The sum of all the fears: the role of attitude towards health and environmental risk in the WTP a premium for organic foods

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Abstract

Many empirical studies underline that the main reasons for purchasing organic foods are the protection of health and the environment and that the price premium associated with organic foods is one of the major barriers to consumption of these products. These studies also show that there is a very strong heterogeneity of these organic premiums as well as the Willingness To Pay (WTP) an organic premium. However, it is also clear from these studies that there is no consensus concerning the determinants of these WTP for organic foods. This article focuses on the question of the formation of these WTP a price premium for organic foods when the consumer decides to commit himself in a long-lasting consumption of organic foods in order to protect his health and environment. We show that there is not one but several WTP a price premium and their determinants are a synthesis combining the characteristics of the consumer (e.g. income, life expectancy) but also his fears on the environmental impact of conventional agriculture as well as his fears about how regular consumption of conventional food directly affects his own life expectancy. We also show that the price barrier should be analyzed dynamically: for a consumer, the same price of organic foods may initially dissuade him from consuming organic foods but not necessarily throughout his life.

Keywords: Organic food, Health risks, Optimal control, Environment, Willingness To Pay

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1. The lack of unanimous and clear factors of WTP a price premium for organic foods in empirical survey

The market for organic products is increasing steadily: for example, the part of French consumers consuming at least organic products once a month has increased from 37% in 2003 to 49% in 2014 (Agence Bio, 2014). More generally, the landfarmed devoted to organic products has nearly quadrupled between 1999 and 2013 (Arbenz et al., 2015). Despite this trend, the market share for organic products remains low (generally below 5% in Europe (Bazoche et al., 2014)) and the share of organic farming still represents only 1% of the global landfarmed and more than 10% of landfarmed in only 11 countries (Arbenz et al., 2015 ; Aschemann-Witzel and Zielke, 2015).

Then there exists a large empirical literature analyzing the favorable and adverse factors for the consumption of organic foods[1]. Thus, the protection of health and the environment concern are the main drivers of the organic foods consumption (Magkos et al., 2006 ; Hughner et al., 2007 ; Hoffmann and Wivstad, 2015;) [2]. In particular, as noted by many scholars (e.g. Ott, 1990; Jolly, 1990; Wilkins and Hillers, 1994), consumers buy organic products because of their desire to avoid chemicals used in conventional food production. The daily consumption of food grown with pesticides is perceived to be associated with long-term and unknown or deleterious effects on human health (Hammitt, 1990), such as cancer, hormonal disorders, decreased fertility, etc.

[1] For a recent literature review see in particular Hoffmann and Wivstad (2015) and Aschemann-Witzel and Zielke (2015)

[2] There are also other motivations such as the belief that organic products taste better. For some consumers, there is a phenomenon of attributes association leading to consider that a food produced with a respect of the environment also has a better organoleptic quality (superior taste) and a better health quality (Larceneux et al., 2014).

Conversely, the price premium of organic foods is listed by most of the studies as the major barrier to the consumption of organic foods[3]. Indeed, organic food is actually much more expensive than conventional food (Hughner et al., 2007; Aertsens et al., 2009, Hoffmann and Wivstad, 2015); Aschemann-Witzel and Zielke, 2015 ; Bazoche et al., 2014). These premiums vary widely between the different types of foods: for instance, in the case of Sweden, the premium ranges from 15-25% for coffee to 50% for eggs (Hoffmann and Wivstad, 2015). This high variability of premiums could be partially explained by the heterogeneity of production conditions (e.g. coffee vs eggs), given that it may be more difficult for some kind of products (and therefore more expensive) to produce in an organic way than for other products. However, this very high variability of premiums is also found for similar foods. For instance, by analyzing the wholesale prices of apples in the United States[4], it can be observed that organic premiums vary from 27% (for the variety "Pink Lady") to 107% (for the variety "Cameo").

Therefore, there is a need to investigate the factors of such heterogeneity, knowing that premiums result from heterogeneous consumers' behavior motivated by subjective beliefs more or less scientifically supported[5]. Thus, the choice for an individual to consume or not organic foods at a given date, is the result of his willingness to pay for an organic food and the actual market price of that organic food. Indeed, if the price observed on the market is greater than the WTP a price premium, the consumer will not buy the organic food considered. It is then relevant to observe empirically these WTP. Various empirical studies show that WTP for organic foods (or for foods with lower concentrations of pesticides such as IMP foods (Integrated Pest

[3] Other factors are also mentioned as a barrier to purchase organic foods such as the lack of organic food availability, skepticism of certification boards and organic labels, insufficient marketing, satisfaction with current food source, sensory defects of organic foods (Hughner et al., 2007).
[4] US DA (2013) : http://www.ers.usda.gov/data-products/organic-prices.aspx
[5] Indeed, it should be emphasized that the consumers' belief regarding the existence of differentiated effects on their health between conventional and organic products is not generally supported incontestably by the scientific literature (Hoffmann and Wivstad, 2015): at present, it is not possible to state categorically from a scientific point of view that eating organic food is better for health.

Management)) are also very heterogeneous (Bazoche et al., 2014), ranging from 0% to 105%, with an average of approximately 30% (Aschemann-Witzel and Zielke, 2015).

In response to these findings, several authors seek to explain the heterogeneity of these WTP a price premium by the heterogeneity of consumers' characteristics (gender, age, income, level of education, etc.) and / or by the characteristics of organic products (ex. appearance, sensory defects, organic certification logo, etc.). As pointed out by Aschemann-Witzel and Zielke (2015), the results provided by the empirical literature appear to be relatively contradictory and do not make it possible to highlight unambiguously and unequivocally the role of the usual explanatory variables. For instance, Bazoche et al. (2014) observe that apart from the higher WTP of women for organic apples, the results do not reveal any other systematic influence (e.g. no gradient for age, income or education), whereas Loureiro and Hine (2002) observe that respondents belonging to the upper class are willing to pay significantly more an organic premium for potatoes and Marette et al. (2012) notes that income (weakly) influences the WTP for organic apples. Consequently, the WTP a price premium for organic foods appears difficult to explain in a simple way by the usual socioeconomic variables. This finding seems quite surprising, because it could be expected that the consumption of organic products would be discriminative in terms of socioeconomic characteristics.

The aim of this article is to show that this absence of unambiguous factors for WTP a price premium for organic foods can be partly explained by a possible ambiguity concerning the protocols of the various empirical studies but it can be also explained analytically by the fact that the determinants of the WTP are a complex synthesis, combining consumers' characteristics and their fears concerning conventional foods. We propose a model of consumer behavior in which we specify two major concerns for a consumer of organic foods: on the one hand, the consumer may be concerned about the environmental effects associated with the conditions of production of conventional foods, which affect his perception of the environmental quality of these foods. On the other hand, the consumer may also fear a link between the consumed quantity of conventional foods and his own health, these two concerns being more or less correlated[6]. Our analysis then explores the following idea which is, to our best knowledge, little discussed in the literature: if the consumer's choice to consume or not organic products integrates the risks for his health, his WTP a price premium should be analyzed in a dynamic context. Indeed, the risks associated with the consumption of conventional foods are long-term and cumulative in relation to the gradual accumulation of chemical residues in consumers' bodies. Therefore, if a consumer of conventional foods decides to consume just once an organic food, this one-time consumption will not have *a priori* any impact on his perceived health. Thus, the decision to consume or not to consume organic foods to protect one's health should be analyzed as a long-lasting commitment and not as a sum of independent and repeated one-time decisions. This decision depends not only on the usual economic factors (e.g. income) and beliefs about this risk (e.g. perceived link between conventional food consumption and accumulation of chemical residues in the body), but it also involves variables related to the influence of time in this decision such as preference for the present and the perceived life expectancy of the consumer at the time of his decision or not to commit to a long-lasting organic consumption.

