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Farmers' adoption of organic production

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Abstract

The paper presents a theoretical model in order to figure out the farmer's decisions of organic production adoption in agriculture. The decisions concern the allocation of lands for conventional and organic farming. This paper suggests that an entirely theoretical exercise can illuminate parts of this complex issue which the empirical work cannot reach. Our results might give some advice to policy makers when contemplating regulations in the agricultural sector. We show the importance of (i) the available quantity of land devoted to agricultural plants, (ii) the productivity of the organic products, (iii) the incentive mechanism and, finally (iv) the constraints on output of organic products. We consider this result as a good example of a new technology. In addition, the result of this article not completely confined in the agricultural production sector. It is possible to open up applications in other fields related to technology transfer.

Keywords: New technology; Adoption; Organic products; Conventional products; Productivity

JEL Classification: O33; C33; Q22

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1 Introduction

Recently, numerous empirical studies have considered the effects of adopting new technologies. Some authors used the logit and probit models for their research (Nerlove and Press, 1973; Schmidt and Strauss, 1975; Kebede et al., 1990; Maddala, 1991; Ayuk, 1997; Negatu and Parikh, 1999; Adesina et al., 2000; Adesina and Chianu, 2002; Adebayo and Oladele, 2013; Ouma and De Groote, 2011; Abebe et al., 2013; Läpple and Kelley, 2015, etc.). These empirical studies measure the factors' effect on probability adoption new technology or new variety in agricultural sector. For example, Adesina et al. (2000) applied a logit model in their study. Their result showed that the negatively significant age variable suggested that younger farmers are more likely to adopt improved production technologies. The positively significant variable on possession of full rights over trees suggested that it has a positive influence on the likelihood to adopt improved production technologies. Besides, they put on some other variables such as gender, age, education, etc. However, they turned out to be insignificant. Ouma and De Groote (2011) computed the factors affecting adoption of improved corn varieties and fertilizer by farmers in Kenya. They used some variables such as education, access to credit, hired labor, extension contacts, distance to market, fertilizer. The result concerning the education variable is significantly positive, revealing its association with adoption of improved maize varieties. However, it did not show significant as related to adoption of fertilizer. Distance to market was negatively associated with adoption of fertilizer, although it was positively associated with the intensity of fertilizer's use. Use of fertilizer and improved maize seed were significantly positive at 1% level, respectively. It means that it is strongly associated with adoption of improved maize seed and fertilizer. Abebe et al. (2013) determined the adoption of improved potato varieties in Ethiopia. The result indicated that higher education of the household head, gender, access to credit, family size, stew quality of local variety and the presence of a radio and/or television also have a significant positive effect on adoption.

Meanwhile, a few studies considered the theoretical aspects. Some of them considered the effects of risk on technology change at the firm level. Stoneman (1981) developed a dynamic version of a single innovation model to prove the inter-firm diffusion of the new technology. This research showed that the expected level of use of the new technology is positively related to profitability but also influenced by uncertainty, attitudes to risk and adjustment costs. After that, Just and Zilberman (1983) developed a model that explains land allocation and technology adoption. The results suggested that risk attitudes play a large role in determining the farm size in technology adoption. Furthermore, Feder et al.

(1985) offered an excellent survey of this literature. The major result of this line of work is that the level of modern inputs used in product to depends on whether these inputs are risk reducing or risk increasing and on whether relative risk aversion is increasing or decreasing. Kim et al. (1992) examined the role of output price as a factor of influence on technological change. The results indicated that a reduction in the variance of output prices will increase the rate of adoption new technologies. However, besides referring to the risks of application of new technology, these studies did not mention the other conditions of firm with adaption of new technology.

An alternative approach, namely Duration Analysis, explored by some authors (Hannan and McDowell, 1984; Levin et al., 1987). This method has been used widely in labor economics, with examples in technology literature, but fewer in agricultural economics (Burton et al., 2003). Especially, the dearth of applications to agricultural adoption literature is rather surprising as Duration Analysis has a great advantage of dealing with both cross-section and time series data.

In this study we mainly focus on the agricultural sector. There is evidence indicating which factors influence the farmers' decision to change their technology. Here, it should be understood more holistically as new fertilizer and new adaptation can modify the technology, etc. Kebede et al. (1990) examined the impact of factors such as income, wealth, family size, farm size, access to outside information, education, experience influence on the adoption of new fertilizer and pesticide technologies in Tegulet-Bulga district, Ethiopia. Strauss et al. (1991) explored the determinants of technology adoption by upland rice and soybean of farmers in Brazil. They used some factors for this study, such as infrastructure to the farm level data containing information on farmer human capital as well as land quantity and quality. The result showed a positive impact of the farmers' education on the decision to accept new technology.

Other studies considered the situation of small farms regarding their technology adoption behavior. In particular, Rauniyar and Goode (1992) showed that farmers differ from one another in their adoption frequency and pointed out that a technology adoption study should address adoption behavior as a continuum rather than as an adopter/non-adopter type of discrete phenomenon. Huang and Rozelle (1996) focused on measuring the relative importance of the role of technology versus the one of institutional innovation in China's rural economy. This analysis identified technology adoption as the most important determinant of rice yield growth, accounting for nearly 40%; institutional reform accounted for 35%. Ayuk (1997) indicated that water availability and the profitability of the technology itself enhance the probability of adopting live hedges. The results provided an insight on the conditions that should be taken into consideration when targeting farmers for this agro-forestry technology. Adesina et al. (2000) showed that the farmer characteristics which influence decisions of adoption include farmer's gender, contact with extension agents, years of experience with agro-forestry and tenancy status in the village. The model results showed the human capital variables to be significant in explaining the farmers' decisions to adapt and modify the technology.

In addition, some studies are related to the organic agricultural sector (Burton et al., 2003; Koesling et al., 2008; Läpple, 2010; Läpple and Van Rensburg, 2011; Läpple and Kelley, 2015). These works aimed to determine factors affect alternative farming practices. The empirical results highlight the importance of gender, age, training, risk attitudes, farming experience, attitudes to the environment, and information networks in determining the adoption of organic farming practices.

Generally, these studies do not fully address the factors that change the technology, each study gives a different variable, and the result is inconsistent each other, especially as they do not consider elements of new technology productivity affecting the adoption. To address these limitations, in this study, we mention some elements as land, labor and productivity in our models. We investigate the effects of these factors on the adoption of organic production or new technology.

Government can encourage farmers to produce organic product. However, this policy is an impulsive action and without any scientific basis. Thus, in this study, we want to examine the relevance of these policies. Our study aims to provide explanations regarding the conditions which could help farmers to move towards an organic production. Three scenario for policies and perception of farmer are illustrated in Section 2. Some recommendations also be drawn about appropriate policies enhancing organic production.

The remaining of the chapter is organized as follows. Section 2 presents our theoretical model and three scenarios which can be derived from it. For each scenario, we give conditions to have farmers changing towards organic production. Section 3 reviews and concludes on the principal results. All the proofs are given in Appendix 4.

2 Theoretical model

The technological adoption is a hotly debated topic. We want to focus on the agricultural economic sector, specifically on agriculture production in which farmers would like to switch to organic product in their farming. We would like to examine under which conditions farmers adopt an organic product (new technology).

Furthermore, the definition of new technology is quite large. Although organic product is not an innovation, it requires the adoption of a different farming practice. In our context, new technology is defined as organic production. In general, in order to make decision on converting from conventional production to organic production, farmers have to select either keeping the farm as a conventional practice or converting it into organic product.

We assume that a producer wants to use a new technology, T_2, to produce some output, Y_2, of organic product with price P_2. The price of conventional product is P_1. Let S_1 be the quantity of land for conventional product, S_2 be the quantity of land needed for the organic product and V be the total quantity of land for the farmer. Let $C(S_1)$ be the cost function for conventional product. When a producer uses the new technology, her/his productivity is expected to gain or lose A. The cost becomes $\Phi(A)C(S_2)$, where the function $\Phi(\cdot)$ is concave, differentiable, increasing, with $\Phi(A) > 0,\ \Phi(0) = 0$. We want to investigate under which conditions a farmer accepts to adopt the organic product.

