How can health concerns improve environmental public good provision through labels?

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Abstract

This paper deals with the environmental performance of labeling strategies promoting an agricultural commodity characterised by the joint and complementary provision of an environmental public good and a private characteristic such as health benefits. In a theoretical analysis, we explore different market settings with an eco-label, health label, or a label promoting both health and the environment to see how the degree of information given to homogeneous consumers on the public and private characteristics affects public good provision. We show that when consumers only have access to partial information on one of the two complementary characteristics (eco-label or health label), public good provision is higher through a health label in most situations. An eco-label leads to higher provision in a small market if consumers' preferences for the environment are higher than for health. We prove that in most situations, public good provision increases when the label promotes both characteristics rather than one (full information). The extent of this increase depends on consumers' preferences and the market size. The public good remains underprovided in all market settings from the perspective of a social planner. However, under certain conditions, a health label and a health and environment label lead to the optimal provision of public good from the perspective of an environmental agency.

Keywords: environmental services, joint production, market differentiation, impure public good model

Introduction

As we face a worldwide climate emergency and critical environmental challenges, the pace of the transition towards a more sustainable economy is too slow. Yet, the European Union (EU) committed itself to ambitious goals. In 2019, the European Commission set the target of carbon neutrality by 2050 and launched the European Green Deal for new climate and environmental policies (European Commission, 2020a, 2019). Agriculture contributes to a large share of EU greenhouse gas emissions, and the dominant farming systems are important factors of the biodiversity sharp decline and deterioration of air, water and soil quality over the last decades. Up to now, the Common Agricultural Policy (CAP) framework and budget allocation was not aligned with achieving environmental and climate targets (Dupraz and Guyomard, 2019).

The Green Deal's ambition regarding food and agriculture is to combine climate, biodiversity and health objectives. Hence, to complement the CAP and in line with the Green Deal is the new European Farm to Fork Strategy that could guide and support transformation paths towards more sustainable agricultural practices. It contains quantitative targets for 2030 for the agricultural and food sector: a reduction of fertiliser use by 20%, chemical pesticides use by 50% and antimicrobials sales by 50%, and 25% of agricultural land dedicated to organic farming. The Farm to Fork Strategy also comprises actions for transforming European food systems, including the development of a food-labelling framework to promote healthy and environment-friendly food consumption (European Commission, 2020b).

Research has emphasized that environment-friendly food products are often (perceived) healthier and more nutritious. Promoting this complementarity in new “sustainability” labels should capture both consumers’ willingness to pay for the environment *and* for joint intrinsic quality product characteristics.

Labels are expected to stimulate both the demand (information on environmental, nutritional and health attributes) and supply (price premium) of sustainable food products. Informing consumers on the sustainability of their food choices to boost behavioural changes is a way to increase the role of the market in agri-environmental and climate public good provision and to partly compensate public policies insufficiencies. Successful labelling initiatives could also help overcoming public budget constraints and reduce the cost of subsidies.

Since the early 1990s, survey evidences suggest that consumers care about the environment and are willing to pay a higher price for a product, including food, that generates less environmental harm (Cason and Gangadharan, 2002; Moon et al., 2002). In a review of studies from the 1990s, (Galarraga Gallastegui, 2002) reports that consumers were willing to pay an eco-premium ranging from 1 to 5% up to 25% of the initial price for greener products. Even if some private food eco-labels (Carbon Trust, Bee Friendly, pasture milk, dolphin-safe tuna, sustainable fishery…) were developed over time to capture this willingness-to-pay, food products are not eligible for the official French or European ecolabel.

In parallel to these eco-labels, other types of label also promote the nutritional quality of food products from environmentally friendly agricultural practices (no use of pesticides, hormones or antibiotics). Indeed, health concerns are raised towards similar agricultural practices than biodiversity concerns, in particular the use of chemical products. A product is considered safe to consume if it does not “give food related diseases, does not contain additives or chemical residues that are detrimental to health, the product is old or provide any other health risk through consumption” (Romstad et al., 2000).

Jointness between environmental, nutritional, health and taste characteristics is a topic of many on-going debates (Bougherara and Combris, 2009). While some complementarities are based on consumers’ perceptions without scientific proof, others have been extensively studied and documented. It has been scientifically proven that dairy cows fed with more grass fodders or extruded linseed both produce milk with higher omega-3 content, that is recommended for a healthy diet (Weill et al., 2002), and decrease their enteric methane emissions (Weill et al., 2009). There is also more and more evidence of the positive impact of organic agriculture on biodiversity (Tuomisto et al., 2012). But while studies investigating consumers attitudes and believes regarding its impact on health are numerous (see, amongst others, Aldanondo-Ochoa and Almansa-Sáez, 2009; Hughner et al., 2007; Kushwah et al., 2019; Loureiro et al., 2001; Schifferstein and Ophuist, 1998), a scientific consensus is still lacking (Mie et al., 2017). The example of the organic label shows that, based on scientific evidences or perceptions, information on complementary private benefits could be effective to attract additional consumers to contribute to environmental public good provision (Grolleau et al., 2009).

In this paper, we explore the opportunities raised by the joint provision of private health and public environmental benefits that can exist with food commodities produced using environmentally friendly agricultural practices. Developing sustainability labels targeting nutrition, health and environmental aspects to capture a high willingness to pay for environmental public goods will require acquiring more knowledge about the scientific and natural processes underlying joint production. Such research are long and costly. It is therefore relevant to theoretically assess the potential of such labels to improve the delivery of environmental public goods compared with current quality labels and eco-labels.

We start with a description of our theoretical framework, inspired by the impure public good model of Kötchen (2005). In a second part, we present the optimal conditions that characterize this economy from a social planner's point of view, and from an environmental agency's point of view. In the third and fourth sections, we derive the different market equilibrium conditions according to the level of information available to the consumer, when an environment-friendly product is labelled for its private characteristic (health label), public characteristic (ecolabel), or both (health and environment label). We then compare the different market settings in terms of environmental public good provision and distance to social and environmental optimality.

1. Preliminaries

We start from the theoretical framework developed by (Kötchen, 2005), which considers that the utility function of consumers depends on the characteristics of the goods rather than on the goods themselves. This approach is widely used to model consumer behaviour (Gorman, 1980; Lancaster, 1966), particularly in models of impure public goods (Cornes and Sandler, 1994, 1984). In this analytical framework, green products are impure public goods, which generate both a private characteristic and a public characteristic (the public good). Kötchen (2005) considers that the consumer has a choice between two goods, a conventionally produced good, which generates a private characteristic, and a green good produced from environmentally friendly practices, which generates the same private characteristic and a public characteristic (the improvement of the quality of the environment). His approach has the advantage of providing substitutes for the green product. The consumer can obtain the private characteristic by buying the conventional product or the green product, and the public characteristic by buying the green product or by making a direct donation to the corresponding environmental cause.