Besides explaining the determinants of the WTP a price premium for organic foods, our modeling aims at answering the following questions: for a given consumer, should a high premium for an organic food be necessarily a definitive barrier to organic consumption or can it be seen as a temporary retardant, even if this price premium, other prices, income and risk perceptions remain unchanged? Is it preferable for that consumer to start by consuming organic

[6] For instance, European consumers may be concerned about the harmful effects of the conventional production of palm oil (in Indonesia, Malaysia, Nigeria, etc.) on forests and natural habitats apart from any concern for their own health.

products over the course of his life and then to finish by consuming conventional products or is it the opposite?

The remainder of the article is organised as follows: in the first section, we show that there is not only one WTP a price premium for organic foods but potentially an infinity of WTP, depending on what it is considered by the consumer. In the second section, a theoretical model upon consumer's choice between an organic food and a conventional food is developed in an optimal control framework. The third section focuses on the analysis of two particular premiums and the resulting optimal consumption path. The effect of consumer's characteristics upon these premiums are analysed in light of empirical results concerning factors of WTP organic price premium. The last section concludes.

How many WTP a price premium for organic foods?

In previous empirical studies attempting to measure and explain WTP an organic price premium, it is implicit that the consumer unambiguously interprets the usual question "How much are you willing to pay for an organic food?" (or any variant of this formulation), assuming that for a given consumer and for a given food, this individual WTP is unique. However, we can show that there is potentially an infinity of individual WTP depending on how the surveyed consumer considers the organic food consumption.

First of all, following Johansson (1996), it should be remembered that the WTP an organic price premium corresponds to a price variation and not to a lump sum to be subtracted from income, since the resulting variation of quantity is not necessary null. Consequently, besides the fact that this WTP does not generally allow a calculation of consumer's surplus (Johansson, 1996), the question of the uniqueness of the WTP an organic price premium should be addressed. Indeed, the WTP stated by the respondent is conditional to the expected share of the organic food: in a hypothetical survey, when the consumer states or accept a WTP of X $ for an organic food, we do not know if this consumer considers consuming only the organic food or he is considering a mix with the conventional food. It can be expected that this WTP will be lower if the consumer considers an exclusive consumption of organic food than if he considers only a small share for organic food. The second reason relates to the fact that organic consumption takes place over time: when the consumer states or accepts a WTP of X $ without any additional information, we do not know if this premium is only for a one-off purchase or for a more or less long period, possibly for the remaining life. Then the WTP stated by the respondent is also conditional to the period considered by him.

If we combine all the possibilities associated with each of these two dimensions (quantity and time), then we can consider an infinite number of possible combinations concerning how the respondent understands the question "How much are you willing to pay for an organic product?" Consequently, this multiplicity of uncontrolled interpretations in surveys could partly explain the heterogeneity of the empirical results concerning the stated price premiums and concerning the explanatory factors.

The question is now how to deal with this potential diversity of WTP. At least, these elements should be controlled by additional questions or by specifying the protocol[7]. However, simultaneously taking into account the organic quantity (or share) and time multiplies the possible scenarios and therefore increases the heterogeneity of the protocols that would seek to control these elements.

Thus, it can be useful to focus on two extreme WTP which would frame all other possible WTP. The first one is the WTP a price premium for the exclusive consumption of organic food for the rest of the life ($WTP_{org.=100\%}$, thereafter): if the premium observed on the market is less than

[7] For example, in their Experiment Design, Biguzzi et al. (2014) require the consumer to choose, for each of the 10 displayed rounds, only one type of tomatoes (i.e. conventional, organic or IMP (Integrated Pest Management)) and they ask them to specify the quantity purchased.

$WTP_{org. = 100\%}$ then the consumer will consume only organic food for the rest of his life. The second one is the WTP a price premium below which the consumer introduces organic food at a time of his remaining life ($WTP_{org > 0\%}$ thereafter): if the market premium is greater than $WTP_{org > 0\%}$ then the consumer will never consume organic food for the rest of his life. The determinants of these two extreme WTP can be analyzed from the following modelling.

A dynamic model of consumer's choice between organic vs conventional food

We use an optimal control model in which the consumer performs an arbitrage for the rest of his life between an organic food that he considers as safe for himself and for the environment and a conventional food which is detrimental for his life expectancy and also affects the environment during its production. Apart from the question of their respective environmental and health effects, these organic and conventional foods are supposed to be perfect substitutes since they are exactly the same type of food (e.g. a specific variety of apples). We assume that the consumer has full confidence[8] in the designation "organic food", particularly in the ability of this product not to contain harmful chemicals. For simplicity, we assume a two stages decision process as in Strotz (1957). At a first stage, the consumer considers the budgeting of his income for a specific food (ex. apples). Then this budget allotment is optimally divided up between the organic food and the conventional food.

Concerning the perceived effect of conventional food on consumer health, the quantity consumed of this food (with a price p_z considered as the reference price, $p_z = 1$) directly impacts the life expectancy of the consumer through the following process: first, the consumer believes that the stock of chemical residues in his body increases with the consumption of conventional

[8] It should be noted that when purchasing or consuming, the consumer is not able to test the true type of food (organic or not), unlike an experience good or a search good: this true characteristic of food is typically part of the problem of a credence attribute characterized by an asymmetry of information between consumers and producers (Goddard et al., 2012).

food over time, and, for mathematical simplicity, we can assume that the consumer considers that this stock of toxic residues increases linearly along with the consumption of conventional food[9]. $\dot{N} = \alpha z(t)$ with $\alpha > 0$ where *N(t)* denotes the stock of toxic residues in the consumer's body at time t and *z(t)* is the quantity of the conventional food consumed. *N(0)* is equal to the initial stock of residues in the body at the decision time and corresponds to the "burden of the past": if *N(0)* = 0, this means that the consumer considers he has never been exposed so far to this type of chemicals. Then, the consumer thinks that his life expectancy decreases with the stock of toxic residues in his body. Therefore, the expected date of death (*T*) is perceived by the consumer as a decreasing function of the final stock of toxic residues (N_T)[10]: $T = \Phi(N_T)$, $\Phi' < 0$. As a result, the stock level of toxic residues in the body is a decreasing function of the date of death: $N_T = \varphi(T)$ $\varphi' < 0$ with $\varphi = \Phi^{-1}$. For simplicity, we can presume again that the consumer considers a linear relation between terminal time *T* and the stock of toxic residue: $T = T_{Max} - \beta N(T)$ where T_{max} is his maximum life expectancy, corresponding to the case of no consumption of conventional food *z* during his life time. In this case, $N(T) = (T_{Max} - T/\beta)$ and φ' is also constant. Concerning the environmental quality level associated to the conventional food relative to the organic food, our model considers that this level directly affects the utility of the consumer. Therefore, we can use the following utility function[11]: $u(x,z) = (x + \theta z)^{\gamma}$ with $0 < \gamma < 1,\ \theta > 0$. *x* corresponds to the consumed quantity of the organic food and γ measures the effect of the consumption of this kind of food (e.g. apples), whether organic or conventional, on utility. θ measures the perceived level of environmental quality associated with the conventional food relative to the organic food: it therefore

[9] Moreover, we can expect that this simple relationship is made by the lay consumer rather than a non-linear relationship that is more complex.
[10] if $N = N_T$ then the consumer will die at date *T*.
[11] In this case, we thus assume a MRS that is constant and equal to θ. This is a simple way to introduce environmental quality in the utility function. For a discussion of more general forms, see in particular Hanemann's article (1984).

synthesizes the effects on utility associated with the supposed adverse environmental characteristics of conventional agriculture. Logically, θ should be positive (since z is a good) and less than 1: the more the consumer fears deleterious environmental effects associated with conventional agriculture, the more θ will tend to 0. Conversely, if θ tends to 1, the perceived environmental impact of conventional agriculture for this food is as not very different from those associated with organic foods. When θ equals 1, the conventional food and the organic food are perfectly substitutable in utility[12]. All the parameters (α, β, φ, θ) are eminently subjective: their respective levels reflect the consumer's fears towards risks associated with conventional food in terms of health and environment.