Let w denote the wage, $L_1,\ L_2$ be the quantities of labor used for producing conventional and organic product. The production function is $F(S, L) = S^{\alpha}L^{1-\alpha},\ 0 < \alpha < 1$. We assume the cost function is $C(S) = \gamma\dfrac{S^2}{2},\ \gamma > 0$. We suppose there is no constraint on labor but the total quantity of land used in production is limited by an amount V. We will present three scenarios, namely three cases that can arise.

Scenario 2.1. ***Each farmer has two kinds of technologies, an old technology (conventional product) which is called*** T_1 ***and a new technology (organic product) called*** T_2***. The production function which corresponds to the conventional product,*** T_1***, is*** $F_1(S_1, L_1) = S_1^{\alpha}L_1^{1-\alpha}$ ***while the technology corresponding to the organic product,*** T_2***, is*** $F_2(S_2, L_2) = AS_2^{\alpha}L_2^{1-\alpha}$ ***with*** $A > 0$***.*** A ***define as productivity. The empirical result of Huang et al. (2002) and Ali and Abdulai (2010) tells us that productivity is influenced by the adoption of technology. The farmer has only the constraint that the supply of land is limited by an quantity*** V***.***

Then, the producer optimization problem $(\mathcal{P}_1)$ is

$$\left.\begin{array}{l} \max\left\{P_1S_1^{\alpha}L_1^{1-\alpha} - wL_1 - C(S_1) + P_2AS_2^{\alpha}L_2^{1-\alpha} - wL_2 - \Phi(A)C(S_2)\right\} \\ \text{subject to}\left\{\begin{array}{l} S_1 + S_2 \leqslant V, \\ S_1 \geqslant 0,\ S_2 \geqslant 0,\ L_1 \geqslant 0,\ L_2 \geqslant 0. \end{array}\right. \end{array}\right\}(\mathcal{P}_1)$$

Lemma 2.1. *Consider* $(\mathcal{P}_1)$*. Let* $S_1^*,\ S_2^*,\ L_1^*,\ L_2^*$ *denote the optimal values of lands and labors for conventional product and organic product; then*

$$(a)\ S_1^* > 0 \quad \Leftrightarrow \quad L_1^* > 0,$$
$$(b)\ S_2^* > 0 \quad \Leftrightarrow \quad L_2^* > 0.$$

The proof of this Lemma 2.1 is given in Appendix 4.1. Lemma 2.1 helps us understanding the relationship between land and labor. This result implies that when the farmer uses the land for cultivating conventional product (old technology) S_1^*, then, at the same time, their use of labor is L_1^*. Similarly, producers also use the land for planting the organic product (new technology) S_2^* and their use of labor is L_2^*.

Proposition 2.1. *Under Scenario 2.1, consider the problem* $(\mathcal{P}_1)$. *Let* $A_1 = \dfrac{P_1}{P_2}$ *and*

$$
\begin{aligned}
Q(P_1, P_2, \alpha, w, \Phi, \gamma, A) &= \frac{\alpha}{\gamma} P_1^{\frac{1}{\alpha}} \left\{ \frac{1-\alpha}{w} \right\}^{\frac{1-\alpha}{\alpha}} + \frac{\alpha}{\gamma \Phi(A)} (P_2 A)^{\frac{1}{\alpha}} \left\{ \frac{1-\alpha}{w} \right\}^{\frac{1-\alpha}{\alpha}} \\
&= \frac{\alpha}{\gamma} P_1^{\frac{1}{\alpha}} \left\{ \frac{1-\alpha}{w} \right\}^{\frac{1-\alpha}{\alpha}} \left[1 + \frac{1}{\Phi(A)} \left(\frac{A}{A_1} \right)^{\frac{1}{\alpha}} \right].
\end{aligned}
$$

(i) If $V \geqslant Q(P_1, P_2, \alpha, w, \Phi, \gamma, A)$ *then the optimal lands and labors are the following*

$$
\begin{aligned}
\textit{land of conventional product, } S_{1a}^* &= \frac{\alpha}{\gamma} P_1^{\frac{1}{\alpha}} \left\{ \frac{1-\alpha}{w} \right\}^{\frac{(1-\alpha)}{\alpha}}, \\
\textit{labor of conventional product } L_{1a}^* &= \frac{\alpha}{\gamma} P_1^{\frac{2}{\alpha}} \left\{ \frac{1-\alpha}{w} \right\}^{\frac{(2-\alpha)}{\alpha}}, \\
\textit{land of organic product, } S_{2a}^* &= \frac{\alpha}{\gamma \Phi(A)} (P_2 A)^{\frac{1}{\alpha}} \left\{ \frac{1-\alpha}{w} \right\}^{\frac{(1-\alpha)}{\alpha}}, \\
\textit{labor of organic product } L_{2a}^* &= \frac{\alpha}{\gamma \Phi(A)} (P_2 A)^{\frac{2}{\alpha}} \left\{ \frac{1-\alpha}{w} \right\}^{\frac{(2-\alpha)}{\alpha}}, \\
\textit{and total land } V &> S_{1a}^* + S_{2a}^*.
\end{aligned}
$$

(ii) If $V < Q(P_1, P_2, \alpha, w, \Phi, \gamma, A)$, *let*

$$
R = (P_2 A)^{\frac{1}{\alpha}} \alpha \left\{ \frac{1-\alpha}{w} \right\}^{\frac{(1-\alpha)}{\alpha}} - P_1^{\frac{1}{\alpha}} \alpha \left\{ \frac{1-\alpha}{w} \right\}^{\frac{(1-\alpha)}{\alpha}},
$$

then the optimal lands and labors will be given in the following sequel.

(ii.a) $R \geqslant 0$ *is equivalent to* $A \geqslant \dfrac{P_1}{P_2}$,

(ii.a1) If $\dfrac{R}{\gamma \Phi(A)} < V < Q(P_1, P_2, \alpha, w, \Phi, \gamma, A)$, *then*

$$
\begin{aligned}
\textit{land of conventional product, } S_{1a}^{**} &= \frac{\gamma \Phi(A) V - R}{\gamma (1 + \Phi(A))} > 0, \\
\textit{labor of conventional product } L_{1a}^{**} &= \left[\frac{\gamma \Phi(A) V - R}{\gamma (1 + \Phi(A))} \right] \left\{ \frac{P_1 (1-\alpha)}{w} \right\}^{\frac{1}{\alpha}} > 0, \\
\textit{land of organic product, } S_{2a}^{**} &= \frac{\gamma V + R}{\gamma (1 + \Phi(A)),} \\
\textit{labor of organic product } L_{2a}^{**} &= \left[\frac{\gamma V + R}{\gamma (1 + \Phi(A))} \right] \left\{ \frac{P_2 A (1-\alpha)}{w} \right\}^{\frac{1}{\alpha}}.
\end{aligned}
$$

(ii.a2) If $V \leqslant \dfrac{R}{\gamma\Phi(A)}$, *then the optimal lands and labors are the following*

$$S_{1a}^{**} = 0,\ S_{2a}^{**} = V,\ L_{1a}^{**} = 0,\ L_{2a}^{**} = V\left\{\frac{P_2 A(1-\alpha)}{w}\right\}^{\frac{1}{\alpha}}.$$

(ii.b) $R < 0$ *is equivalent to* $A < \dfrac{P_1}{P_2}$.