Following Kötchen's work, we propose to consider two food products, a conventional good c and a green good g. These two goods generate the same private characteristic X, corresponding to the need to feed oneself. The green good generates, together with the private characteristic X, two additional characteristics, a public characteristic Y and another private characteristic H. Since the good g is produced by more environmentally friendly agricultural practices, it is assumed that its production and consumption allow for the improvement of the quality of the environment, corresponding to the public good Y. The originality of our approach is to take into account the fact that this green good also has nutritional qualities superior to the conventional good c, or in other words, that the consumption of g improves the health of its consumer, that is a private characteristic H.

The question we wish to answer is whether the information given to consumers on food products impacts the provision of environmental public goods. More specifically, we want to know if the valorisation of products for their nutritional qualities or for their benefits for health is an approach to be encouraged in the framework of environmental policies. To do so, we compare three markets (Table 1), which differ only by the information given to consumers on the products they consume. This information will modify their consumption choices according to their preferences, and potentially influence the provision of environmental public goods.

Table 1. The different models compared in the paper.

Market settings	**Goods**	**Characteristics**
Eco-label	good c	private characteristic X
	good g	private characteristic X and public characteristic Y
Health label	good c	private characteristic X
	good g	private characteristics X and H
Health and environment label	good c	private characteristic X
	good g	private characteristics X and H, and public characteristic Y

In the first market, consumers know that good g is produced using environmentally friendly practices. They have no a priori information its superior nutritional quality. The second market offers a conventional product and a product with a label guaranteeing a healthy diet. Consumers know that the good g has superior nutritional qualities compared with good c, but they have no information on the environmental impact of the agricultural practices associated with their production. In the third market, we assume that the information is complete for consumers, thanks to a label that identifies both the environmental and nutritional qualities of product g.

We consider $i = 1, \dots, I$ consumers. Each individual's preferences are represented by a strictly increasing and strictly quasi-concave utility function $U^i(X^i, Y, H^i)$, where X^i and H^i are individual i's private consumption of characteristics X (food product) and H (nutritional quality), and Y (environmental quality) is the provision of the public characteristic such that $Y = \sum_i^I Y^i$, where Y^i is individual i's private contribution. Each individual takes the contribution of others for the public characteristic as exogenous, such that $Y = Y^i + \sum_{j \neq i}^I Y^j = Y^i + Y^{-i}$.

Each individual can allocate his wealth r^i to purchase a quantity c^i of conventional good c at price p_c and a quantity g^i of impure public good g at price p_g, such that $p_c c^i + p_g g^i \leq r^i$. It is assumed that $p_g > p_c$ in order to ensure the viability of the conventional good on the market. It implies that buying the good c is the least-cost way to obtain the private characteristic X. The agricultural technologies are such that buying one unit of c leads to the provision of one unit of X, while buying one unit of g leads to the provision of one unit of X, α units of H and β units of Y, with $\alpha > 0$ and $\beta > 0$. The relation between the quantities of goods c^i and g^i and the consumption of the characteristics X^i, H^i and Y^i is then defined by $X^i = c^i + g^i$, $H^i = \alpha g^i$

and $Y^i = \beta g^i$. Given these relationships, the budget constraints can be written in such a way that the characteristics appear (1.a) and (1.b).

$$p_c X^i + \left(\frac{p_g - p_c}{\alpha}\right) H^i \leq r^i \qquad (1.a)$$

$$p_c X^i + \frac{(p_g - p_c)}{\beta} Y \leq r^i + \frac{(p_g - p_c)}{\beta} Y^{-i} \qquad (1.b)$$

On the production side of the economy, we consider one representative producer. He produces the two goods c and g, subject to technological constraints represented by the strictly concave production functions $c = c(z_c)$ and $g = g(z_g)$, with z_c and z_g inputs used in the production process. The input uses are constrained such that $z_c + z_g = 1$. These products are sold at prices p_c and p_g. Since $p_g > p_c$, the marginal cost of producing good g must be greater than the marginal cost of producing good c to prevent the producer from allocating all the input to the production of the good g.

2. Optimal regulation of our economy

In this section, we describe the optimal conditions characterizing our economy from a social planner's point of view, and from an environmental agency's point of view. The social planner seeks a Pareto optimal outcome by taking into account both the nutritional and environmental characteristics of the food products. In contrast, we assume that the environmental agency seeks to optimize the provision of the public good Y, for instance by subsidising the production of g, but ignores the increase of consumer's utility derived from the consumption of the health characteristic H.

2.1. Social optimum

If a social planner had the ability to choose the optimal level of public good provision, he would maximize social welfare W and solve the following problem:

$$\max_{X^i, H^i, Y, z_c} \mathrm{W} = \sum_i U^i(X^i, Y, H^i) \qquad (2)$$

subject to: $\sum_i X^i = c(z_c) + g(1 - z_c), Y = \beta g(1 - z_c), \sum_i H^i = \alpha g(1 - z_c)$

Note that the maximum of the welfare function subject to the possibilities constraint is a Pareto optimum. Taking first-order conditions with respect to X^i, H^i, Y and z_c (see more details of the derivation in Appendix A), we obtain the Bowen-Lindahl-Samuelson condition, which characterises the Pareto optimal allocation:

$$\beta \sum_i \frac{\delta U^i / \delta Y_p}{\delta U^i / \delta X_p^i} + \alpha \frac{\delta U^i / \delta H_p^i}{\delta U^i / \delta X_p^i} = \left(\frac{\delta c(\, z_c) / \delta z_c}{\delta g(\, 1 - z_c) / \delta z_c} - 1\right) \qquad (3a)$$

To facilitate the comparison between the different market equilibria derived in the following sections, and the optimality conditions, we assume a functional form to the utility function, which is $U^i(X^i, Y, H^i) = a \ln X^i + b \ln Y + c \ln H^i$. The condition for the socially optimal amount of public good provision Y_p becomes:

$$\frac{X_p^i}{Y_p} = \frac{1}{\beta} \frac{a}{Ib + Ic} \left(\frac{\delta c(\, z_c)/\delta z_c}{\delta g(\, 1 - z_c)/\delta z_c} - 1 \right) \tag{3b}$$

