptions is a crucial step in order to guide the development of such an infant (fastly-growing) technology. We pose specific questions: to what extent consumers' perceived benefits and perceived risks influence their willingness to buy? How perceptions are influenced by general attitudes? Our research speaks in this direction and provides concrete answers to the above raised questions.

3 Materials and methods

3.1 Data

In order to understand how consumers' willingness to buy foods with nanotechnologies applications is influenced by individuals' attitudes, we collected a rich set of information. The survey has involved a large set of respondents in order to cover the entire Italian territory: the size of the survey allows us to rely on a representative sample and conclude on the willingness to buy food with nanotech applications.

Data have been collected through a 1033 questionnaire administered in May and June 2015 to more the one thousand potential consumers. The investigation has been designed so to understand the attitudes toward new technologies applied to food production, the general attention to health in food choices, the perception of risks and benefits and the willingness to buy food products that include nanotechnologies and, more specifically, that include nano-nutrients, nano-ingredients, nutraceutical nano-ingredients and nano-protectors. In addition, the questionnaire includes questions on trust in institutions and socio-demographic characteristics. Descriptive statistics of the sample are provided in table 1. In addition, we show statistics (averages) on perceived benefits, perceived risks and willingness to buy in table 2.

Table 1.
Socio-demographic characteristics of the sample

Variables	Relative frequency (%)		Relative frequency (%)
Gender		*Occupation*	
Male	28.5	Self-employed	10
Female	71.5	Manager	3
Age		Employee	34
0-30	12.5	Retired	7
31-40	21.5	Unemployed	8.5
41-50	33.5	Student	6.5
51-60	22	Housekeeper	31
61-70	8	*Number of households*	
71-99	1	One	4.5
No answer	1.5	Two	14.5
Education		Three	23
Elementary school	5	Four	43.5
Second degree school	18.5	Five	13
Middle School	56	Six	0.5
Bachelor	16.5	Seven	0.5
Post-lauream	3	No answer	0.5
No answer	1	*Monthly income*	
Under-14 children		<1000 €	10.5
Yes	31	1000 – 1500 €	33
No	67	1500 – 2000 €	19.5
No answer	2	2000 – 3000 €	17.5
		3000 – 5000 €	11
		>5000 €	4
		No answer	9
Total observations	*1033*		

Table 2.
Descriptive statistics of nanotechnologies applications.

	Perceived benefit		Perceived risk		Willingness to buy	
	Average	SD	Average	SD	Average	SD
Nano-Nutrients	2.55	0.809	2.46	0.830	2.19	0.847
Nano-Ingredients	2.52	0.888	2.42	0.931	2.23	0.932
Nano-Nutraceutics	2.75	0.846	2.39	0.893	2.43	0.996
Nano-Projectors	2.68	0.934	2.46	0.897	2.31	0.926

3.2 Survey design

Participants received some general information (as specified in the present section) about nanotechnology as well as specific information about four different food applications. In fact, prior collection of questionnaires, we informed respondents that nanotechnologies involve the production and application of microscopic particles of variable size ranging between 1 and 100 nanometers[1]. Furthermore, we informed potential respondents that nanotechnology applications are of great interest and that numerous applications have been already

[1]It is worth recalling that 1 nanometer is 1 millionth of a meter, or one thousandth of a millimeter.

implemented in different fields. We argued that the potential applications of nanotechnology involve various industries including electronics, the pharmaceutical, cosmetic, food and agriculture. Despite the increasing expansion of this innovative technologies and the wide range of applications to the food sector, we are far from reaching a consensus on the possible health risks related to the consumption of food products that incorporates nano-particles. Their attitudes toward innovation, health and institutionshave been measured using a 7-points Likert scale. As already described, we focus on different innovations due to the use of nanotechnologies: nano-nutrients, nano-ingredients, nutraceutical nano-ingredients and nano-protectors. As for the first category we need to point that some nanotechnology offers the possibility to artificially synthesize proteins, vitamins and other nutrients in forms that are more easily assimilated by the body and that are more stable to common food treatments (e.g. cooking or storage). Using these *enriched* foods it is possible to easily satisfy the requirements of a balanced diet (without the need of varying the diet and consuming unwelcome foods, as well as expensive in order to acquire specific nutrients).