(ii.b1) If $-\dfrac{R}{\gamma} < V < Q(P_1, P_2, \alpha, w, \Phi, \gamma, A)$, *then*

$$\begin{aligned}
S_{1a}^{**} &= \frac{\gamma\Phi(A)V - R}{\gamma(1+\Phi(A))} > 0,\\
L_{1a}^{**} &= \left[\frac{\gamma\Phi(A)V - R}{\gamma(1+\Phi(A))}\right]\left\{\frac{P_1(1-\alpha)}{w}\right\}^{\frac{1}{\alpha}} > 0,\\
S_{2a}^{**} &= \frac{\gamma V + R}{\gamma(1+\Phi(A))} > 0,\\
L_{2a}^{**} &= \left[\frac{\gamma V + R}{\gamma(1+\Phi(A))}\right]\left\{\frac{P_2 A(1-\alpha)}{w}\right\}^{\frac{1}{\alpha}}.
\end{aligned}$$

(ii.b2) If $V \leqslant -\dfrac{R}{\gamma}$ *the optimal lands and labors are the following*

$$S_{2a}^{**} = 0,\ S_{1a}^{**} = V,\ L_{2a}^{**} = 0,\ L_{1a}^{**} = V\left\{\frac{P_1(1-\alpha)}{w}\right\}^{\frac{1}{\alpha}}.$$

The proof of Proposition 2.1 is given in Appendix 4.2.

Observe that $Q(P_1, P_2, \alpha, w, \Phi, \gamma, A)$ is the total land required by the producer when there is no constraint on land supply. Statement (i) tells us that, if land supply V is more than $Q(P_1, P_2, \alpha, w, \Phi, \gamma, A)$, the producer will behave as if she/he does not face the supply constraint. She shares her lands following conventional product (old technology) S_{1a}^*, organic product (new technology) S_{2a}^* and she will allocate labors following the conventional product L_{1a}^* and the organic product L_{2a}^*.

Statement (i) is consistent with the study of Strauss et al. (1991), as their result indicates that the total area of land owned by the farmer is unrelated to the adoption of new technology. But statement (i) is more precise: the empirical results in Strauss et al. (1991) are true when the total area is large enough.

Statement (ii) indicates that, if land supply V is less than $Q(P_1, P_2, \alpha, w, \Phi, \gamma, A)$, the land constraint will bind. However, we observe two cases. The first case corresponds to a productivity A larger than $\dfrac{P_1}{P_2}$. We determine a threshold value $\dfrac{R}{\gamma\Phi(A)}$. If the land is beyond this threshold value $\dfrac{R}{\gamma\Phi(A)}$ and is less than the total land $Q(P_1, P_2, \alpha, w, \Phi, \gamma, A)$, then the farmer will use his land following S_{1a}^{**}, S_{2a}^{**} and assigns his labor following L_{1a}^{**},

L_{2a}^{**} (Proposition 2.1($ii.a1$)). In the statement ($ii.a2$), if land V is less than the threshold value $\dfrac{R}{\gamma\Phi(A)}$, then the farmer prefers to plant only the organic product (new technology) S_{2a}^{**} and to use labor L_{2a}^{**}.

The second case corresponds to a productivity A lower than $\dfrac{P_1}{P_2}$. Again, there is a threshold value $-\dfrac{R}{\gamma}$. If the farmer land is beyond the threshold value $-\dfrac{R}{\gamma}$ and is less than the total land $Q(P_1, P_2, \alpha, w, \Phi, \gamma, A)$, then the farmer will distribute its land following the conventional product (old technology) S_{1a}^{**}, the organic product (new technology) S_{2a}^{**} and will share out his labor following L_{1a}^{**}, L_{2a}^{**} (Statement ($ii.b1$)). In statement ($ii.b2$), if land V is beyond the threshold value $-\dfrac{R}{\gamma}$, then the farmer will plant only conventional product, S_{1a}^{**} and use all labor L_{1a}^{**} for planting this product. Here the productivity A is too low to incite farmers to adopt it.

Finally, when A is very large, case ($ii.a2$) of Proposition 2.1 shows that total land will be devoted to organic production. And when A is very small, case ($ii.b2$) of Proposition 2.1 shows that total land will be used for conventional product.

Proposition 2.2. *If we have ($ii.a1$) or ($ii.b1$) then there exist values $\widehat{A}$ and $\tilde{A}$ such that if $A > \widehat{A}$ then S_{2a}^{**} is an increasing function of A, and if $A < \tilde{A}$ then S_{2a}^{**} is a decreasing function of A.*

Proof.

From the case ($ii.a1, ii.b1$) in Proposition 2.1, we have

$$S_{2a}^{**} = \frac{\gamma V + R}{\gamma(1+\Phi(A))},\ R = (P_2 A)^{\frac{1}{\alpha}} \alpha \left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}} - P_1^{\frac{1}{\alpha}} \alpha \left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}}.$$

Then, we get $S_{2a}^{**} = \dfrac{V(1+\frac{R}{\gamma V})}{1+\Phi(A)}$.
We first prove for ($ii.a1$).
We observe that $\dfrac{R}{\gamma V} - \Phi(A) < 0$.

We obtain

$$\begin{aligned}
\text{Log} S_{2a}^{**} &= \text{Log} V + \text{Log}(1 + \frac{R}{\gamma V}) - \text{Log}(1+\Phi(A)) \\
\frac{d}{dA}\text{Log} S_{2a}^{**} &= \frac{1}{(1+\frac{R}{\gamma V})} \times \frac{1}{\gamma V}\left[P_2^{\frac{1}{\alpha}}\left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}} A^{\frac{(1-\alpha)}{\alpha}}\right] - \frac{1}{1+\Phi(A)}\Phi'(A) \\
&= \frac{1}{\gamma V + R} P_2^{\frac{1}{\alpha}}\left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}} A^{\frac{(1-\alpha)}{\alpha}} - \frac{\Phi'(A)}{1+\Phi(A)}.
\end{aligned}$$

Observe that $\dfrac{1}{\gamma V + R} > \dfrac{1}{\gamma V(1+\Phi(A))}$. Hence,

$$\frac{d}{dA}\text{Log} S_{2a}^{**} > \frac{1}{1+\Phi(A)}\left[\frac{1}{\gamma V} \times P_2^{\frac{1}{\alpha}}\left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}} A^{\frac{(1-\alpha)}{\alpha}} - \Phi'(A)\right].$$

Let

$$\phi(A) = \frac{1}{\gamma V} \times P_2^{\frac{1}{\alpha}} \left\{ \frac{1-\alpha}{w} \right\}^{\frac{(1-\alpha)}{\alpha}} A^{\frac{(1-\alpha)}{\alpha}} - \Phi'(A).$$

Function ϕ is increasing. It takes a negative value $-\Phi'(0)$ when $A = 0$ and equals $+\infty$ when $A = +\infty$. Hence there exists a value $\hat{A}$ such that if $A > \hat{A}$ then $\phi(A) > 0$ implying $\frac{d}{dA}\text{Log}S_{2a}^{**} > 0$.
When $A \to 0$,

$$\frac{1}{\gamma V + R} P_2^{\frac{1}{\alpha}} \left\{ \frac{1-\alpha}{w} \right\}^{\frac{(1-\alpha)}{\alpha}} A^{\frac{(1-\alpha)}{\alpha}} - \frac{\Phi'(A)}{1+\Phi(A)} \to -\Phi'(0) < 0.$$

Hence there exists $\tilde{A}$ such that, if $A < \tilde{A}$ then $\frac{d}{dA}\text{Log}S_{2a}^{**} < 0$. The proof for the case $(ii.b1)$ is similar. $\square$

In the study of Langyintuo and Mungoma (2008), there is a significant and negative relationship between land size and adoption. They assert that for a unit increase in land size, the intensity of use of high yielding maize varieties decreases by 0.4 percent. Similarly, in the study of Akinola et al. (2010), land size has negative and insignificant effect on adoption of balance nutrient management systems-rotation in the northern Guinea savanna of Nigeria. The second statement of Proposition 2.2 explains these empirical results: the adoption technology is low. Meanwhile, Kebede et al. (1990) show that land size has a positive effect on adoption of new technology. This variable has the most significant effect on adoption of production technologies. Adebayo and Oladele (2013) showed that farmers with a large land size are more likely to use organic farming practices than farmers with a small land size. The first statement of Proposition 2.2 makes precise these results. It shows that these empirical results hold if A is large enough.