2.2. Environmental agency's optimum

If an environmental agency had the ability to choose the optimal level of public good provision, it would only consider food production X and the public good Y jointly produced with g, and solve the following problem:

$$\max_{X^i, Y, z_c} \; \mathrm{W} = \sum\nolimits_i U^i(X^i, Y, H^i) \tag{5}$$

subject to: $\sum_i X^i = c(z_c) + g(1 - z_c), Y = \beta g(1 - z_c)$,

The corresponding private consumption H^i is obtained from $\sum_i H^i = \alpha g(1 - z_c^*)$ when z_c^* solves (5). The Bowen-Lindahl-Samuelson condition for the optimal provision Y_{ea} of the public good is defined by:

$$\sum_i \frac{\delta U^i/\delta Y_{ea}}{\delta U^i/\delta X_{ea}^i} = \frac{1}{\beta} \left(\frac{\delta c(\, z_c)/\delta z_c}{\delta g(\, 1 - z_c)/\delta z_c} - 1 \right) \tag{6a}$$

The sum of the marginal rates of substitution between public and private goods must be equal to the marginal rate of transformation between public and private goods (see more details in Appendix B). Note that this condition is also the Pareto optimum condition associated to the model of green consumption defined by Kötchen (2005), which does not consider the private characteristic H^i.

Assuming a utility function such that $U^i(X^i, Y, H^i) = a \ln X^i + b \ln Y + c \ln H^i$, this condition becomes:

$$\frac{X_{ea}^i}{Y_{ea}} = \frac{1}{\beta} \frac{a}{Ib} \left(\frac{\delta c(\, z_c)/\delta z_c}{\delta g(\, 1 - z_c)/\delta z_c} - 1 \right) \tag{6b}$$

3. Equilibria under incomplete information

In this section, we derive the different market equilibria according to the level of consumer information on the products, and compare these equilibria to the regulators' optima defined in the previous section.

3.1. Eco-label

In the first market setting, we assume that consumers know that good g is produced using environmentally friendly practices. But they have no a priori information on the nutritional qualities of the product. Each consumer i maximises his utility function $U^i(X^i, Y, H^i)$ under his budget constraint (1.b). The derivation of this model is detailed in Appendix D1. The first order conditions are derived only in relation to the product characteristics known by the consumers, X^i and Y. These conditions, associated to the producer's equilibrium (defined in Appendix C) lead to the following market equilibrium condition:

$$\frac{\delta U^i/\delta Y_e^i}{\delta U^i/\delta X_e^i} = \frac{1}{\beta}\left(\frac{\delta c(\,z_c)/\delta z_c}{\delta g(\,1 - z_c)/\delta z_c} - 1\right) \qquad (7a)$$

These conditions correspond to market equilibrium of the green consumption model of Kötchen (2005). Each agent does not take into account the fact that the public good provision that he finances also benefits other agents. Agent i contributes to the provision of the public good until the marginal cost in private good is equal to its marginal rate of substitution.

Assuming a utility function such that $U^i(X^i, Y, H^i) = a \ln X^i + b \ln Y + c \ln H^i$, the market equilibrium condition of the eco-label leading to the public good provision level Y_e becomes:

$$\frac{X_e^i}{Y_e} = \frac{1}{\beta}\frac{a}{b}\left(\frac{\delta c(\,z_c)/\delta z_c}{\delta g(\,1 - z_c)/\delta z_c} - 1\right) \qquad (7b)$$

Consumers as a whole contribute less to the public good than what would be desirable to achieve Pareto optimality or the environmental agency's optimality.

3.2.Health label

In this second market setting, we assume that consumers know that good g has superior nutritional qualities compared with good c but have no information on the environmental impact of the agricultural practices associated with the production process. Each consumer i maximises his utility function $U^i(X^i, Y, H^i)$ under his budget constraint (1.a). The first order conditions are derived in relation to the product characteristics known by the consumers, X^i and H^i. The derivation of this model is detailed in Appendix D2. These conditions, associated to the producer's equilibrium, lead to the following market equilibrium condition:

$$\frac{\delta U^i/\delta H_h^i}{\delta U^i/\delta X_h^i} = \frac{1}{\alpha}\left(\frac{\delta c(\,z_c)/\delta z_c}{\delta g(\,1 - z_c)/\delta z_c} - 1\right) \qquad (8a)$$

Even if consumers do not have information on the positive environmental externality associated with their consumption, the public good Y is provided jointly with the production of good g. Assuming a utility function such that $U^i(X^i, Y, H^i) = a \ln X^i + b \ln Y + c \ln H^i$, the market equilibrium condition of the health label leading to the public good provision level Y_h becomes:

$$\frac{X_h^i}{Y_h} = \frac{1}{\beta}\frac{a}{Ic}\left(\frac{\delta c(\, z_c)/\delta z_c}{\delta g(\, 1 - z_c)/\delta z_c} - 1\right) \qquad (8b)$$

As for the eco-label model, the market equilibrium does not correspond to a Pareto optimal allocation. Nevertheless, recalling the environmental agency optimum (6b), the market equilibrium of the health label leads to the optimal public good provision from the perspective of an environmental regulator if consumer preferences for health are equal to preferences for the environment ($c = b$). Moreover, we can easily show that the level of public good provision Y_h increases with c, and the provision of environmental public good exceeds the optimal level Y_{ea} when $c \geq b$.

4. Equilibrium under complete information

This section presents the market equilibrium conditions under complete information, thanks to a label that identifies the environmental and nutritional qualities of product g (health and environment label). The levels of public good provision under the three market settings with different degree of information (eco-label, health label and health and environment label) are then compared.