Then, the consumer problem is to choose a consumption path for the organic food which maximizes his utility over his lifespan. The consumer’s program is written as follows:

(1) $$\underset{x(t),z(t)}{Max}\, U = \int_0^T u(x(t) + \theta z(t))^{\gamma} e^{-\rho t} dt$$

(2) $$\text{st } z = y - p_x x \quad \text{with } p_z = 1$$

(3) $$\dot{N} = \alpha z(t) \text{ with } \alpha > 0$$

(4) $$T = \Phi(N_T),\ \Phi' < 0 \quad \Rightarrow \quad N_T = \varphi(T) \quad \varphi' < 0 \quad \text{with } \varphi = \Phi^{-1}$$

(5) $$N(0) \geq 0$$

y is the income devoted to the consumption of the (organic or conventional) food at stake. Moreover, we can expect that $p_x > 1$ since the conventional food z is assumed to provide a welfare systematically lower than those provided by the organic food x, because of its toxicity and because of the supposed absence of sensory defect. Replacing z by its expression as a function of x in equation (1) and specifying the shape of u, we obtain:

(6) $$\underset{x(t)}{Max}\, U = \int_0^T \left(x(1 - p_x \theta) + \theta y \right)^{\gamma} e^{-\rho t} dt$$

[12] On the other hand, if θ also takes into account other characteristics such as organoleptic and visual quality, the overall quality measured by θ could possibly be more than 1, when sensory defects associated with organic foods are so strong that they could challenge the hierarchy between organic food and conventional food. This aspect is discussed for instance by Bazoche et al. (2012 ; 2014).

$$\text{st } \dot{N} = \alpha z(t) = \alpha\left(y - x(t).p_x\right),\ \alpha > 0$$

$$N_T = \varphi(T),\ \varphi' < 0 \quad \text{with } \varphi = \Phi^{-1}$$

$$N(0) \geq 0\ ;\ x(t) \in \left[0; y / p_x\right]$$

Characterizing the WTP a price premium for consuming organic food exclusively and the WTP a price premium for introducing organic food (for the remaining life)

From this model, we can now determine the explanatory factors of the two typical WTP i.e. $WTP_{org.=100\%}$ and $WTP_{org.>0\%}$. In this sense, we calculate the two thresholds for the relative prices p_x of the organic good which will condition the commitment or not in a long-lasting consumption of the organic food. For each of these two prices, the relative price premium (%) associated with the purchase of the organic food is then simply defined by $\pi = 100 \times (p_x - p_z) / p_z = 100 \times (p_x - 1)$. One can expect two levels of relative prices for the organic food *x*, namely a low price (p_{xL}) and a high price (p_{xH}) such that above p_{xH}, the consumer always consumes the conventional food and below p_{xL} he only consumes the organic food throughout his life respectively, that is: if $p_x < p_{xL}$ then $\forall t, x(t) = y / p_x$ and if $p_x > p_{xH}$ then $\forall t, x(t) = 0$.

From Appendix A, we can prove that the low price threshold p_{xL} is thus defined as:

(7) $$p_{xL} = \frac{1 - \alpha y e^{-\rho T_{\max}} / \left(\gamma \varphi'\right)}{\theta}$$

The maximum price premium that the consumer is willing to pay to consume exclusively organic produce throughout remaining life is then:

(8) $$WTP_{org.=100\%}(\%) = 100 \times \left[\frac{1 - \alpha y e^{-\rho T_{\max}} / \left(\gamma \varphi'\right)}{\theta} - 1\right].$$

Similarly, from Appendix A, we can also calculate the high price threshold p_{xH}, above which the consumer will consume only the conventional food throughout his remaining life:

(9) $$p_{xH} = \frac{1}{\theta} \times \frac{1}{1-\alpha y / \left(\gamma(\alpha y - \varphi')\right)}$$

From this high price threshold[13], we can deduce the WTP a price premium for introducing organic product in foods for the rest of the life, such as if the organic premium on the market is higher than $WTP_{org>0\%}$ then the consumer will never consume organic food until the end of his life:

(10) $$WTP_{org>0\%} = 100 \times \left(\frac{1}{\theta} \times \frac{1}{1-\alpha y / \left(\gamma(\alpha y - \varphi')\right)} - 1 \right)$$

We can now analyze the variations of $WTP_{org.=100\%}$ and $WTP_{org>0\%}$ according to the perceived health risk and environmental quality connected with the conventional food and according to the consumer characteristics (cf. Appendix B for details concerning derivatives).

Table 1: Effects of consumer's characteristics and perceived risks concerning conventional food on $WTP_{org = 100\%}$ and $WTP_{org > 0\%}$

Characteristics	y	T_{max}	ρ	α	φ'	θ	γ
Effect on $WTP_{org = 100\%}$	+	-	-	+	+	-	-
Effect on $WTP_{org > 0\%}$	+	0	0	+	+	-	-

We can observe that an increase of all the consumer's fears concerning the conventional food will higher the WTP for an exclusive consumption of organic food and the WTP for introducing organic food for the remaining life. These fears can come from an upward revaluation in

[13] p_{xH} exists only if $\gamma(\alpha y - \varphi') > \alpha y$), that is always checked when γ =1.

perceived toxic residues in conventional food (cf. α) or in the perceived rate at which the stock of toxic residues decreases life expectancy (cf. φ') and a downward revaluation of the perceived environmental quality of the conventional agriculture (cf. θ). Besides, $WTP_{org=100\%}$ and $WTP_{org>0\%}$ will be also promoted by an increase in the overall budget for this kind of food (cf. y). Conversely, a short-sightedness about future (cf. ρ) and / or an increase in life expectancy will reduce the $WTP_{org=100\%}$ but not $WTP_{org>0\%}$ which is invariant with respect to T_{Max} and ρ. Besides, a greater preference (cf. γ) for the kind of food at stake (e.g. apples), will also reduce the $WTP_{org=100\%}$ and $WTP_{org>0\%}$: this result would be quite surprising, but it means that when a consumer is very attracted to a specific food, he seems less concerned about its environmental and helth quality and the other way round for more ordinary foods. This result could explain why some ordinary foods such as eggs, milk, fruits etc. seem more concerned with the organic certification while some luxury foods or drinks such as great wines, Champaign, caviar etc. seems less concerned by this issue. This result could also explain why, for instance, in the field of (French) wine productions, it can be observed that for mid-range market wines there is an important communication from organic producers (e.g. via an organic logo on the label) while great wines (e.g. great wines of Bordeaux) producers do not communicate on this characteristic although most of these great wines are organic as if this organic characteristic doesn't matter a lot for them. This attitude which may seem irrational can be explained by our model: the consumers' preferences for these products are so high that they outweigh largely their environmental and sanitary characteristics.

Therefore, it is interesting to note that a change in intangible characteristics such as the perception of toxic effects associated with conventional food (i.e. α and φ') or some invisible characteristics specific to consumers (i.e. T_{Max}, ρ, γ) can induce a complete disappearance of the demand for the conventional food meanwhile the tangible characteristics (i.e. p_x and y) remain unchanged.