The role of the land supply constraint is examined in Proposition 2.1. We will now, in Proposition 2.3, focus on the role of productivity A on the farmer's decision of technology adoption. We require Lemma 2.2 which helps us capturing some conditions on productivity A when the farmer wants to shift to organic product (new technology).

Lemma 2.2. *Assume* $\Phi'(0) = +\infty$, $\Phi'(+\infty) = 0$. *Let*

$$R = (P_2 A)^{\frac{1}{\alpha}} \alpha \left\{ \frac{1-\alpha}{w} \right\}^{\frac{(1-\alpha)}{\alpha}} - P_1^{\frac{1}{\alpha}} \alpha \left\{ \frac{1-\alpha}{w} \right\}^{\frac{(1-\alpha)}{\alpha}}.$$

Let V_1, A_0, A_1, A_2, A_3 be defined by $V_1 = \dfrac{\alpha}{\gamma} P_1^{\frac{1}{\alpha}} \left\{ \dfrac{1-\alpha}{w} \right\}^{\frac{(1-\alpha)}{\alpha}}$,

$$
\begin{aligned}
&A_1 = \frac{P_1}{P_2},\\
&\text{when } V \leqslant V_1, \text{ then } A_0 = A_1 \times \left[1 - \frac{V}{V_1} \right]^{\alpha},\\
&\text{when } V > V_1, \text{ then } A_0 < 0,\\
&\text{when } V \geqslant V_1, \text{ then } \frac{A_2{}^{\frac{1}{\alpha}}}{\Phi(A_2)} = A_1^{\frac{1}{\alpha}} \times \left[\frac{V}{V_1} - 1 \right],\\
&\text{when } V < V_1, \text{ then } A_2 < 0,\\
&\text{and } A_3 \text{ be defined by } \frac{A_3^{\frac{1}{\alpha}} - A_1^{\frac{1}{\alpha}}}{\Phi(A_3)} \times \frac{1}{A_1^{\frac{1}{\alpha}}} = \frac{V}{V_1}.
\end{aligned}
$$

We have

(i) $R \geqslant 0 \Leftrightarrow A \geqslant A_1 = \dfrac{P_1}{P_2}$.

(ii) Assume $V > V_1$.

(ii.1) Then $V \leqslant Q(P_1, P_2, \alpha, w, \Phi, \gamma, A) \Leftrightarrow A \geqslant A_2$.

We have

$$A_2 \geqslant A_1 \quad \Leftrightarrow \quad \frac{1}{\Phi(A_1)} \leqslant \left[\frac{V}{V_1} - 1 \right].$$

(ii.2) We have $A_2 < A_3,\ A_1 < A_3$ *and*

$$\frac{R}{\gamma \Phi(A)} \quad \leqslant \quad V \Leftrightarrow A \leqslant A_3.$$

(ii.3) We have $V > -\dfrac{R}{\gamma}$.

(iii) Assume $V \leqslant V_1$,

(iii.1) We have $V \leqslant -\dfrac{R}{\gamma} \Leftrightarrow A \leqslant A_0$,

(iii.2) $A_1 < A_3$ *and* $\dfrac{R}{\gamma \Phi(A)} \leqslant V \Leftrightarrow A \leqslant A_3$.

The proof of this lemma is given in Appendix 4.3.

Proposition 2.3. *We use the definitions given in Lemma 2.2. Let* $V_1 = \dfrac{\alpha}{\gamma} P_1^{\frac{1}{\alpha}} \left\{ \dfrac{1-\alpha}{w} \right\}^{\frac{1-\alpha}{\alpha}}$. *Assume* $\Phi'(0) = +\infty,\ \Phi'(+\infty) = 0$.

(i) Assume $V \leqslant V_1$,

(i.1) If $A \leqslant A_0$, *then* $S_{2a}^{**} = 0,\ S_{1a}^{**} = V,\ L_{2a}^{**} = 0,\ L_{1a}^{**} = V \left\{ \dfrac{P_1(1-\alpha)}{w} \right\}^{\frac{1}{\alpha}}$.

(i.2) If $A_0 < A < A_3$, then

$$\begin{aligned}
S_{1a}^{**} &= \frac{\gamma\Phi(A)V - R}{\gamma(1+\Phi(A))} > 0,\\
L_{1a}^{**} &= \left[\frac{\gamma\Phi(A)V - R}{\gamma(1+\Phi(A))}\right]\left\{\frac{P_1(1-\alpha)}{w}\right\}^{\frac{1}{\alpha}} > 0,\\
S_{2a}^{**} &= \frac{\gamma V + R}{\gamma(1+\Phi(A))} > 0,\\
L_{2a}^{**} &= \left[\frac{\gamma V + R}{\gamma(1+\Phi(A))}\right]\left\{\frac{P_2A(1-\alpha)}{w}\right\}^{\frac{1}{\alpha}} > 0.
\end{aligned}$$

(i.3) If $A \geqslant A_3$, then $\quad S_{1a}^{**} = 0,\ S_{2a}^{**} = V,\ L_{1a}^{**} = 0,\ L_{2a}^{**} = V\left\{\frac{P_2A(1-\alpha)}{w}\right\}^{\frac{1}{\alpha}}.$

(ii) Assume $V > V_1$,

(ii.1) If $A \leqslant A_2$, then

$$\begin{aligned}
S_{1a}^{*} &= \frac{\alpha}{\gamma}P_1^{\frac{1}{\alpha}}\left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}},\\
L_{1a}^{*} &= \frac{\alpha}{\gamma}P_1^{\frac{2}{\alpha}}\left\{\frac{1-\alpha}{w}\right\}^{\frac{(2-\alpha)}{\alpha}},\\
S_{2a}^{*} &= \frac{\alpha}{\gamma\Phi(A)}(P_2A)^{\frac{1}{\alpha}}\left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}},\\
L_{2a}^{*} &= \frac{\alpha}{\gamma\Phi(A)}(P_2A)^{\frac{2}{\alpha}}\left\{\frac{1-\alpha}{w}\right\}^{\frac{(2-\alpha)}{\alpha}},\\
V &> S_{1a}^{*} + S_{2a}^{*}.
\end{aligned}$$

(ii.2) If $A_2 < A < A_3$, then

$$\begin{aligned}
S_{1a}^{**} &= \frac{\gamma\Phi(A)V - R}{\gamma(1+\Phi(A))} > 0,\\
L_{1a}^{**} &= \left[\frac{\gamma\Phi(A)V - R}{\gamma(1+\Phi(A))}\right]\left\{\frac{P_1(1-\alpha)}{w}\right\}^{\frac{1}{\alpha}} > 0,\\
S_{2a}^{**} &= \frac{\gamma V + R}{\gamma(1+\Phi(A))} > 0,\\
L_{2a}^{**} &= \left[\frac{\gamma V + R}{\gamma(1+\Phi(A))}\right]\left\{\frac{P_2A(1-\alpha)}{w}\right\}^{\frac{1}{\alpha}} > 0.
\end{aligned}$$

(ii.3) If $A \geqslant A_3$, then $\quad S_{1a}^{**} = 0,\ S_{2a}^{**} = V,\ L_{1a}^{**} = 0,\ L_{2a}^{**} = V\left\{\frac{P_2A(1-\alpha)}{w}\right\}^{\frac{1}{\alpha}}.$

The proof of Proposition 2.3 is given in Appendix 4.4.