4.1. Environment and health label

Similarly, to the previous market settings, each consumer i maximises his utility function $U^i(X^i, Y, H^i)$ under his budget constraints (1.a) and (1.b). In this third case, the first order conditions are derived from the three characteristics X^i, H^i and Y, all of them being known by consumers. The derivation of this model is detailed in Appendix D3. These conditions, associated to the producer's equilibrium lead to the following market equilibrium conditions:

$$\frac{\delta U^i/\delta Y_{eh}}{\delta U^i/\delta X_{eh}^i} = \frac{1}{\beta}\left(\frac{\delta c(\, z^c)/\delta z^c}{\delta g(\, 1 - z^c)/\delta z^c} - 1\right)\left(\frac{\lambda_2}{\lambda_1 + \lambda_2}\right) \qquad (9a)$$

$$\frac{\delta U^i/\delta H_{eh}^i}{\delta U^i/\delta X_{eh}^i} = \frac{1}{\alpha}\left(\frac{\delta c(\, z^c)/\delta z^c}{\delta g(\, 1 - z^c)/\delta z^c} - 1\right)\left(\frac{\lambda_1}{\lambda_1 + \lambda_2}\right) \qquad (10a)$$

Because the consumer's maximisation problem has two budget constraints, the Lagrange multipliers λ_1 and λ_2 appear in the conditions. λ_1 corresponds to the marginal effect of individual revenue r^i on the equilibrium level of consumer utility, while λ_2 is the marginal effect of what Kötchen defines as « full-income » $r^i + \frac{1}{\beta}(p_g - p_c)Y^{-i}$ (individual revenue and environmental quality spill-ins) on the equilibrium utility level. Those shadow-costs depend on the functional form of the utility function, hence on consumer preferences.

Assuming a standard form of the utility function $U^i(X^i, Y, H^i) = a \ln X^i + b \ln Y + c \ln H^i$, the market equilibrium condition of the health and environment label leading to the public good provision level Y_{eh} becomes:

$$\frac{X_{eh}^i}{Y_{eh}} = \frac{1}{\beta} \frac{a}{(Ic+b)} \left(\frac{\delta c(\, z^c)/\delta z^c}{\delta g(\, 1 - z^c)/\delta z^c} - 1 \right) \tag{9b}$$

$$\frac{X_{eh}^i}{H_{eh}^i} = \frac{1}{\alpha} \frac{Ia}{(Ic+b)} \left(\frac{\delta c(\, z^c)/\delta z^c}{\delta g(\, 1 - z^c)/\delta z^c} - 1 \right) \tag{10b}$$

The conditions are not Pareto optimal (see demonstration in Appendix E). However, similarly to the health label case, the market equilibrium of the health and environment label leads to the optimal public good provision from the perspective of an environmental regulator if the relative consumer preferences are such that $\frac{c}{b} = 1 - \frac{1}{I}$. It suggests that the level of public good provision targeted by the environmental agency can be reached through a health and environment label even if preferences for health are lower than preferences for the environment. Moreover, we can easily show that the level of public good provision Y_{eh} increases with c, and the provision of environmental public good exceeds the optimal level Y_{ea} when $\frac{c}{b} \geq 1 - \frac{1}{I}$. The smaller the market size, the "easiest" for the environmental optimum to be reached, even if preferences for health are relatively low.

4.2. Comparison of public good provision

In this section, we compare the level of public good provision from the three types of label (eco-label, health label, health and environment label) using the consumer demand functions derived in Appendices D1, D2 and D3, still assuming a standard form of the utility function $U^i(X^i, Y, H^i) = a \ln X^i + b \ln Y + c \ln H^i$ and homogeneous consumers. As previously defined, Y_e corresponds to the equilibrium provision of public good with an eco-label, Y_h with a health label, and Y_{eh} with a health and environment label.

$$Y_e = I \frac{1}{a+b} \left(\beta b \frac{1}{p_g - p_c} r^i - (I-1) a Y^i \right) \tag{11}$$

$$Y_h = \beta\, I \frac{c}{(a+c)} \frac{1}{(p_g - p_c)} r^i \tag{12}$$

$$Y_{eh} = \beta\, \frac{I(b+Ic)}{b + I(a+c)} \frac{1}{(p_g - p_c)} r^i = \frac{I}{a+b+Ic} \left(\beta(b+Ic) \frac{1}{p_g - p_c} r^i - (I-1) a Y^i \right) \tag{13}$$

The level of public good provided from the three types of label are compared according the level of preferences parameters a, b and c, and the number of consumers I (see Table 2).

When information is incomplete and consumers only have access to information on one of the two complementary characteristics (eco-label or health label), more public good is provided through the market of a health label in most situation.

$$Y_h - Y_e = I\frac{a}{a+b}\left(\beta\frac{c-b}{a+c}\frac{1}{p_g-p_c}r^i + (I-1)Y^i\right) \tag{14}$$

A health label leads to higher provision of public good when preferences for health are higher than for the environment ($c > b$) whatever the market size, and when they are identical ($c = b$) if there is more than one consumer. If consumers have higher preferences for the environment ($c < b$), a health label will still lead to higher levels of public good if the population is bigger than a threshold S equal to $1 + \beta\frac{(b-c)}{(a+c)}\frac{1}{(p_g-p_c)}\frac{r^i}{Y^i}$ (big market). Below this threshold, an eco-label will provide more public good (small market).

Under perfect information (health and environment label), and when consumers exhibit preferences for the three characteristics ($a, b, c > 0$), the provision of public good is always higher than the market outcomes of an eco-label or a health label.

$$Y_{eh} = \frac{(b+Ic)}{b+I(a+c)}\frac{(a+c)}{c}Y_h = \left(\frac{ab}{bc+Ica+Icc}+1\right)Y_h \tag{15}$$

$$Y_{eh} = \frac{(b+Ic)}{(a+b+Ic)}\frac{(a+b)}{b}Y_e = \left(\frac{Iac}{ab+b^2+Ibc}+1\right)Y_e \tag{16}$$

Because the general model with no willingness to pay for the environment is equivalent to the health label model, the level of provision is the same when consumers have no preferences for the environment ($b = 0$). The reasoning is the same when consumers have no preferences for health ($c = 0$). Provision levels are identical with the three types of labels when consumers have no preferences for the private characteristic X^i ($a = 0$), as consumers would spend all their income on good g in the three markets settings.