A possible explanation for the empirical results concerning the WTP for organic foods

From our analytical results, we have observed that these two typical WTP a price premium for organic foods are obviously different since they do not share the same explicative variables exactly (cf. presence or not of T_{max} and ρ) and they don't display the same functional form. Several numeric simulations show that $WTP_{org=100\%}$ and $WTP_{org>0\%}$ can differ dramatically, according to the values of the parameters at stake. For instance, if y = 10 \$, T_{max} = 60 years, ρ = 5%, φ'= -0.05, α = $1.25.10^{-3}$, γ = 0.75, θ = 0.8, then $WTP_{org=100\%} = 27.1\%$ and $WTP_{org>0\%} = 70.5\%$. These results can partly explain the observed heterogeneity concerning empirical measures of WTP for similar foods whenever the consumer's interpretation of WTP (i.e. $WTP_{org=100\%}$, $WTP_{org>0\%}$ or every WTP between these two boundaries) are not controlled during the survey. In fact, for the same food, if two identical respondents (in terms of age, income, tastes etc.) interpret the asked WTP as a $WTP_{org=100\%}$ and a $WTP_{org>0\%}$ respectively, then they will provide two very different WTP despite their common observed characteristics. Consequently, we can connect this result with the question of the absence of unambiguous effects of socioeconomic factors in the empirical analysis of the WTP a price premium for organic foods. Moreover, even if we assume that all the surveyed consumers think in an unambiguous way concerning the nature of the asked WTP (e.g. all of them think in terms of $WTP_{org=100\%}$), we can nevertheless deduce from our analytical results that most of usual socioeconomic variables may act in a complex way on this WTP, partly due to correlation between them. First of all, we can observe that, a higher age (via a decrease of the remaining life expectancy[14]) and an higher income will act unambiguously and positively on $WTP_{org=100\%}$, if they are considered separately. However, it is plausible that age and income are also correlated but not in a monotonic way (e.g. income first may increase with age and then may decrease with age in connection with retirement). Consequently, from an econometric model that tries to explain the WTP an organic price premium, results can be different from a survey to another, depending on how these two important variables are introduced in the model. Besides, while it could be expected that higher education level would act on the WTP positively, many empirical results don't confirm such an obvious statement. Our analytical results can give pieces of explanations about this paradox. Indeed, an higher education level should logically increase the negative perception of conventional food in terms of health risks and environmental hazards (i.e. an increase of α and φ', a decrease of θ) and then, according to our model, it will result in an increase of $WTP_{org=100\%}$. At the same time, a higher education level generally generates a higher level of income and therefore, according to our model, a rise in $WTP_{org=100\%}$ too. On the other hand, a higher education level is connected on average with a higher life expectancy, which, according to our model, acts negatively on $WTP_{org=100\%}$. Therefore, the overall effect of educational level may be ambivalent depending on the context of the study. Consequently, we can deduce that the observed absence of convincing and / or consensual effects of various socio-economic characteristics on WTP is not necessarily the result of inaccurate measurements in empirical studies concerning the WTP, socioeconomics variables nor inaccuracies in protocols, but can be an inherent result of the problem of consumer's attitude towards organic foods. This observation suggests that, in this type of survey, there is a need for

[14] Remember that T is a life expectancy at time $t = 0$, i.e. at the moment of the decision. It does not correspond to life expectancy at birth but life expectancy for instance at adulthood. In this case, this means that, for a twenty-years old consumer, $T_{max} = 50$ years corresponds to a life expectancy at birth of 70 years.

additional variables concerning subjective consumer's perception and attitude towards health and environmental risks associated with conventional foods as well as variables on the perception of his own life expectancy.

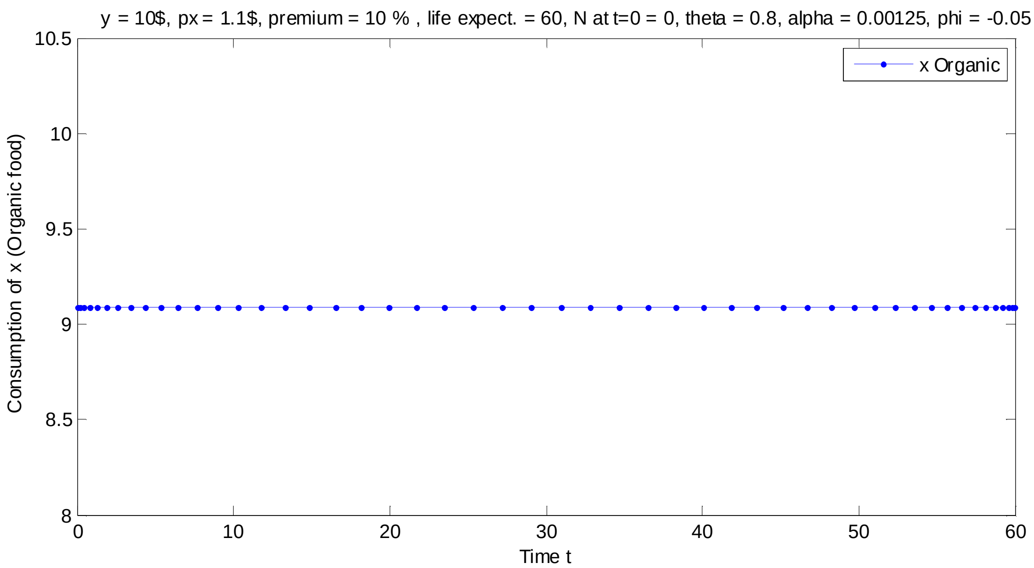
What is the optimal consumption path for the organic foods?

The consumption path of the organic food over time depends on the level of its market prime π. We already know that if $\pi < WTP_{org=100\%}$ (resp. $\pi > WTP_{org>0\%}$), then the consumer will consume the organic food (resp. conventional food) exclusively during his remaining life. Otherwise the consumption path for the organic food will not be uniformly null nor uniformly equal to the maximum quantity (i.e. y / p_x) over time. In the presence of a combination between the conventional food (z) and the organic food (x), quantities $x(t)$ and $z(t)$ correspond to optimal interior solutions of the optimal control problem. From Appendix C we can see that there is no simple analytical solution to describe this path of consumption. Only various numerical simulations can be considered (cf. infra). However, before displaying these simulations, an important analytical result can be considered (cf. Appendix C for details): we can show that, for this intermediate configuration, the organic food (resp. conventional food) consumption should necessarily increase (resp. decrease) over time. Thus, for $WTP_{org=100\%} < \pi < WTP_{org>0\%}$, the optimal way for the consumer is to start by consuming the conventional food exclusively (for a more or less long period) and then he should reduce more or less gradually his consumption of conventional food in favour of organic food, but never the reverse.

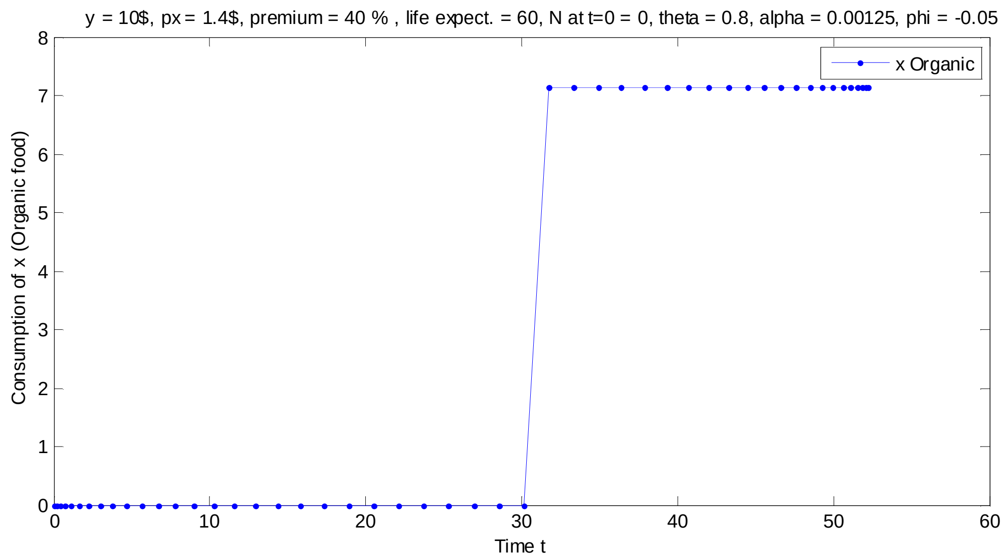
Another important result is that, for the same consumer, the organic price premium π can be a barrier to the consumption of the organic food at the beginning (i.e. at $t = 0$) and then this unchanged π will be less and less such an barrier as the consumer ages and shortens his life expectancy by the consumption of conventional food. Therefore, the organic price premium should be regarded as a relative and temporary barrier, even if all other parameters (e.g.