Proposition 2.3 clarifies the role of productivity A. First, notice that V_1 is the required quantity of land when the producer has no constraint on land supply. We observe two cases. In the first case, land supply V is less than V_1 (Case (i)). Statement ($i.1$) says that, if the productivity of organic product (new technology) A is less than a productivity A_0, then it is not worthwhile to adopt organic product (new technology). The producers will only plant conventional product (old technology) S_{1a}^{**}, with their labor being L_{1a}^{**}. However, statement ($i.2$) indicates that if the productivity of organic product A is between a productivity A_0 and A_3, then the farmers will cultivate both types of product, conventional product land being S_{1a}^{**} with labor following L_{1a}^{**} and organic product land S_{2a}^{**} with labor following L_{2a}^{**}. Also, in statement ($i.3$), we can see that if the productivity of organic product A is higher than productivity A_3, it becomes worthwhile for farmers to only cultivate organic product on the surface S_{2a}^{**} with labor L_{2a}^{**}.

In the second case, land supply becomes large enough, i.e. V is higher than V_1 (Case (ii)). Statement ($ii.1$) indicates that if the productivity of organic product A is less than some productivity A_2, then farmers will cultivate both types of product, conventional product land being S_{1a}^{*} with labor following L_{1a}^{*} and organic product land S_{2a}^{*} and labor L_{2a}^{*}. But they will not use all the available land V. Statement ($ii.2$) shows that if the productivity of organic product A is between productivity A_2 and productivity A_3 then the farmer will plant both types of product, conventional product land being S_{1a}^{**} with labor L_{1a}^{**} and organic product land being S_{2a}^{**} with labor L_{2a}^{**}. The difference with Case ($ii.1$) is that farmers will use all the available land.

In addition, if the productivity of organic product A is more than some productivity A_3, farmers will only product organic product using all the available land V and labor L_{2a}^{**} (Statement ($ii.3$)).

Our results show that the role of productivity are very important in the adoption of new technology. These results are consistent with the results of Zepeda (1994) and Ojiako et al. (2007). The results are very important for policy makers because basing on each different productivity the farmer has a different choice. Thus, this result may help policy markers in giving a reasonable policy to encourage farmers to produce organic product (new technology).

Scenario 2.2. ***Consider the situation when the government encourages the farmers to produce organic product by giving a subsidy*** $m(S_2, L_2)S_2$***. The subsidy per unit of land devoted to organic product depends on*** (S_2, L_2)***. However, the government is rational and hence also maximizes its gain. Let*** $\sigma > 0$ ***denotes the mark-up rate of the government. It pays the farmer with the price*** P_2 ***but resells on the market with the price*** $P_2(1+\sigma)$***.***

In this case, it solves the problem, $\max\limits_{S_2\geqslant 0}\Big\{(1+\sigma)P_2AS_2^{\alpha}L_2^{1-\alpha} - mS_2\Big\}$. We get the solution $m(S_2, L_2) = \alpha(1+\sigma)AP_2S_2^{\alpha-1}L_2^{1-\alpha}$. The producer maximizes the following problem $(\mathcal{P}_2)$

$$\left.\begin{array}{l} \max\Big\{P_1S_1^{\alpha}L_1^{1-\alpha} - wL_1 - C(S_1) + P_2AS_2^{\alpha}L_2^{1-\alpha} - wL_2 - \Phi(A)C(S_2) + m(S_2,L_2)S_2\Big\} \\ \text{subject to}\begin{cases} S_1 + S_2 \leqslant V, \\ S_1 \ \geqslant 0,\ S_2 \geqslant 0,\ L_1 \geqslant 0,\ L_2 \geqslant 0. \end{cases} \end{array}\right\} (\mathcal{P}_2)$$

This problem turns out to be

$$\max\Big\{P_1S_1^{\alpha}L_1^{1-\alpha} - wL_1 - C(S_1) + P_2A'S_2^{\alpha}L_2^{1-\alpha} - wL_2 - \Phi(A)C(S_2)\Big\},$$

with $A' = A\big[\alpha(1+\sigma)\big]$, A' define as productivity of this Scenario. We obtain the following propositions, the proofs of which can be easily adapted from the ones of Propositions 2.1 and 2.3.

Proposition 2.4. *Under Scenario 2.2, consider the problem* $(\mathcal{P}_2)$*. Let* $A_1 = \dfrac{P_1}{P_2}$ *and*

$$\begin{aligned} Q_1(P_1,P_2,\alpha,w,\Phi,\gamma,A') &= \frac{\alpha}{\gamma}P_1^{\frac{1}{\alpha}}\left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}} + \frac{\alpha}{\gamma\Phi(A)}(P_2A')^{\frac{1}{\alpha}}\left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}} \\ &= \frac{\alpha}{\gamma}P_1^{\frac{1}{\alpha}}\left\{\frac{1-\alpha}{w}\right\}^{\frac{1-\alpha}{\alpha}}\left[1 + \frac{1}{\Phi(A)}\left(\frac{A'}{A_1}\right)^{\frac{1}{\alpha}}\right]. \end{aligned}$$

(i) If $V \geqslant Q_1(P_1,P_2,\alpha,w,\Phi,\gamma,A')$*, then the optimal lands and labors are the following*

$$\begin{aligned} \textit{land of conventional product,} \quad S_{1b}^* &= \frac{\alpha}{\gamma}P_1^{\frac{1}{\alpha}}\left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}}, \\ \textit{labor of conventional product,} \quad L_{1b}^* &= \frac{\alpha}{\gamma}P_1^{\frac{2}{\alpha}}\left\{\frac{1-\alpha}{w}\right\}^{\frac{(2-\alpha)}{\alpha}}, \\ \textit{land of organic product,} \quad S_{2b}^* &= \frac{\alpha}{\gamma\Phi(A)}\big(P_2A\big[\alpha(1+\sigma)\big]\big)^{\frac{1}{\alpha}}\left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}}, \\ \textit{labor of organic product,} \quad L_{2b}^* &= \frac{\alpha}{\gamma\Phi(A)}\big(P_2A\big[\alpha(1+\sigma)\big]\big)^{\frac{2}{\alpha}}\left\{\frac{1-\alpha}{w}\right\}^{\frac{(2-\alpha)}{\alpha}}, \\ \textit{and total land} \quad V &> S_{1b}^* + S_{2b}^*. \end{aligned}$$

(ii) If $V < Q_1(P_1, P_2, \alpha, w, \Phi, \gamma, A')$, let $A' = A\big[\alpha(1+\sigma)\big]$,

$$R = (P_2 A\big[\alpha(1+\sigma)\big])^{\frac{1}{\alpha}}\alpha\left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}} - P_1^{\frac{1}{\alpha}}\alpha\left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}},$$

then the optimal lands and labors will be given in the following sequel.

(ii.a) $R \geqslant 0$ is equivalent to $A' \geqslant \dfrac{P_1}{P_2}$

(ii.a1) If $\dfrac{R}{\gamma\Phi(A)} < V < Q_1(P_1, P_2, \alpha, w, \Phi, \gamma, A')$, then

$$\begin{aligned}
\textit{land of conventional product,} \quad S_{1b}^{**} &= \frac{\gamma\Phi(A)V - R}{\gamma(1+\Phi(A))} > 0,\\
\textit{labor of conventional product} \quad L_{1b}^{**} &= \left[\frac{\gamma\Phi(A)V - R}{\gamma(1+\Phi(A))}\right]\left\{\frac{P_1(1-\alpha)}{w}\right\}^{\frac{1}{\alpha}} > 0,\\
\textit{land of organic product,} \quad S_{2b}^{**} &= \frac{\gamma V + R}{\gamma(1+\Phi(A))},\\
\textit{labor of organic product} \quad L_{2b}^{**} &= \left[\frac{\gamma V + R}{\gamma(1+\Phi(A))}\right]\left\{\frac{P_2 A\big[\alpha(1+\sigma)\big](1-\alpha)}{w}\right\}^{\frac{1}{\alpha}}.
\end{aligned}$$

(ii.a2) If $V \leqslant \dfrac{R}{\gamma\Phi(A)}$, then the optimal lands and labors are the following

$$S_{1b}^{**} = 0,\ S_{2b}^{**} = V,\ L_{1b}^{**} = 0,\ L_{2b}^{**} = V\left\{\frac{P_2 A\big[\alpha(1+\sigma)\big](1-\alpha)}{w}\right\}^{\frac{1}{\alpha}}.$$

(ii.b) $R < 0$ is equivalent to $A' < \dfrac{P_1}{P_2}$.