Table 2. Comparison of public good provision[1]

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<tr><th colspan="2"></th><th>$I=1$</th><th>$I<S$</th><th>$I=S$</th><th>$I>S$</th></tr>
<tr><td>$a=0$</td><td></td><td colspan="4">$Y_{eh}=Y_h=Y_e$</td></tr>
<tr><td rowspan="6">$a>0$</td><td>$0=b=c$</td><td colspan="4">$Y_{eh}=Y_h=Y_e=0$</td></tr>
<tr><td>$0=b<c$</td><td colspan="4">$Y_{eh}=Y_h>Y_e=0$</td></tr>
<tr><td>$0<b<c$</td><td colspan="4">$Y_{eh}>Y_h>Y_e$</td></tr>
<tr><td>$0<b=c$</td><td>$Y_{eh}>Y_h=Y_e$</td><td colspan="3">$Y_{eh}>Y_h>Y_e$</td></tr>
<tr><td>$b>c>0$</td><td colspan="2">$Y_{eh}>Y_e>Y_h$</td><td>$Y_{eh}>Y_h=Y_e$</td><td>$Y_{eh}>Y_h>Y_e$</td></tr>
<tr><td>$b>c=0$</td><td colspan="4">$Y_{eh}=Y_e>Y_h=0$</td></tr>
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Our analysis shows that preference parameters influence market outcomes. This is an expected result as the impact of individual preferences has already been highlighted in numerous studies on consumers demand and the efficiency of differentiated markets (Aldanondo-Ochoa and Almansa-Sáez, 2009; Brécard et al., 2012, 2009; Lusk et al., 2007; Moon et al., 2002; Schifferstein and Ophuist, 1998). This literature also emphasizes that consumer preferences are heterogeneous. Papers suggest that consumers with high preferences for the environment have different socio-economic characteristics than those with high preferences for health. On the one hand, willingness to pay for environmental attributes increases with income, altruism, education and environmental awareness, and decreases with age (Aldanondo-Ochoa and Almansa-Sáez, 2009; Brécard et al., 2009; Lusk et al., 2007; Moon et al., 2002). On the other hand, willingness to pay for health attributes decreases with education and increases with age (Brécard et al., 2012; Govindasamy and Italia, 1999; Schifferstein and Ophuist, 1998). In our theoretical analysis, we do not account for this heterogeneity although we know it exists. We focus on the market outcome considering the behaviour of a consumer representative of the average preferences of the population. Adding heterogeneity might bring additional nuancing elements but would not impact the overall results and conclusions.

Empirical evidence suggest that when it comes to food, consumers preferences for health, a private characteristic, tend to be higher than for environmental quality (Aldanondo-Ochoa and Almansa-Sáez, 2009; Rudd et al., 2011). It suggests that $b<c$ in most actual market settings and there is a real opportunity for environmental public good provision in demonstrating and providing information on the complementary health benefits of environment-friendly food

[1] With $S = 1 + \beta \frac{(b-c)}{(a+c)} \frac{1}{(p_g - p_c)} \frac{r^i}{Y^i}$.

consumption. Similarly to (Grolleau et al., 2009), we find that environmental quality is improved more when both egoistic and altruistic motives are captured rather than only altruistic ones. These results are also in line with some empirical studies on consumers' willingness to pay according to the information provided on products. For instance, (Loureiro et al., 2001) investigated consumers behaviour when choosing between organic, eco-labelled or conventional apples with identical prices. They showed that consumers tend to purchase organic apples (health and environment label) rather than the alternatives when they have both health and environmental concerns.

We also show that the market size (number of consumers) affects the relative environmental performance of the types of label. One can notice the bigger the market, the smaller the difference of provision between the health and environment label and the health label. It suggests that adding an information on the joint production of a public characteristic on a label that initially promoted a private characteristic has more environmental impact in a small market. By contrast, the smaller the market the smaller the difference of provision between the health and environment label and the eco-label. Adding an information on the joint production of a private characteristic to an eco-label has more environmental impact in a big market. So far, the interaction between market size and information available to consumers has received little attention in the literature. Our theoretical findings bring new elements to tackle this gap.

5. Concluding remarks

In this paper, we investigate the potential of markets of a healthy and environment-friendly good to contribute to the improvement of environmental public good provision. Our model applies when environment-friendly agricultural practices jointly improve the nutritional quality (or any other intrinsic characteristic) of a food product. That is when health and environmental characteristics are complementary.

The theoretical analysis provides two main results. First, when consumers only have access to partial information on one of the two complementary characteristics (eco-label or health label), only a health label leads to the optimal amount of public good provision from the perspective of an environmental agency under certain conditions. Second, providing full information on the public and private characteristics of the food product increases public good provision compared with a health label or an eco-label in most cases. The extent of this increase depends on consumers' preferences and the market size.

The European Commission recently presented its Farm to Fork strategy as part of the Green Deal with the objective of developing labels promoting both health and environment benefits. Our results suggest that from an environmental policy perspective, nutritional and health labeling is a relevant tool to increase public good provision and complement agri-environmental subsidies.

Our approach relies on several hypotheses on complementary joint production. We assume no additional cost of labelling on two characteristics rather than one. In practice, transaction costs and in particular the costs of providing, disseminating and processing information are likely to modify the market outcomes in many cases. Moreover, we consider a well-defined complementary joint production. Natural processes behind joint production are complex and often context-dependent. It might not always be technically feasible to link an agricultural commodity to a measured health and/or environmental attribute.

Nevertheless, examples of food labels based on a strict complementarity between health and environmental characteristics do exist. The French quality BBC (Bleu-Blanc-Coeur) branch is a good illustration. The BBC label was created in the early 2000s to offer consumers differentiated animal products providing nutritional benefits to human health by enriching livestock diet with sources of omega-3 fatty acids (Weill et al., 2002). This nutritional label has particularly developed in the dairy sector and represented 1% of the volume of milk collected in France in 2011 (Magrini and Duru, 2014). The omega-3 content of BBC milk is twice as high as for conventional milk (Association Bleu-Blanc-Coeur, 2008).

In parallel to the development of the BBC market, new research emerged showing that enteric methane emissions decline as ruminants' feed is enriched with unsaturated omega-3 fatty acids (Dong et al., 1997; Grainger and Beauchemin, 2011; Martin et al., 2011, 2008). Those findings led to the development of the Eco-Methane methodology for calculating enteric methane emissions per litre of milk from the fatty acid profile of milk. The equation was co-invented by teams from the animal feed manufacturing company Valorex (P. Weill and G. Chesneau) and the French National Institute for Agricultural Research INRA of Theix - Clermont (Y. Chilliard, M. Doreau and C. Martin) and received a patent in 2009 (Weill et al., 2009). The availability of new information on the positive environmental impact of the BBC nutritional approach offered new perspectives. The label now communicates on both the nutritional and environmental attributes of dairy products. Enteric methane emissions per litre of BBC milk are 12 to 15% less than per litre of conventional milk (Magrini and Duru, 2014). The nutritional and environmental quality pledges of the BBC label are scientifically validated, based on the relationship between animal diet and human nutrition on the one hand, and animal diet and enteric methane emissions on the other hand. The nutritional and environmental importance of the BBC approach has the official recognition of the French government, while the Eco-Methane methodology is recognised by the United Nations (UNFCCC, 2016).