purchasing power or consumer tastes) remain unchanged. Finally, we propose various numerical simulations with the previous values for the different parameters displayed upstream i.e. y = 10; T_{Max} = 60; $N(0)$ = 0; ρ = 5%; φ'= -0.05; γ = 0.75; α =1.25 10^{-3}; θ = 0.8 and the resulting values for the extreme WTP i.e. $WTP_{org=100\%} = 27.1\%$ and $WTP_{org>0\%} = 70.5\%$. Then, for various market premiums for the organic food, the respective simulated consumption paths are displayed in figure 1.

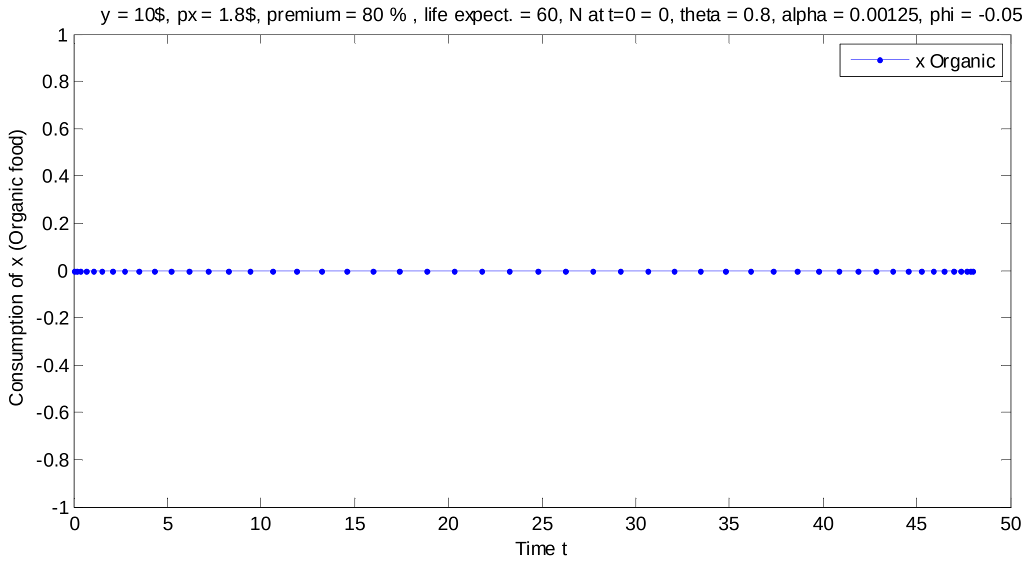
Figure 1. Consumption path of the conventional food associated with various relative prices (p_z)



1.a



1.b



1.c

As predicted by the model, when the market premium is less than $WTP_{org=100\%}$, (here π = 10%, cf. figure 1.a) the consumption over time will concentrate on the organic food; in this situation life expectancy (at time t = 0) is maximum (T = T_{max} = 60 years).

If the organic price premium π increases and is between $WTP_{org=100\%}$ and $WTP_{org>0\%}$, (here π = 40%, cf. figure 1.b), the consumer will begin in the early next years (up to ≈31 years) with the conventional food exclusively; then he will quickly concentrate his consumption on the organic food that will become exclusive on the last next years of his life knowing that his life expectancy will be 8 years shorter ($T \approx 52$ years).

When the organic premium increases again (here $\pi = 80$ %), cf. figure 1.c), the consumer will consumes only the conventional food which will lead to a lower life expectancy ($T = 48$ years[15]).

Conclusion

This article aimed to provide analytical answers to the problems raised by empirical studies concerning the measure and the explanation of the WTP a price premium for organic foods. After pointing out that for the same consumer there is no only one but several WTP an organic premium, depending on the part and duration that the consumer grants to the consumption of organic foods, we have developed an optimal control model for a consumer for whom the consumption of organic food is justified by two main fears (more or less strongly correlated): risks for the environment and risks for his own health over the long term (these two dimensions being more or less correlated). This model analytically explains the determinants of two extreme WTP: the WTP a price premium to consume only organic food throughout his remaining life and the WTP a price premium to start introducing the organic food during his remaining life. Our results indicate that these 2 WTP do not respond in an identical way to the various variables underlying the choice of organic foods and conventional foods, which may explain the heterogeneity of the empirical results when it is not known exactly what WTP is measured. Moreover, our analytical results make it possible to clarify that the socio-economic variables (age, income, etc.) usually introduced into econometric models to explain WTP an organic price premium are likely to act in a contradictory way on the level of WTP: this would explain why there is no consensus between the various empirical studies on the role of these variables. We also show that, except when the consumer wants to consume only organic foods

[15] In this case, T can be determined exactly in an analytical manner (cf. Appendix D).

or only conventional foods throughout his remaining life, the optimal path of consumption is to increase his consumption of organic foods, as he ages for, but never the reverse. Moreover, the interest of this model is to show that concerning the choice between a conventional food and an organic food, the present consumption and the future consumption are not a simple extrapolation of the past. Indeed, due to the gradual accumulation of toxic residues in the body, a consumer purchasing only conventional food in "his early life" has little chance *in fine* to do so throughout his remaining life and he is likely to become, more or less progressively, an organic food consumer. This result is important because it means that, all things being equal (in particular concerning income and level of education), an ageing population will tend to increase its consumption of organic food.

In the model proposed in this article, subjective consumer fears concerning the health effects of conventional foods are modeled in a simple and non-random way ((cf. $\dot{N} = \alpha z(t)$ et φ' is constant): apart from greater simplicity and readability, we think that the average consumer has in mind this kind of simple and linear relationships. However, it would be interesting to consider more general flexible relationships (e.g. the use of Weibull functions), in particular with the perceived existence of a safety threshold above which the consumption of the conventional food does not increase[16] the stock of harmful residues in the body. Similarly, it would also be relevant to introduce, in a more elaborate model, improvements such as a natural process for the elimination of toxic residues in the body or to consider the negative health effect not only in terms of reduction of the life expectancy but also in terms of quality of life through the explicit occurrence of a disease during the remaining life. Finally, as pointed out by Ay et al. (2017), from a survey on residents of a French wine production region, organic premium for wine

[16] Formally, the introduction of a threshold effect generates analytical complexification due to the non-differentiability of the function at the threshold point. The use of a Weibull function (whose curvature and amplitude are controlled by two parameters) allowing more or less pronounced S-shaped curves can therefore be an interesting alternative.

decreases with the distance between the participant's home and a vineyard, meaning possibly that the motivation for organic production is linked to improving their immediate environment and therefore to protecting their own health. This finding could signify that for some consumers leaving near agricultural production areas, there is a perceived link between the environmental quality of the food (via θ) and their own health (via expected life T in our model). This aspect could be also introduced in a future model focusing on these types of consumers.