The nano-ingredients (artificially synthesized) are added to foods in order to confer particular flavors to the food product or to give a particular consistency. An example is the addition of ingredients to get creamy ice cream or warm cookies without using fats or using much lower quantities of nano-emulsions. Other nano-substances can mask unpleasant odors and thus improve substantially the organoleptic characteristics.

The nutraceutical nano-ingredients may help improving the quantities of specific substances such as Omega 3, lycopene, beta-carotene, and certain antioxidants. These substances can provide specific health benefits (e.g. prevention of occurrence of certain diseases), but are naturally present in foods in very small quantities. In addition, these substances are usually not easily assimilated by the body and, in other cases, they are very unstable and therefore they are deteriorated by common food treatments such as cooking and long conservation. The nanotechnology offers the possibility to artificially synthesize these substances and provide them in form that are either easily assimilated by the body and more resistant to common food treatments. The nanoprotectors offer the possibility to artificially synthesize substances capable of hindering the development of microorganisms that are primarily responsible for food spoilage (mold, bacteria, etc.). By adding nanoprotectors it may be greatly extended the retention period of foods, ensuring edibility and healthiness.

3.3 Model

The theoretical model adopted is a simultaneous equations model, also known as Path model, able to elicit how willingness to buy is (directly and indirectly) influenced by perception of benefits and risks, as well as by general attitudes. In particular, we postulate that perceived benefits and perceived risks influence willingness to buy "nanotechnology food" (Siegrest 2006, Siegrest et al, 2007), with a complex mechanism that may depend on consumers' attitudes toward innovation, health and institutions. As such, the model includes variables that proxy consumers' attitudes toward trust in science, trust in food industry and retail, attitude toward technology, preference for healthy food, preference for organic products and preference for food supplements.

Analytically, the approach consists in a two-stage regression model. In the first stage (equation 1) we regress perceived benefits (PB) and perceived risks (PR) on their potential determinants (attitude towards innovations, N, attitude toward health issues, H, and trust in institutions, I) and on control factors (CF), such as knowledge of nanotech, type of job, class of income, and presence of household members under the age of 14. In the second stage (equation 2) we quantify the effects of estimated perceived benefits and perceived risks on the willingness to buy (WTB) of food with nanotechnologies applications:

$$1)\quad \begin{cases} PB = f(N, I, H, CF) \\ PR = f(N, I, H, CF) \end{cases} \text{ First Stage}$$

$$2)\quad WTB = f\left(\widehat{PB}, \widehat{PR}\right) \qquad \text{Second Stage}$$

More specifically, we use a linear specification in order to quantify the impact of attitudes on perceptions (perceived benefit and perceived risks). The following equation show the linear specification for perceived benefit, but it would be essentially identical for the equation of perceived risks, exception made for the dependent variable:

$$3)\ PB = \alpha + \sum_{i=1}^{N} \beta_i Innovation_i + \sum_{j=1}^{I} \gamma_j Institution_j + \sum_{k=1}^{H} \delta_k Health_k + \sum_{z=1}^{Z} \varphi_z Control_z + \varepsilon$$

where the coefficients (β, γ, and δ) quantify the impact (i.e. the marginal change induced by the independent variable, that is $\beta\_i = \partial PB / (\partial [Innovation]\_i)$ of attitudes on perceived benefits, and ε is an i.i.d. error term, assumed to be normally distributed with zero mean. The second stage is estimated by using the following specification:

$$4)\quad WTB = \mu + \vartheta \widehat{PB} + \lambda \widehat{PR} + \eta$$

where $\widehat{PB}$ and $\widehat{PR}$ represent, respectively, the estimated perceived benefits and perceived risk from the first stage, and η is an i.i.d. error term, assumed to be normally distributed with zero mean. Analytically, $\widehat{PB}$ is obtained as follows (and $\widehat{PR}$ is obtained in an identical way, exception made for the dependent variable and the estimated coefficients):

$$5)\quad \widehat{PB} = \alpha + \sum_{i=1}^{N} \widehat{\beta_i} Innovation_i + \sum_{j=1}^{I} \widehat{\gamma_j} Institution_j + \sum_{k=1}^{H} \widehat{\delta_k} Health_k + \sum_{z=1}^{Z} \widehat{\varphi_z} Control_z$$