(ii.b1) If $-\dfrac{R}{\gamma} < V < Q_1(P_1, P_2, \alpha, w, \Phi, \gamma, A')$, then

$$\begin{aligned}
S_{1b}^{**} &= \frac{\gamma\Phi(A)V - R}{\gamma(1+\Phi(A))} > 0,\\
L_{1b}^{**} &= \left[\frac{\gamma\Phi(A)V - R}{\gamma(1+\Phi(A))}\right]\left\{\frac{P_1(1-\alpha)}{w}\right\}^{\frac{1}{\alpha}} > 0,\\
S_{2b}^{**} &= \frac{\gamma V + R}{\gamma(1+\Phi(A))},\\
L_{2b}^{**} &= \left[\frac{\gamma V + R}{\gamma(1+\Phi(A))}\right]\left\{\frac{P_2 A\big[\alpha(1+\sigma)\big](1-\alpha)}{w}\right\}^{\frac{1}{\alpha}}.
\end{aligned}$$

(ii.b2) If $V \leqslant -\dfrac{R}{\gamma}$, then the optimal lands and labors are the following

$$S_{2b}^{**} = 0,\ S_{1b}^{**} = V,\ L_{2b}^{**} = 0,\ L_{1b}^{**} = V\left\{\frac{P_1(1-\alpha)}{w}\right\}^{\frac{1}{\alpha}}.$$

The comments of the results are similar to the ones for Proposition 2.1. The main difference is that, in Scenario 2.2, the land supply V must be larger than the one in Scenario 2.1.

Statement (i) show that under condition V must be larger than $Q_1(P_1, P_2, \alpha, w, \Phi, \gamma, A')$, when farmers are given subsidies they tend to invest on farm practices.

However, the subsidies in Statement (ii) are not significant. Statement (ii) are in line with the results of Lohr and Salomonsson (2000) in Sweden. They indicate that the subsidy helped offset transition costs to organic production for the farmers was not the effect. In addition, the result of Adebayo and Oladele (2013) also showed that subsidy received shows a significantly negative relationship with farmer' attitude to organic techniques. This implies that those that did not receive subsidy are more likely to practice organic farming. They argue that their result is not true because subsidy will encourage the farmers to adopt organic farming techniques. However, this argument is not sufficiently objective and unfounded.

We will now characterize the role of productivity $A' = A\big[\alpha(1+\sigma)\big]$ on farmer's behavior. The role of technology A' is given in Proposition 2.5.

Proposition 2.5. *The quantities defined in Lemma 2.2 are unchanged. We use Proposition 2.3. Let* $V_1 = \frac{\alpha}{\gamma} P_1^{\frac{1}{\alpha}} \left\{ \frac{1-\alpha}{w} \right\}^{\frac{1-\alpha}{\alpha}}$ *and assume* $\Phi'(0) = +\infty,\ \Phi'(+\infty) = 0$.

(i) Assume $V \leqslant V_1$,

(i.1) If $A' \leqslant A_0$, *then* $S_{2b}^{**} = 0,\ S_{1b}^{**} = V,\ L_{2b}^{**} = 0,\ L_{1b}^{**} = V\left\{ \frac{P_1(1-\alpha)}{w} \right\}^{\frac{1}{\alpha}}$.

(i.2) If $A_0 < A' < A_3$, *then*

$$\begin{aligned}
S_{1b}^{**} &= \frac{\gamma\Phi(A)V - R}{\gamma(1+\Phi(A))} > 0, \\
L_{1b}^{**} &= \left[\frac{\gamma\Phi(A)V - R}{\gamma(1+\Phi(A))}\right] \left\{ \frac{P_1(1-\alpha)}{w} \right\}^{\frac{1}{\alpha}} > 0, \\
S_{2b}^{**} &= \frac{\gamma V + R}{\gamma(1+\Phi(A))} > 0, \\
L_{2b}^{**} &= \left[\frac{\gamma V + R}{\gamma(1+\Phi(A))}\right] \left\{ \frac{P_2 A\big[\alpha(1+\sigma)\big](1-\alpha)}{w} \right\}^{\frac{1}{\alpha}} > 0.
\end{aligned}$$

(i.3) If $A' \geqslant A_3$, *then* $S_{1b}^{**} = 0,\ S_{2b}^{**} = V,\ L_{1b}^{**} = 0,\ L_{2b}^{**} = V\left\{ \frac{P_2 A\big[\alpha(1+\sigma)\big](1-\alpha)}{w} \right\}^{\frac{1}{\alpha}}$.

(ii) Assume $V > V_1$.

(ii.1) If $A' \leqslant A_2$, then

$$
\begin{aligned}
S_{1b}^{*} &= \frac{\alpha}{\gamma} P_1^{\frac{1}{\alpha}} \left\{ \frac{1-\alpha}{w} \right\}^{\frac{(1-\alpha)}{\alpha}}, \\
L_{1b}^{*} &= \frac{\alpha}{\gamma} P_1^{\frac{2}{\alpha}} \left\{ \frac{1-\alpha}{w} \right\}^{\frac{(2-\alpha)}{\alpha}}, \\
S_{2b}^{*} &= \frac{\alpha}{\gamma\Phi(A)} \big(P_2 A\big[\alpha(1+\sigma)\big]\big)^{\frac{1}{\alpha}} \left\{ \frac{1-\alpha}{w} \right\}^{\frac{(1-\alpha)}{\alpha}}, \\
L_{2b}^{*} &= \frac{\alpha}{\gamma\Phi(A)} \big(P_2 A\big[\alpha(1+\sigma)\big]\big)^{\frac{2}{\alpha}} \left\{ \frac{1-\alpha}{w} \right\}^{\frac{(2-\alpha)}{\alpha}}, \\
V &> S_{1b}^{*} + S_{2b}^{*}.
\end{aligned}
$$

(ii.2) If $A_2 < A' < A_3$, then

$$
\begin{aligned}
S_{1b}^{**} &= \frac{\gamma\Phi(A)V - R}{\gamma(1+\Phi(A))} > 0, \\
L_{1b}^{**} &= \left[\frac{\gamma\Phi(A)V - R}{\gamma(1+\Phi(A))} \right] \left\{ \frac{P_1(1-\alpha)}{w} \right\}^{\frac{1}{\alpha}} > 0, \\
S_{2b}^{**} &= \frac{\gamma V + R}{\gamma(1+\Phi(A))} > 0, \\
L_{2b}^{**} &= \left[\frac{\gamma V + R}{\gamma(1+\Phi(A))} \right] \left\{ \frac{P_2 A\big[\alpha(1+\sigma)\big](1-\alpha)}{w} \right\}^{\frac{1}{\alpha}} > 0.
\end{aligned}
$$

(ii.3) If $A' \geqslant A_3$, then $S_{1b}^{**} = 0,\ S_{2b}^{**} = V,\ L_{1b}^{**} = 0,\ L_{2b}^{**} = V \left\{ \frac{P_2 A\big[\alpha(1+\sigma)\big](1-\alpha)}{w} \right\}^{\frac{1}{\alpha}}$.