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<u>Appendix A:</u> Determination of the price thresholds

The current value Hamiltonian connected with our optimal control problem is:

(11) $H = \left(x(t)(1-p_x\theta)+\theta y\right)^{\gamma} + \lambda(t)\dot{N}(t) = \left(x(t).(1-p_x\theta)+\theta y\right)^{\gamma} + \lambda(t).\ \alpha\left(y-x(t).p_x\right)$

where the coefficient λ is the current value multiplier associated with (3) and can be interpreted as the implicit price of toxic residues (*N*) present in the conventional food *z*. For this problem and with the Hamiltonian defined by equation (11), the maximum principle conditions are:

(12) $$\dot{N} = \alpha z(t) = \alpha\left(y-x(t).p_x\right),\ N(0)\geq 0$$

(13) $$\partial H/\partial N(t) = \rho\lambda(t) - \dot{\lambda}$$

(14) $$[H-\lambda(t)\varphi']_{t=T} = 0$$

Equation (14) corresponds to the terminal condition associated with a terminal curve since *T* and *N* are here linked via equation (4) (Chiang, 2000). Moreover, we know that: $\partial H/\partial N(t) = \partial\left(\left(x(1-p_x\theta)+\theta y\right)^{\gamma} + \lambda(t).\alpha\left(y-x(t).p_x\right)\right)/\partial N(t) = 0$, since *N* doesn't enter the utility function directly. Then equation (13) gives:

(15) $$\partial H/\partial N(t) = \rho\lambda(t) - \dot{\lambda}(t) = 0 \Rightarrow \rho\lambda(t) = \dot{\lambda}(t)$$

Furthermore, since $x(t)\in\left[0; y/p_x\right]$ meaning possible corner solutions, the conditions of Kuhn-Tucker are used, namely if *x(t)* is an interior solution then: $\partial H/\partial x = 0$ else: *x(t)* = 0 or *x(t)* = y/p_x

Determination of the low price threshold p_{xL}

Formally, the optimal consumption path of the organic food *x* is linked to the values taken by the multiplier $\lambda(t)$ over time (cf. equation 11). Logically this implicit price λ of *N* is expected to be negative and, more and more negative with the accumulation of *N* in the consumer's body.

In a first step, we determine the conditions on $\lambda(t)$ when $\forall t, x(t) = y / p_x$ due to the fact that the price p_x is sufficiently low so that the organic food is consumed exclusively. In this situation, the life expectancy is maximum ($T = T_{max}$) since the consumer is not intoxicated by any conventional food. Thus, at any time t, the function H reaches its maximum at the higher boundary ($x(t) = y/p_x$). Then $\forall t, \partial H / \partial x \geq 0$.

Reminding that: $H = \left(x(t)(1-\theta.p_x) + \theta y \right)^{\gamma} + \lambda(t).\alpha\left(y / p_z - x(t) p_x \right)$ (cf. equation 11), it follows that:

(16) $$\partial H / \partial x = \gamma(1-\theta p_x)\left(x(t)(1-\theta.p_x) + \theta y \right)^{\gamma-1} - \lambda(t).\alpha.p_x \geq 0$$

As $x(t)=y/p_x$ then:

(17) $$\gamma(1-\theta p_x)\left(y / p_x \right)^{\gamma-1} - \lambda(t).\alpha.p_x \geq 0$$

Then: (18) $$\lambda(t) \leq \gamma(1-\theta p_x)\left(y / p_x \right)^{\gamma-1} / \left(\alpha p_x \right)$$

With: $$\gamma > 0,\ \alpha > 0, 1 > \theta > 0 \ \textit{and} \ p_x > 1 (= p_z)$$

In a second step, starting from equation (13) and the terminal condition (14), we can determine the expression of $\lambda(t)$. Indeed, we know via equation (13) that $\dot{\lambda} = d\lambda / dt = \rho\lambda(t)$. Since it is a homogeneous first-order ordinary differential equation, its solution is:

(19) $\lambda(t) = ke^{\rho t}$, where k is a parameter to be determined.

The value of k is obtained via the terminal condition (14): $[H - \lambda\varphi']_{t=T} = 0$.

Knowing that $x(T)=y/p_x$ and $T=T_{max}$, we obtain: $\left(y / p_x \right)^{\gamma} - \lambda(T_{\max})\varphi'(T_{\max}) = 0$. Then: $\left(y / p_x \right)^{\gamma} - ke^{\rho T_{\max}}\varphi'(T_{\max}) = 0$ and finally

(20) $$k = \left(y / p_x \right)^{\gamma} / (e^{\rho T_{\max}}\varphi'(T_{\max}))$$

If a linear relationship[17] is assumed between N and T, then $\varphi'(t)$ is constant. Consequently:

(21) $$k = \left(y / p_x\right)^{\gamma} / (e^{\rho T_{\max}} \varphi')$$

Moreover, as $\varphi' < 0$ then $k < 0$. Hence, $\forall t, \lambda(t) < 0$ because $\lambda(t) = ke^{\rho t}$ (cf. equation 19) and k<0, and $\lambda'(t) < 0$. Hence:

(22) $$\lambda(t) = \left(y / p_x\right)^{\gamma} e^{-\rho(T_{\max}-t)} / \varphi'$$

It can be noticed that λ is a decreasing function with respect to time t and is more and more negative.

In a third step, we can now determine the low price threshold p_{xL}. If at time t = 0, $x(0) = y/p_x$ and $z(0) = 0$ are the optimal solution for the price $p_{Lx}(0)$, then it can be shown that for every time t > 0 and for this same price $p_{Lx}(0)$, $x(t) = y / p_x$ and $z(t) = 0$, will be also the optimal solution because $\lambda(t)$ is negative and decreasing for every value of t.

Indeed, consider that at time t = 0, $p_{Lx}(0)$ is the low threshold price, that is: if $p_x(0) = p_{xL}(0)$ then $x(0) = y/p_x$ and $z(0) = 0$ are the optimal solution. Then:

(23) $$\partial H / \partial x(0) \geq 0 \Rightarrow \gamma(1-\theta.p_{xL}(0))\left(y / p_{xL}(0)\right)^{\gamma-1} - \lambda(0).\alpha.p_{xL}(0) \geq 0$$

Now, as $\forall t, \lambda(t) < 0$ and $\lambda(t)$ is more and more negative, hence:

(24) $$\forall t,\ \gamma(1-\theta.p_{xL}(0))\left(y / p_{xL}(0)\right)^{\gamma-1} - \lambda(t).\alpha.p_{xL}(0) > 0$$

It follows that for $p_x = p_{xL}(0)$, if $x(t) = y/p_x$ and $z(t) = 0$ then $\partial H / \partial x(t) > 0$. It means that $x(t) = y / p_{xL}(0)$ and $z(t)$ = 0, are also the optimal solution at time t. Consequently, the organic price p_{xL} below which the consumption of the conventional food z will be all the time equal to zero (and the consumption of the organic food will be always maximum) corresponds to the

[17] It is not absurd to assume that ordinary consumer considers a simple linear relationship rather than any other more complex relationship.

organic price threshold $p_{xL}(0)$ canceling the consumption of *z* at *t* = 0 since every organic price threshold $p_{xL}(t)$ for t > 0 will be necessarily higher than the price $p_{xL}(0)$. We can now calculate this organic price p_{xL}. Reminding that:

$$\lambda(t) \le \gamma(1-\theta p_x)\left(y/p_x\right)^{\gamma-1}/\left(\alpha p_x\right), \lambda(t) = ke^{\rho t} = \left(y/p_x\right)^{\gamma} e^{-\rho(T_{\max}-t)}/\varphi'$$

Then: $$\left(y/p_x\right)^{\gamma} e^{-\rho(T_{\max}-t)}/\varphi' \le \gamma(1-\theta p_x)\left(y/p_x\right)^{\gamma-1}/\left(\alpha p_x\right)$$