4 Results and discussion

Our results are derived through a model of simultaneous equations which has been estimated using a two-stage regressions technique. The first stage provides insights on the effects that attitudes play on perceptions of benefits and risks, while the second stage assesses how those perceptions impact the decision of buying or not food with nanotechnologies' applications.

The estimates (Table 3) show that perceived benefits and perceived risks are differently influenced by consumers' attitudes. First, knowledge of nanotechnologies is only crucial in determining perception of benefits, whereas no effect is found for the perception of risks. Second, the attitudes toward innovations play an opposite role: a positive attitude towards new technologies increase the perception of benefits, and decrease the perception of risks. Differently, the attention toward health issues influence risks and benefits perception in a similar fashion. Lastly, trust in institutions is also a key variable: the higher the trust in institutions the higher the perceived benefits and the lower the perceived risks. We found no major influence of control factors such as the type of occupation, and the presence of household members under the age of 14. Instead, we found that consumers in higher income classes tend to have a lower perception of risks associated with nanotechnologies.

The second-stage regression reveals interesting findings. First, in all cases we found perceived benefits to be positively associated with a higher willingness to buy food with nanothecnologies applications, and perceived risks to be negatively associated with a lower willingness to buy food with nanothecnologies applications. Also, in all cases these correlations are statistically significant at the 1% level of significance.

In addition, we found that informed consumers (i.e. those who have deeper knowledge of nanotechnologies) have higher perceptions of benefits, but not of risks; richer consumers (i.e. those who belong to higher classes of income) have lower perceptions of risks, but not of benefits. Taken together the findings suggest that innovations in the food industry face a "knowledge-wealth paradox": both knowledge and wealth indirectly increase the willingness to buy, but the functioning mechanisms are opposite. Building knowledge allows to communicate and comprehend the benefits of innovations, whereas wealth tends to decrease the perceptions of risks favoring the willingness to buy foods with nanotechnologies applications.

Lastly, it is worth noting that the effects of benefits and risks perceptions are heterogeneous across different types of nano-inside applications. However, in all cases the impact of perception of benefits is up to twice as large as that of perception of risks: a sign that the boldness of trying innovative foods dominates the fear of avoiding them. Among nano-inside applications, nano-nutrients are those for which such a difference is the largest, whereas for nano-ingredients and nano-protectors the differences are the lowest. In general we can conclude that our findings are in favor of the use of nanotechnologies in food industry.

5 Conclusions

In this study willingness to buy nanotechnology food and the perceived risk and perceived benefit associated with these products were analysed by presenting four nanotechnology applications in the food sector: people are still unfamiliar with nanotechnology and acceptance of products varied among different applications. Our quantitative analysis, via a path model, revealed that perceived benefits explain a large part of variance in willingness to buy. In line with the vast majority of studies on consumers' attitudes (e.g. Santeramo et al., 2017a, 2017b; Giampietri etl al, 2017) in addition, trust in science and technology help explaining consumers' perceptions of risks and benefits for nanotechnology applications. The higher consumers' trust in science, food industry and retail channels, the higher their perception of benefits with respect to the risks of nanotechnologies (Sodano et al. 2016). Our findings compare with previous studies, which also showed different effects of perceived benefits and perceived risks for the acceptance of nanothech application in the food industry. In particular, Frewer et al. (2015) state that "[…] *people differentiate nanotechnology applications based on the extent to which they perceive them to be beneficial, useful, necessary and important. The benefits may be offset by perceived risks focusing on fear and ethical concerns*." Our results are in the opposite direction.