The comments are similar to the ones for Proposition 2.3. However, we can observe that, since $A' = A\big[\alpha(1+\sigma)\big] > A$, compared to Scenario 2.1, the probability to produce only conventional product $(i.1)$ becomes lower and the probability to produce only organic product $(i.3, ii.3)$ becomes higher.

Scenario 2.3. ***When the government has a contract with the farmer. The farmer will have a bonus if the output of organic product is higher than some quantity $\widehat{Y_2} > 0$, i.e. $AS_2^{\alpha} L_2^{1-\alpha} \geqslant \widehat{Y_2}$. Let $\widetilde{Y}_2$ denote the output of organic product without this additional constraint. The incentive constraint will be $\widehat{Y_2} \geqslant \widetilde{Y}_2$. At the optimum we have $AS_2^{\alpha} L_2^{1-\alpha} = \widehat{Y_2}$. Indeed, suppose at the optimum, $AS_2^{\alpha} L_2^{1-\alpha} > \widehat{Y_2}$. In this case, this optimum corresponds to the problem without the constraint $AS_2^{\alpha} L_2^{1-\alpha} \geqslant \widehat{Y_2}$ and $AS_2^{\alpha} L_2^{1-\alpha} = \widetilde{Y}_2$. This is a contradiction.***

Consequently, the producer maximizes the problem $(\mathcal{P}_3)$, with m denoting the bonus:

$$\left.\begin{array}{l} \max\left\{P_1 S_1^{\alpha} L_1^{1-\alpha} - wL_1 - C(S_1) + P_2 A S_2^{\alpha} L_2^{1-\alpha} - wL_2 - \Phi(A)C(S_2) + m\right\} \\ \text{subject to} \begin{cases} S_1 + S_2 \leqslant V, \\ A S_2^{\alpha} L_2^{1-\alpha} \geqslant \widehat{Y_2}, \\ S_1 \geqslant 0,\ S_2 \geqslant 0,\ L_1 \geqslant 0,\ L_2 \geqslant 0. \end{cases} \end{array}\right\} (\mathcal{P}_3)$$

In the following proposition, for simplicity we assume that the land supply is larger than the required lands when there is no constraint on land supply. Its proof is given in Appendix 4.5.

Proposition 2.6. *Under Scenario 2.3, consider the problem* $(\mathcal{P}_3)$. *Assume that the total lands of farmer* V *is not limited,* $\frac{\alpha}{\gamma} P_1^{\frac{1}{\alpha}} \left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}} + \left\{\frac{w\alpha}{\gamma\Phi(A)}\right\}^{\frac{1-\alpha}{(2-\alpha)}} \left\{\frac{\widehat{Y_2}}{A}\right\}^{\frac{1}{(2-\alpha)}} \leqslant V$. *Then, the optimal solution is*

$$\begin{aligned} \textit{land of conventional product } S_{1c}^{*} &= \frac{\alpha}{\gamma} P_1^{\frac{1}{\alpha}} \left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}}, \\ \textit{labor of conventional product } L_{1c}^{*} &= \frac{\alpha}{\gamma} P_1^{\frac{2}{\alpha}} \left\{\frac{1-\alpha}{w}\right\}^{\frac{(2-\alpha)}{\alpha}}, \\ \textit{land of organic product } S_{2c}^{*} &= \left\{\frac{\alpha}{(1-\alpha)} \frac{w}{\gamma\Phi(A)}\right\}^{\frac{1-\alpha}{(2-\alpha)}} \left\{\frac{\widehat{Y_2}}{A}\right\}^{\frac{1}{(2-\alpha)}}, \\ \textit{labor of organic product } L_{2c}^{*} &= \left\{\frac{\alpha}{(1-\alpha)} \frac{w}{\gamma\Phi(A)}\right\}^{-\frac{\alpha}{(2-\alpha)}} \left\{\frac{\widehat{Y_2}}{A}\right\}^{\frac{2}{(2-\alpha)}}. \end{aligned}$$

In Proposition 2.6, when the land supply V is not limited, the production of organic products corresponds to demand from the government $\widehat{Y_2}$. Land and labor used for conventional products are independent from the target of products producers $\widehat{Y_2}$. At the same time, land and labor used for the organic products production in case with the target. In this case, productivity is not significant for the farmer decision.

Our result is interesting and surprising because when the farmers apply a new technology, they would be usually concerned about the productivity of the new technology. However, our result implies that farmers will not be concerned with productivity of organic products. This allows us to explain that, if productivity of organic products (new technology) is lower than the one of conventional products (old technology), it does not affect the transition to producing organic products (new technology). This finding is interesting and may help the policy makers to bring out good policy for a development strategy of organic products in the future.

3 Conclusion

In this paper, the theoretical model is formulated to describe the farmers' decisions regarding adoption of organic production, given the constraints they face. The results imply significant policy implications. This should alert all policy makers to contemplate regulations concerning agricultural production process.

In the first Scenario, the condition of adoption is derived under the assumptions including no constraint on the labor and limitation of the total quantity of land, V. If the farmer's lands are large enough and if we have a productivity A being low, e.g. $A \leqslant A_0$, then the farmers would use all their lands for the conventional product S_{1a}^{**}. If productivity A is between A_0 and A_3 ($A_0 < A < A_3$), then the farmer will produce both products. In the case of productivity A being relatively high, e.g. superior to A_3 ($A \geqslant A_3$), then the farmers will use all their lands for the organic products. In the other cases, the farmers would share out their lands to produce both products. However, in the case of a very large A, e.g. A_3 ($A \geqslant A_3$), lands would be used for planting only organic products.

In the second Scenario, a government could encourage the farmers to produce organic products by giving a subsidy $m(S_2, L_2)S_2$. The subsidy per unit of land devoted to new product depends on (S_2, L_2). To determine this subsidy, a government maximizes its benefits. Let $\sigma > 0$ denotes the mark-up rate of the government. It pays the farmers with the price P_2 but resells on the market with the price $P_2(1+\sigma)$. We obtain the following results. If lands are large enough, and if productivity is low, e.g. $A' = A\big[\alpha(1+\sigma)\big] \leqslant A_0$, then the farmers will use all their lands for the conventional products. In the case of productivity $A' = A\big[\alpha(1+\sigma)\big]$ being between A_0 and A_3 ($A_0 < A' < A_3$), the farmers would use their lands to produce both products. However, if productivity $A' = A\big[\alpha(1+\sigma)\big]$ is high, say more than A_3 ($A' \geqslant A_3$), then all lands would be used for planting only the organic product, S_{2b}^{**}. In the case lands are not large enough, the farmers would share lands for producing both products: conventional product being S_{1b}^{*} and organic product being S_{2b}^{*}. Besides this, as before, if productivity $A' = A\big[\alpha(1+\sigma)\big]$ is large, say higher than A_3 ($A' \geqslant A_3$), then all lands would be used for the organic products.

Existing studies did not consider elements of productivity of new technology that can affect its adoption (e.g., Kebede et al., 1990; Strauss et al., 1991; Rauniyar and Goode, 1992; Huang and Rozelle, 1996; Ayuk, 1997; Adesina et al., 2000; Läpple and Van Rensburg, 2011; Abebe et al., 2013; Adebayo and Oladele, 2013; Läpple and Kelley, 2015, etc.). To address these limitations, we mentioned some elements including land, labor and productivity in our model. Then, we investigate how these factors impact adoption of organic production. Our work highlights the role of productivity on farmer's behavior. We often think of the role of prices and other factors affecting the acceptance of technological change by farmers. However, in our results, price does not affect the acceptance of technological change, but the productivity is an important element affecting technology adoption. The results of Scenario 2.1 and 2.2 will bring a new point of view about the role of these factors on technological change, which most of empirical studies did not mention.