(25) $$p_x \le \left(1-\alpha y e^{-\rho(T_{\max}-t)}/\left(\gamma\varphi'\right)\right)/\theta$$

Remembering that p_{XL} is defined in reference to *t* = 0, then:

(26) $$p_{xL} = p_{xL}(0) = \left(1-\alpha y e^{-\rho T_{\max}}/\left(\gamma\varphi'\right)\right)/\theta$$

Reminding that $\alpha > 0$, $\gamma > 0$, $y > 0$, $1 > \theta > 0$ and $\varphi' < 0$, then: $p_{xL} > 1$ $(= p_z)$

Determination of the high price thresholds p_{xH}

Intuitively, there would be a price threshold p_{xH} such that if $p_x > p_{xH}$, then $\forall t$, *x(t)* = 0 and *z(t)* = y. The price of the organic food is so high that the consumer can only consume the (risky) conventional food *z* throughout his life. For any time *t*, $\lambda(t)$ must be defined in such a way that the Hamiltonian $H(t)$ takes a value corresponding to the situation where the maximum is reached on the lower bound of the range of variation of x i.e. *x(t)* = 0. This implies that terminal time *T* is equal to T_{min} (the value of T_{min} will be determined downstream) and $\forall t, \partial H/\partial x \le 0$

Remind that $H = \left(x(t)(1-\theta.p_x)+\theta y\right)^{\gamma} + \lambda(t).\alpha\left(y - x(t)p_x\right)$ (cf. equation 11), and

$\partial H/\partial x = \gamma(1-\theta p_x)\left(x(t)(1-\theta.p_x)+\theta y\right)^{\gamma-1} - \lambda(t).\alpha.p_x \le 0$ (cf. equation 16).

As *x(t)* = 0, then: $\partial H/\partial x \le 0 \Rightarrow \gamma(1-\theta p_x)\left(\theta y\right)^{\gamma-1} - \lambda(t).\alpha.p_x \le 0$

(27) $$\lambda(t) \ge \gamma(1-\theta p_x)\left(\theta y\right)^{\gamma-1}/\left(\alpha p_x\right)$$

The expression of $\lambda(t)$ can then be determined from the equation (13) and from the terminal condition (14). As $\lambda(t) = ke^{\rho t}$ and $[H - \lambda\varphi']_{t=T_{\min}} = 0$, $x(T_{min}) = 0$ and $z(T_{min}) = y$

(28) $$(\theta y)^{\gamma} + \lambda(T_{\min})\alpha.y - \lambda(T_{\min})\varphi' = 0$$

By replacing $\lambda(T_{\min})$ with $ke^{\rho T_{\min}}$, we obtain:

(29) $$(\theta y)^{\gamma} + ke^{\rho T_{\min}}\alpha y - ke^{\rho T_{\min}}\varphi' = 0$$

Then,

(30) $$k = -(\theta y)^{\gamma} e^{-\rho T_{\min}} / (\alpha y - \varphi')$$

And

(31) $$\lambda(t) = ke^{\rho t} = -(\theta y)^{\gamma} e^{-\rho(T_{min} - t)} / (\alpha y - \varphi')$$

Remembering that $\varphi' < 0$, we can observe once again that $k < 0$. It follows that $\lambda(t)$ is negative and always decreasing again.

We can now determine the high price threshold p_{xH}. We can show that, if at time t = T_{min}, $x(T_{min})$ = 0 and $z(T_{min})$ = y are the optimal solution for a given price $p_{xH}(T_{min})$, then it can be shown that for every time $t < T_{min}$ and for this same price $p_{xH}(T_{min})$, $x(t) = 0$ and $z(t) = y$, will be also the optimal solution for because $\lambda(t)$ is negative and decreasing with respect to t. Indeed, consider that at time $t = T_{min}$, $p_{xH}(T_{min})$ is the high price threshold, that is: if $p_x(T_{\min}) = p_{xH}(T_{\min})$ then $x(T_{min}) = 0$ and $z(T_{min}) = y$ are the optimal solution. Then:

(32) $$\partial H / \partial x(T_{\min}) \leq 0 \Rightarrow \gamma(1 - \theta.p_{xH}(T_{\min}) / p_z)(y)^{\gamma-1} - \lambda(T_{\min}).\alpha.p_{xH}(T_{\min}) \leq 0$$

As $\forall t, \lambda(t) < 0$ and $\lambda(t)$ is more and more negative with respect to t, hence:

(33) $$\forall t < T_{\min},\ \gamma(1 - \theta.p_{xH}(T_{\min}) / p_z)(y)^{\gamma-1} - \lambda(t).\alpha.p_{xH}(T_{\min}) < 0$$

It follows that for $p_x = p_{xH}(T_{\min})$, if $x(t) = 0$ then $\partial H / \partial x(t) < 0$. It means that $x(t) = 0$ and $z(t) = y$, are also the optimal solution at time t. Consequently, the organic price p_{xH} beyond which the consumption of the organic food x will be all the time equal to zero (and the consumption of the conventional food will be always maximum) corresponds to the organic price threshold $p_{xH}(T_{\min})$ canceling the consumption of x at $t = T_{min}$.

We can now calculate this organic price p_{xH}. Reminding that:

$\lambda(t) \geq \gamma(1-\theta p_x)(\theta y)^{\gamma-1} / (\alpha p_x)$ and $\lambda(t) = ke^{\rho t} = -(\theta y)^{\gamma} e^{-\rho(T_{\min}-t)} / (\alpha y - \varphi')$

Then:

$$(34) \qquad -(\theta y)^{\gamma} e^{-\rho(T_{\min}-t)} / (\alpha y - \varphi') \geq \gamma(1-\theta p_x)(\theta y)^{\gamma-1} / (\alpha p_x)$$

Thus, in order to obtain $\forall t, x(t) = 0$, it is sufficient that the relation (27) $\lambda(t) \geq \gamma(1-\theta p_x)(\theta y)^{\gamma-1} / (\alpha p_x)$ is verified at time $t = T_{min}$ to be verified for all $t \in [0; T_{\min}]$.

Thus: $-(\theta y)^{\gamma} e^{-\rho(T_{\min}-t)} / (\alpha y - \varphi') \geq \gamma(1-\theta p_x)(\theta y)^{\gamma-1} / (\alpha p_x)$ reduces to:

$-(\theta y)^{\gamma} / (\alpha y - \varphi') \geq \gamma(1-\theta p_x)(\theta y)^{\gamma-1} / (\alpha p_x)$

$p_x \left(1 - \alpha y / (\gamma(\alpha y - \varphi'))\right) \geq 1/\theta$

then $p_x \geq \dfrac{1}{\theta} \times \dfrac{1}{1 - \alpha y / (\gamma(\alpha y - \varphi'))}$ if $\gamma(\alpha y - \varphi') > \alpha y$

And finally, the high price threshold is:

$$(35) \qquad p_{xH} = \frac{1}{\theta} \times \frac{1}{1 - \alpha y / (\gamma(\alpha y - \varphi'))} \quad \text{if } \gamma(\alpha y - \varphi') > \alpha y$$

If $\gamma(\alpha y - \varphi') < \alpha y$ then $p_x \leq -\dfrac{1}{\theta} \times \dfrac{1}{1 - \alpha y / (\gamma(\alpha y - \varphi'))}$. The direction of this inequality is contradictory to the very notion of p_{xH}, reminding that p_{xH} was defined as follows: if $p_x > p_{xH}$, then $\forall t$, $x(t) = 0$ and $z(t) = y$ i.e. the price of the organic food is so high that the consumer can only consume the conventional food z throughout his life. Consequently, the existence of a high price threshold p_{xH} for the organic food above which the consumer will consume only conventional food throughout his life, exists only when. $\gamma(\alpha y - \varphi') > \alpha y$