Our theoretical analysis suggests that a health and environment label such as the BBC label would contribute more to methane emissions abatement than a dairy eco-label on the reduction of enteric methane emissions. Our theoretical results suggest that it will be even more the case as the BBC market size and health concerns regarding the consumption of dairy products increase.

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Appendix A – Social optimum

A social planner solves (A.1).

$$\max_{X^i, H^i, Y, z_c} \ \mathrm{W} = \sum_i U^i\left(X^i, Y, H^i\right) \tag{A.1}$$

subject to: $\sum_i X^i = c(z_c) + g(1 - z_c)$, $Y = \beta g(1 - z_c)$, $\sum_i H^i = \alpha g(1 - z_c)$

The first order conditions are derived from the Lagrangian function (A.2).

$$L = \sum_i U^i\left(X^i, Y, H^i\right) + \lambda_1 \left(\sum_i X^i - c(z_c) - g(1 - z_c)\right) + \lambda_2\left(Y - \beta g(1 - z_c)\right) + \lambda_3 \left(\sum_i H^i - \alpha g(1 - z_c)\right) \tag{A.2}$$

$$\frac{\delta L}{\delta X^i} = 0 \Rightarrow \frac{\delta\, U^i}{\delta X^i} - \lambda_1 = 0 \Rightarrow \frac{\delta\, U^i}{\delta X^i} = \lambda_1$$

$$\frac{\delta L}{\delta Y} = 0 \Rightarrow \sum_i \frac{\delta\, U^i}{\delta \mathrm{Y}} - \lambda_2 = 0 \Rightarrow \sum_i \frac{\delta\, U^i}{\delta \mathrm{Y}} = \lambda_2$$

$$\frac{\delta L}{\delta H^i} = 0 \Rightarrow \frac{\delta\, U^i}{\delta H^i} - \lambda_3 = 0 \Rightarrow \frac{\delta\, U^i}{\delta H^i} = \lambda_3$$

$$\frac{\delta L}{\delta z_c} = 0 \Rightarrow -\lambda_1 \frac{\delta c(z_c)}{\delta z_c} + (\lambda_1 + \beta\lambda_2 + \alpha\lambda_3) \frac{\delta g(1 - z_c)}{\delta z_c} = 0$$

$$\Rightarrow \frac{\lambda_1}{(\lambda_1 + \beta\lambda_2 + \alpha\lambda_3)} = \frac{\delta g(1 - z_c)}{\delta z_c} \Big/ \frac{\delta c(z_c)}{\delta z_c}$$

Leading to the Pareto optimality condition (A.3).

$$\beta \sum_i \frac{\delta U^i / \delta Y_p}{\delta U^i / \delta X_p^i} + \alpha \frac{\delta U^i / \delta H_p^i}{\delta U^i / \delta X_p^i} = \left(\frac{\delta c(\, z^c) / \delta z^c}{\delta g(\, 1 - z^c) / \delta z^c} - 1\right) \tag{A.3}$$

Appendix B – Environmental agency's optimum

An environmental agency solves (B.1).

$$\max \mathrm{W} = \sum_i U^i\left(X^i, Y, H^i\right) \tag{B.1}$$

subject to: $\sum_i X^i = c(z_c) + g(1 - z_c), Y = \beta g(1 - z_c)$

The first order conditions are derived from the Lagrangian function (B.2).

$$L = \sum_i U^i\left(X^i, Y, H^i\right) + \lambda_1\left(\sum_i X^i - c(z_c) - g(1 - z_c)\right) + \lambda_2\left(Y - \beta g(1 - z_c)\right) \tag{B.2}$$

$$\frac{\delta L}{\delta X^i} = 0 \Rightarrow \frac{\delta\, U^i}{\delta X^i} - \lambda_1 = 0 \Rightarrow \frac{\delta U^i}{\delta X^i} = \lambda_1$$

$$\frac{\delta L}{\delta Y} = 0 \Rightarrow \sum_i \frac{\delta\, U^i}{\delta \mathrm{Y}} - \lambda_2 = 0 \Rightarrow \sum_i \frac{\delta U^i}{\delta \mathrm{Y}} = \lambda_2$$

$$\frac{\delta L}{\delta z_c} = 0 \Rightarrow -\lambda_1 \frac{\delta c(z_c)}{\delta z_c} + (\lambda_1 + \beta\lambda_2)\frac{\delta g(1 - z_c)}{\delta z_c} = 0 \Rightarrow \frac{\lambda_1}{(\lambda_1 + \beta\lambda_2)} = \frac{\delta g(1 - z_c)}{\delta z_c} \Big/ \frac{\delta c(z_c)}{\delta z_c}$$

Leading to the environmental agency optimality condition (B.3).

$$\sum_i \frac{\delta U^i/\delta Y_{ea}}{\delta U^i/\delta X^i_{ea}} = \frac{1}{\beta}\left(\frac{\delta c(\,z^c)/\delta z^c}{\delta g(\,1 - z^c)/\delta z^c} - 1\right) \tag{B.3}$$

Appendix C – Producer equilibrium

The producer solves (C.1).

$$\max_{z_c} \Pi = p_c c(z_c) + p_g g(1 - z_c) \qquad (C.1)$$

Solving for the first order condition.

$$\frac{\delta \Pi}{\delta z_c} = p_c \frac{\delta c(z_c)}{\delta z_c} - p_g \frac{\delta g(1 - z_c)}{\delta z_c} = 0$$

We obtain the producer equilibrium condition (C.2).

$$\frac{p_g}{p_c} = \frac{\delta c(z_c)/\delta z_c}{\delta g(1 - z_c)/\delta z_c} \qquad (C.2)$$

Appendix D1 – Consumer equilibrium – eco-label

The consumers have no information on the intrinsic characteristics of good g and there is no demand for H. An individual solves (D.1.1.a), a maximisation problem that can alternatively be written (D.1.1.b) such that the characteristics appear in the budget constraint.

$$\max_{c^i,g^i} U^i(X^i, Y, H^i) \qquad (D.1.1.a)$$

s.t. $X^i = c^i + g^i, Y^i = \beta g^i, \ Y = Y^i + Y^{-i}, \ p_c c^i + p_g g^i \leq r^i$

$$\max_{X^i,Y} U^i(X^i, Y, H^i) \qquad (D.1.1.b)$$

s.t. $p_c X^i + \frac{1}{\beta}(p_g - p_c)Y \leq r^i + \frac{1}{\beta}(p_g - p_c)Y^{-i}$