Table 3.
Perceived benefits and perceived risks: Empirical results

First Stage			
Perceived Benefits (PB)		Perceived Risk (PR)	
Knowledge	0.064	Knowledge	0.043
	(2.41)*		(1.35)
Innovations	0.193	Innovations	-0.258
	(7.99)**		(8.93)**
Health	0.095	Health	0.141
	(3.86)**		(4.82)**
Institutions	0.401	Institutions	-0.279
	(16.39)**		(9.60)**
Job: manager	-0.340	Job: manager	0.440
	(1.21)		(1.31)
Job: employee	0.176	Job: employee	-0.033
	(1.27)		(0.20)
Job: retired	0.065	Job: retired	0.026
	(1.09)		(0.36)
Job: unemployed	-0.158	Job: unemployed	0.124
	(2.31)*		(1.52)
Job: student	0.046	Job: student	-0.123
	(0.40)		(0.88)
Job: housekeeper	0.229	Job: housekeeper	-0.139
	(2.17)*		(1.11)
Under-14 Age	-0.042	Under-14 Age	-0.037
	(0.72)		(0.53)
Income Class	0.020	Income Class	-0.038
	(1.88)		(2.98)**
Constant	2.436	Constant	2.912
	(18.49)**		(18.51)**
Second Stage			
Nano-nutrients		Nano-ingredients	
PB	0.618	PB	0.468
	(30.51)**		(23.60)**
PR	-0.227	PR	-0.307
	(11.95)**		(16.12)**
Constant	1.216	Constant	1.798
	(13.51)**		(19.77)**
Nano-nutraceutical		Nano-protectors	
PB	0.524	PB	0.450
	(25.16)**		(20.65)**
PR	-0.291	PR	-0.324
	(14.34)**		(15.33)**
Constant	1.639	Constant	1.883
	(16.93)**		(18.69)**
Observations 1,033			

In particular, trust in science and institutions and attitudes towards new technologies show a significant effect on perceived benefits and perceived risks; attention to health is correlated with perceived risks but not with perceived benefits. This result is of particular interest as it may initiate a virtuous mechanism. In fact, as recently shown by Kim at al. (2014) "*benefit perceptions positively affect public support for nanotechnology*", and may therefore act as a catalyst for the diffusion of innovations in the nanotech-food industry.

The Path analysis showed that perceived benefits explain a large part of variance in willingness to buy and showed that trust in science and technology was the strongest variable in explaining the variance of perceived risk and perceived benefit of nanotechnology applications. The more consumers trust science, the food industry and retail, the higher they perceive the benefits and the lower they perceive the risks. These findings are in line with other studies, which also showed that perceived benefits are more important than perceived risks for the acceptance of this food technology (e.g. Sodano et al., 2016).

A major contribution of our study is the identification of the “knowledge-wealth paradox”. Again, we found that both knowledge and wealth indirectly increase the willingness to buy but while building knowledge allows to communicate and comprehend the benefits of innovations, increasing wealth (or targeting high income class consumers) tends to decrease the perceptions of risks favoring the willingness to buy foods with nanotechnologies applications. In addition, we prove that, at least for innovations such as nano-inside applications, the boldness of trying innovative foods dominates the fear of avoiding them.

Few limitations of the study should be pointed: our study cannot generalize the findings to other countries, as no comparison was made. Indeed, to the extent that our large dataset capture the essence of the Italian population, the validity of our findings may be extended to countries with populations that share common characteristics with the Italian consumers.

How to increase the public’s perceived benefits and decrease its perceived risks of applying nanotechnology is an important task for government, other authorities concerned, and the manufacturers. Increasing the use of nanotechnologies in the food industry may prove effective to boost the uptake of calories and proteins, which tend to be income-inelastic (Santeramo and Shabnam, 2015; Shabnam et al., 2016), as well as to increase the intake of micronutrients to decrease the (negative) impacts of food insecurity and low access to food (Santeramo, 2015a, 2015b). Regulations, public education and clear communication programs could be public methods to better comprehend this new technology. To the extent that no conclusive recommendations may be provided with the current state of knowledge, exploring these issues represent not only a promising area of research, but a pressing question calling for immediate answers.

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