<u>Appendix B:</u> Partial derivatives of the price thresholds and of their associated WTP a price premium for organic foods

Reminding that $\alpha > 0,\ y > 0,\ 0 < \gamma < 1,\ \varphi' < 0$, we obtain for p_{xH} and for WTP $_{org=100\%}$:

(36) $\partial p_{xL} / \partial \alpha = -\frac{y}{\theta\gamma\varphi'} e^{-\rho T_{MAX}} > 0$ and $\partial WTP_{org=100\%} / \partial \alpha > 0$

(37) $\partial p_{xL} / \partial \varphi' = \frac{\alpha}{\gamma\theta} \frac{y}{(\varphi')^2} e^{-\rho T_{MAX}} > 0$ and $\partial WTP_{org=100\%} / \partial \varphi' > 0$

(38) $\partial p_{xL} / \partial \theta = -\left(1 - \alpha y e^{-\rho T_{\max}} / (\gamma\varphi')\right) / \theta^2 < 0$ and $\partial WTP_{org=100\%} / \partial \theta < 0$

(39) $\partial p_{xL} / \partial y = -\alpha e^{-\rho T_{\max}} / (\gamma\varphi') / \theta > 0$ and $\partial WTP_{org=100\%} / \partial y > 0$

(40) $\partial p_{xL} / \partial T_{MAX} = \frac{\alpha\rho y}{\theta\gamma\varphi'} e^{-\rho T_{MAX}} < 0$ and $\partial WTP_{org=100\%} / \partial T_{MAX} < 0$

(41) $\partial p_{xL} / \partial \rho = \frac{\alpha y T_{Max}}{\theta\gamma\varphi'} e^{-\rho T_{Max}} < 0$ and $\partial WTP_{org=100\%} / \partial \rho < 0$

(42) $\partial p_{H} / \partial \gamma = \frac{\alpha y}{\theta\gamma^2\varphi'} e^{-\rho T_{MAX}} < 0$ and $\partial WTP_{org=100\%} / \partial \gamma < 0$

Concerning p_{xH} and $WTP_{org>0\%}$ we obtain for:

(43) $\partial p_{xH} / \partial \alpha = -\frac{\frac{y^2\alpha}{\gamma(y\alpha-\varphi')^2} - \frac{y}{\gamma(y\alpha-\varphi')}}{\theta(1-\frac{y\alpha}{\gamma(y\alpha-\varphi')})^2} > 0$ and $\partial WTP_{org>0\%} / \partial \alpha > 0$

(44) $\partial p_{xH} / \partial \varphi' = \frac{y\alpha}{\gamma\theta(1-\frac{y\alpha}{\gamma(y\alpha-\varphi')})^2 (y\alpha-\varphi')^2} > 0$ and $\partial WTP_{org>0\%} / \partial \varphi' > 0$

(45) $\partial p_{xH} / \partial \theta = -1/\theta^2 \left(1 - \frac{y\alpha}{\gamma(y\alpha-\varphi')}\right) < 0$ and $\partial WTP_{org>0\%} / \partial \theta < 0$

(46) $\partial p_{xH} / \partial y = -\frac{\frac{y\alpha^2}{\gamma(y\alpha-\varphi')^2} - \frac{\alpha}{\gamma(y\alpha-\varphi')}}{\theta(1-\frac{y\alpha}{\gamma(y\alpha-\varphi')})^2} > 0$ and $\partial WTP_{org>0\%} / \partial y > 0$

(47) $\partial p_{xH} / \partial T = 0$ and $\partial WTP_{org>0\%} / \partial T = 0$

(48) $\partial p_{xH} / \partial \rho = 0$ and $\partial WTP_{org>0\%} / \partial \rho = 0$

(49) $\partial p_{xH} / \partial \gamma = -\dfrac{y\alpha}{\gamma^2 \theta (1 - \dfrac{y\alpha}{\gamma(y\alpha - \varphi')})^2 (y\alpha - \varphi')} < 0$ and $\partial WTP_{org>0\%} / \partial \gamma < 0$

Appendix C:

In the presence of a combination between *z* and *x*, quantity *x(t)* corresponds to an optimal interior solution obtained from the condition:

$\partial H / \partial x = 0$ i.e. $\partial H / \partial x = \gamma(1-\theta p_x)\left(x(t)(1-\theta.p_x)+\theta y\right)^{\gamma-1} - \lambda(t).\alpha.p_x = 0$

Hence:

$$(50) \qquad x(t) = \left(\left[\alpha\lambda(t)p_x / (\gamma(1-\theta p_x))\right]^{\frac{1}{\gamma-1}} - \theta y \right) / (1-\theta p_x)$$

From the terminal condition (14): $[H - \lambda\varphi']_{t=T} = 0$, we know that:

$$\lambda(t) = k \times e^{\rho t} = -\left(\theta y + (1-\theta p_x)x(T)\right)^{\gamma} e^{-\rho(T-t)} / \left(\alpha(y - x(T)p_x) - \varphi'\right)$$

Then λ is negative again and it is a decreasing function with respect to time t.

We obtain:

$$(51) \quad x(t) = \frac{\left[\dfrac{-\alpha p_x\left(\theta y + (1-\theta p_x)x(T)\right)^{\gamma} e^{-\rho(T-t)}}{\left(\gamma(1-\theta p_x)\left(\alpha(y - x(T)p_x) - \varphi'\right)\right)}\right]^{\frac{1}{\gamma-1}} - \theta y}{(1-\theta p_x)}$$

It follows that *x(t)* increases with time. Thus, for $p_{xL} < p_x < p_{xH}$, the consumer will start by consuming a certain quantity of conventional food and then he will reduce his consumption of conventional food in favour of organic food, but never the reverse. We observe that the consumption *x* at time *t* depends particularly on the terminal time *T*. This terminal time *T* depends on the toxic residue stock *N* and this stock depends on the path consumption of *x* (and *z*) over time. Therefore, because of this circular relationship between *x(t)* and *T*, there is no simple analytical solution, particularly concerning the switching time t_s when $z(t_s)$ becomes null.

Appendix D: Life expectancy associated with the only conventional food consumption throughout life

Remind that T_{max} is the maximum life expectancy when no conventional food is consumed, and $\dot{N}(t) = \alpha z(t)$ (cf. equation 3). If, for simplicity, we presume that the consumer considers a linear relationship between terminal time T and the stock of toxic residue, then:

(52) $$T = \Phi(N_T) = T_{Max} - \beta N(T) = T_{Max} + N(T)/\varphi'$$

(53) $$dN = \alpha z(t)\, dt \Rightarrow \int_{N(0)}^{N(T)} dN = \alpha \int_0^T z(t) dt$$

Since consumer eats only conventional food throughout his life i.e. $\forall t, z(t) = y / p_z = Cste$, it follows that:

(54) $$\int_{N(0)}^{N(T)} dN = \alpha y / p_z \int_0^T dt \Rightarrow \left[N(t)\right]_0^T = \alpha y / p_z \left[t\right]_0^T = \left(\alpha y / p_z\right) T$$

Then: $N(T) = N(0) + \left(\alpha y / p_z\right) T$

By using equation (52), we obtain: $T = T_{Max} + \left[N(0) + \left(\alpha y / p_z\right) T\right] / \varphi'$

Then:

(55) $T_{Min} = \left(T_{Max} + N(0)/\varphi'\right) / \left(1 - \alpha y / (p_z \varphi')\right)$, since it is the worst situation in terms of life expectancy.

Then:

(56) $$T_{Min} = \left(T_{Max} + N(0)/\varphi'\right) / \left(1 - \alpha y / (p_z \varphi')\right)$$