Deriving the Lagrangian function of the problem, we obtain the equilibrium condition (D.1.2).

$$L = U^i(X^i, Y, H^i) + \lambda\left(r^i + \frac{1}{\beta}(p_g - p_c)Y^{-i} - p_c X^i - \frac{1}{\beta}(p_g - p_c)Y\right)$$

$$\frac{\delta L}{\delta X^i} = \frac{\delta U^i}{\delta X^i} - \lambda p_c = 0$$

$$\frac{\delta L}{\delta Y} = \frac{\delta U^i}{\delta Y} - \frac{\lambda}{\beta}(p_g - p_c) = 0$$

$$\frac{\delta L}{\delta \lambda} = r^i + \frac{1}{\beta}(p_g - p_c)Y^{-i} - p_c X^i - \frac{1}{\beta}(p_g - p_c)Y = 0$$

$$\frac{\delta U^i/\delta Y_e^i}{\delta U^i/\delta X_e^i} = \frac{1}{\beta}\frac{(p_g - p_c)}{p_c} = \frac{1}{\beta}\left(\frac{p_g}{p_c} - 1\right) \qquad (D.1.2)$$

Assuming $U^i(X^i, Y, H^i) + a\ln X^i + b\ln Y + c\ln H^i$, we obtain the demand functions:

$$X_e^{i^*} = \frac{a}{a+b}\frac{1}{p_c}\left[r^i + \frac{1}{\beta}(p_g - p_c)Y^{-i}\right] \qquad (D.1.3)$$

$$Y_e^* = \frac{b}{a+b}\left[\beta\frac{1}{(p_g - p_c)}r^i + Y^{-i}\right] \qquad (D.1.4)$$

$$g_e^{i^*} = \frac{1}{a+b}\left[b\frac{1}{(p_g - p_c)}r^i - \frac{1}{\beta}aY^{-i}\right] \qquad (D.1.5)$$

$$c_e^{i^*} = \frac{1}{a+b}\frac{p_g}{p_c}[\left(\frac{1}{p_g - p_c}\left(a - \frac{p_c}{p_g}\right)r^i + \frac{1}{\beta}aY^{-i}\right] \qquad (D.1.6)$$

Appendix D2 – Consumer equilibrium – health label

The consumers have no information on the public characteristic of good g and there is no demand for Y. An individual solves (D.2.1.a), a maximisation problem that can alternatively be written (D.2.1.b) such that the characteristics appear in the budget constraint.

$$\max_{c^i,g^i} U^i\left(X^i, Y, H^i\right) \qquad (D.2.1.a)$$

s.t. $X^i = c^i + g^i$, $H^i = \alpha g^i$, $p_c c^i + p_g g^i \leq r^i$

$$\max_{X^i,H^i} U^i\left(X^i, Y, H^i\right) \qquad (D.2.1.b)$$

s.t. $p_c X^i + \frac{1}{\alpha}(p_g - p_c)H^i \leq r^i$

Deriving the Lagrangian function of the problem, we obtain the equilibrium condition (D.2.2).

$$L = U^i\left(X^i, Y, H^i\right) + \lambda\left(r^i - p_c X^i - \frac{1}{\alpha}(p_g - p_c)H^i\right)$$

$$\frac{\delta L}{\delta X^i} = \frac{\delta U^i}{\delta X^i} - \lambda p_c = 0$$

$$\frac{\delta L}{\delta H^i} = \frac{\delta U^i}{\delta H^i} - \frac{\lambda}{\alpha}\left(p_g - p_c\right) = 0$$

$$\frac{\delta L}{\delta \lambda} = r^i - p_c X^i - \frac{1}{\alpha}\left(p_g - p_c\right)H^i = 0$$

$$\frac{\delta U^i/\delta H_h^i}{\delta U^i/\delta X_h^i} = \frac{1}{\alpha}\left(\frac{p_g}{p_c} - 1\right) \qquad (D.2.2)$$

Assuming $U^i\left(X^i, Y, H^i\right) + a \ln X^i + b \ln Y + c \ln H^i$, we obtain the demand functions:

$$X_h^{i^*} = \frac{a}{a+c}\frac{1}{p_c}r^i \qquad (D.2.3)$$

$$H_h^{i^*} = \alpha\frac{c}{a+c}\frac{1}{\left(p_g - p_c\right)}r^i \qquad (D.2.4)$$

$$g_h^{i^*} = \frac{c}{a+c}\frac{1}{\left(p_g - p_c\right)}r^i \qquad (D.2.5)$$

$$c_h^{i^*} = \frac{1}{a+c}\left(a\frac{1}{p_c} - c\frac{1}{\left(p_g - p_c\right)}\right)r^i \qquad (D.2.6)$$

Appendix D3 – Consumer equilibrium –health and environment label

The consumers have full information on the characteristics of good g. An individual solves (D.3.1).

$$\max_{X^i,H^i,Y} U^i\left(X^i, Y, H^i\right) \qquad (D.3.1)$$

s.t. $p_c X^i + \frac{1}{\alpha}(p_g - p_c)H^i \leq r^i$, $p_c X^i + \frac{1}{\beta}(p_g - p_c)Y \leq r^i + \frac{1}{\beta}(p_g - p_c)Y^{-i}$

Deriving the Lagrangian function of the problem, we obtain the equilibrium conditions (D.3.2.a), (D.3.3.a) and (D.3.4.a).

$$L = U^i\left(X^i, Y, H^i\right) + \lambda_1\left(r^i - p_c X^i - \frac{1}{\alpha}\left(p_g - p_c\right)H^i\right) + \lambda_2\left(r^i + \frac{1}{\beta}\left(p_g - p_c\right)Y^{-i} - p_c X^i - \frac{1}{\beta}\left(p_g - p_c\right)Y\right)$$

$$\frac{\delta L}{\delta X^i} = \frac{\delta U}{\delta X^i} - \lambda_1 p_c - \lambda_2 p_c = 0$$

$$\frac{\delta L}{\delta Y} = \frac{\delta U}{\delta Y} - \frac{\lambda_2}{\beta}\left(p_g - p_c\right) = 0$$

$$\frac{\delta L}{\delta H^i} = \frac{\delta U}{\delta H^i} - \frac{\lambda_1}{\alpha}\left(p_g - p_c\right) = 0$$

$$\frac{\delta L}{\delta \lambda_1} = r^i - p_c X^i - \frac{1}{\alpha}\left(p_g - p_c\right)W^i = 0$$

$$\frac{\delta L}{\delta \lambda_2} = r^i + \frac{1}{\beta}\left(p_g - p_c\right)Y^{-i} - p_c X^i - \frac{1}{\beta}\left(p_g - p_c\right)Y = 0$$

$$\frac{\delta U/\delta X^i}{\delta U/\delta H^i} = \alpha \frac{p_c}{\left(p_g - p_c\right)} \frac{(\lambda_1 + \lambda_2)}{\lambda_1} \qquad (D.3.2.a)$$

$$\frac{\delta U/\delta X^i}{\delta U/\delta Y} = \beta \frac{p_c}{\left(p_g - p_c\right)} \frac{(\lambda_1 + \lambda_2)}{\lambda_2} \qquad (D.3.3.a)$$

$$\frac{\delta U/\delta H^i}{\delta U/\delta Y} = \frac{\beta}{\alpha} \frac{\lambda_1}{\lambda_2} \qquad (D.3.4.a)$$

At the market equilibrium, supply and demand equal such that $\sum_i H^i = IH^i = \frac{\alpha}{\beta} Y$. Assuming $U^i\left(X^i, Y, H^i\right) = a \ln X^i + b \ln Y + c \ln H^i$, (D.3.4) and the constraints of the model allows us to obtain $\lambda_1 = \frac{\alpha}{\beta} \frac{c}{b} \frac{Y}{H^i} \lambda_2$ and to derive (D.3.2.b), (D.3.3.b) and (D.3.4.b) and demand functions.

$$\frac{\delta U^i/\delta X^i}{\delta U^i/\delta H^i} = \alpha \frac{p_c}{(p_g - p_c)} \frac{(Ic + b)}{Ic} \tag{D.3.2.b}$$

$$\frac{\delta U^i/\delta X^i}{\delta U^i/\delta Y} = \beta \frac{p_c}{(p_g - p_c)} \frac{(Ic + b)}{b} \tag{D.3.3.b}$$

$$\frac{\delta U^i/\delta H^i}{\delta U^i/\delta Y} = \frac{\beta}{\alpha} \frac{Ic}{b} \tag{D.3.4.b}$$

$$X_{eh}^{i^*} = \frac{a}{a + b + Ic} \frac{1}{p_c} (r^i + \frac{1}{\beta} (p_g - p_c) Y^{-i}) H_{eh}^{i^*} = \alpha \frac{b + Ic}{b + I(a + c)} \frac{1}{(p_g - p_c)} r^i \tag{D.3.5}$$

$$Y_{eh}^{*} = I\beta \frac{b + Ic}{b + I(a + c)} \frac{1}{(p_g - p_c)} r^i = \frac{b + Ic}{a + b + Ic} \left(\beta \frac{1}{(p_g - p_c)} r^i + Y^{-i} \right) \tag{D.3.6}$$

$$g_{eh}^{i^*} = \frac{b + Ic}{b + I(a + c)} \frac{1}{(p_g - p_c)} r^i = \frac{1}{a + b + Ic} \left(\frac{b + Ic}{(p_g - p_c)} r^i - \frac{1}{\beta} a Y^{-i} \right) \tag{D.3.7}$$

$$c_{eh}^{i^*} = \frac{1}{(p_g - p_c)} \left(I \frac{a}{b + I(a + c)} \frac{p_g}{p_c} - 1 \right) r^i \tag{D.3.8}$$

Appendix E - Proof by contradiction that the market equilibrium of the health and environment label model is not a Pareto optimum.

We have previously derived the following results:

Pareto optimality condition: $\frac{X_p^i}{Y_p} = \frac{1}{\beta}\frac{a}{Ib+Ic}\left(\frac{\partial c(z)/\partial z}{\partial g(z)/\partial z} - 1\right)$

Health and environmental label market equilibrium: $\frac{X_{eh}^i}{Y_{eh}} = \frac{1}{\beta}\frac{a}{b+Ic}\left(\frac{\partial c(z)/\partial z}{\partial g(z)/\partial z} - 1\right)$

Therefore we have : $\frac{X_p^i}{Y_p} < \frac{X_{eh}^i}{Y_{eh}}$

In addition, we have shown that: $Y = \frac{\beta}{\alpha} IH^i$.

Let us assume that $\boldsymbol{Y_{eh} > Y_p}$. It also implies $\boldsymbol{H_{eh}^i > H_p^i}$.

Then we have: $U(X_p^i, Y_{eh}, H_p^i) > U(X_p^i, Y_p, H_p^i)$

Yet, we must have $U(X_p^i, Y_p, H_p^i) \geq U(X_{eh}^i, Y_{eh}, H_{eh}^i)$ by definition of Pareto optimality.

Therefore $U(X_p^i, Y_{eh}, H_p^i) > U(X_{eh}^i, Y_{eh}, H_{eh}^i) > U(X_{eh}^i, Y_{eh}, H_p^i)$

And $U(X_p^i, Y_{eh}, H_p^i) > U(X_{eh}^i, Y_{eh}, H_p^i)$

We obtain $X_p^i > X_{eh}^i$ and $\frac{X_p^i}{Y_p} > \frac{X_{eh}^i}{Y_p}$

Given that, $\frac{X_{eh}^i}{Y_{eh}} > \frac{X_p^i}{Y_p}$, it means that $\frac{X_{eh}^i}{Y_{eh}} > \frac{X_p^i}{Y_p} > \frac{X_{eh}^i}{Y_p}$, **implying that $\boldsymbol{Y_{eh} < Y_p}$, which is absurd as we assumed that $\boldsymbol{Y_{eh} > Y_p}$.**

Let us now assume that $\boldsymbol{Y_{eh} = Y_p}$. It also implies $\boldsymbol{H_{eh}^i = H_p^i}$:

Given that $\frac{X_p^i}{Y_p} < \frac{X_{eh}^i}{Y_{eh}}$, we must have $X_{eh}^i > X_p^i$

Yet, $U(X_p^i, Y_p, H_p^i) \geq U(X_{eh}^i, Y_{eh}, H_{eh}^i) = U(X_{eh}^i, Y_p, H_{eh}^i) = U(X_{eh}^i, Y_p, H_p^i)$

We find that $\boldsymbol{X_{eh}^i < X_p^i}$, which is absurd.

We demonstrated that $Y_{eh} < Y_p$.