In the last Scenario, in order to give incentives for adoption of new technologies, a government could stimulate farmers to produce organic product by giving a bonus. But in exchange they impose a minimum of output of organic product. The result is as follows. If the lands are large enough, then the farmers produce both products. However, lands and labor used for conventional product are independent from the target of the government while lands and labor used for organic product are positively related to the target. Notably, the result of Scenario 2.3 indicates that the productivity is not significant for the farmer's decision. Our result implies that farmers will not be concerned about the productivity of new technology. This allows us to explain that, if productivity of new technology is lower than the one of old technology, it does not affect the towards new technology. However, if the government continues to apply this policy in the long term, then it would likely have an adverse impact, because the farmers will reliance the role of government and they will refuse the creativity to increase productivity.

Despite our classic production function (Cobb Douglas), according to our experience, to prove a problem with many tight conditions is not easy. Initially we thought it was a simple matter that we easily find out the answer, but in fact the investigation becomes complex. Fortunately, our findings are interesting and could be useful for other research applications. This study shed light on a new look and direction for further research.

In addition, the results of this chapter are not completely confined in the agricultural literature. It is possible to open up applications in other fields related to technology transfer.

4 Appendix

4.1 Appendix 1: Proof of Lemma 2.1

Proof. Denote

$$M = \max\Big\{P_1 S_1^{\alpha} L_1^{1-\alpha} - wL_1 - C(S_1) + P_2 A S_2^{\alpha} L_2^{1-\alpha} - wL_2 - \Phi(A)C(S_2)\Big\}$$

$$\text{subject to} \begin{cases} S_1 + S_2 \leqslant V, \\ S_1 \geqslant 0,\ S_2 \geqslant 0,\ L_1 \geqslant 0,\ L_2 \geqslant 0. \end{cases}$$

Observe $M \geqslant 0$ (take $S_1 = S_2 = L_1 = L_2 = 0$).

(a) Suppose $S_1^* > 0$ and $L_1^* = 0$. Then,

$$P_1 S_1^{*\alpha} L_1^{*1-\alpha} - wL_1^* - C(S_1^*) = -C(S_1^*).$$

For $\varepsilon > 0$, define $\eta(\varepsilon) = P_1 S_1^{*\alpha} \varepsilon^{1-\alpha} - w\varepsilon$. We have

$$\frac{\eta(\varepsilon)}{\varepsilon} = P_1 S_1^{*\alpha} \varepsilon^{-\alpha} - w \to +\infty \text{ as } \varepsilon \to 0.$$

Hence, $\eta(\varepsilon) > 0$ for $\varepsilon > 0$, small enough. Take $L_1 = \varepsilon$. We get, for $\varepsilon > 0$, small enough

$$P_1 S_1^{*\alpha} L_1^{1-\alpha} - wL_1^* - C(S_1^*) = \eta(\varepsilon) - C(S_1^*) > -C(S_1^*)$$

which is a contradiction since L_1^* is the optimal value. Thus $S_1^* > 0 \Rightarrow L_1^* > 0$.

(b) Let us prove the converse. Assume $L_1^* > 0$ and $S_1^* = 0$. Then,

$$P_1 S_1^{*\alpha} L_1^{1-\alpha} - C(S_1^*) - wL_1^* = -wL_1^*.$$

For $\varepsilon > 0$, define $\eta(\varepsilon) = P_1 \varepsilon^{\alpha} L_1^{*1-\alpha} - \dfrac{\gamma\varepsilon^2}{2}$. We have

$$\frac{\eta(\varepsilon)}{\varepsilon} = P_1 \varepsilon^{\alpha-1} L_1^{*1-\alpha} - \frac{\gamma\varepsilon}{2} \to +\infty \text{ as } \varepsilon \to 0.$$

Hence, $\eta(\varepsilon) > 0$ for $\varepsilon > 0$, small enough. Take $S_1 = \varepsilon$. We get, for $\varepsilon > 0$, small enough

$$P_1 S_1^{*\alpha} L_1^{1-\alpha} - C(S_1^*) - wL_1^* = \eta(\varepsilon) - wL_1^* > -wL_1^*$$

which is a contradiction since S_1^* is the optimal value. Thus $L_1^* > 0 \Rightarrow S_1^* > 0$. The proof is similar for $S_2^* > 0 \Leftrightarrow L_2^* > 0$. □

4.2 Appendix 2: Proof of Proposition 2.1

Proof. Let $\mathfrak{L}$ denote the Lagrangian. Assume first the optimal values of land and labor are strictly positive. We have

$$\begin{aligned} \mathfrak{L} \;\; = \;\; & \Big\{ P_1 S_1^{\alpha} L_1^{1-\alpha} - wL_1 - C(S_1) + P_2 A S_2^{\alpha} L_2^{1-\alpha} - wL_2 - \Phi(A)C(S_2) \\ & - \lambda(S_1 + S_2 - V) + \mu_1 S_1 + \mu_2 S_2 + \beta_1 L_1 + \beta_2 L_2 \Big\}, \end{aligned}$$

with some conditions as $\lambda \geqslant 0,\ \mu_1 \geqslant 0,\ \mu_2 \geqslant 0,\ \beta_1 \geqslant 0,\ \beta_2 \geqslant 0$. Assume first the optimal values $S_1^*,\ L_1^*,\ S_2^*,\ L_2^*$ are strictly positive. We obtain the following First Order

Conditions (FOC)

$$\frac{\partial \mathfrak{L}}{\partial S_1} = 0 \Leftrightarrow P_1\alpha\left(\frac{L_1^*}{S_1^*}\right)^{1-\alpha} - C'(S_1^*) - \lambda + \mu_1 = 0 \tag{1}$$

$$\text{or } P_1\alpha\,(L_1^*)^{1-\alpha} - C'(S_1^*)\,(S_1^*)^{1-\alpha} - (\lambda-\mu_1)\,(S_1^*)^{1-\alpha} = 0$$

$$\frac{\partial \mathfrak{L}}{\partial L_1} = 0 \Leftrightarrow P_1(1-\alpha)\left(\frac{S_1^*}{L_1^*}\right)^{\alpha} - w + \beta_1 = 0 \tag{2}$$

$$\text{or } P_1(1-\alpha)\,(S_1^*)^{\alpha} - (w-\beta_1)\,(L_1^*)^{\alpha} = 0$$

$$\frac{\partial \mathfrak{L}}{\partial S_2} = 0 \Leftrightarrow P_2A\alpha\left(\frac{L_2^*}{S_2^*}\right)^{1-\alpha} - \Phi(A)C'(S_2^*) - \lambda + \mu_2 = 0 \tag{3}$$

$$\frac{\partial \mathfrak{L}}{\partial L_2} = 0 \Leftrightarrow P_2A(1-\alpha)\left(\frac{S_2^*}{L_2^*}\right)^{\alpha} - w + \beta_2 = 0 \tag{4}$$

$$\lambda(S_1^* + S_2^* - V) = 0 \tag{5}$$

$$\mu_1 S_1 = 0,\ \beta_1 L_1 = 0,\ \mu_2 S_2 = 0,\ \beta_2 L_2 = 0. \tag{6}$$

Since we assume the optimal values $S_1^*,\ L_1^*,\ S_2^*,\ L_2^*$ are strictly positive, from (6) we have $\mu_1 = \mu_2 = \beta_1 = \beta_2 = 0$. From equation (2), we have

$$\left(\frac{S_1^*}{L_1^*}\right)^{\alpha} = \frac{w}{P_1(1-\alpha)} \Leftrightarrow \left(\frac{L_1^*}{S_1^*}\right)^{(1-\alpha)} = \left\{\frac{P_1(1-\alpha)}{w}\right\}^{\frac{(1-\alpha)}{\alpha}}. \tag{7}$$

From equations (1) and (7), we obtain

$$P_1^{\frac{1}{\alpha}}\alpha\left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}} = \lambda + C'(S_1^*) = \lambda + \gamma S_1^*. \tag{8}$$

From equation (4), we get

$$\left(\frac{S_2^*}{L_2^*}\right)^{\alpha} = \frac{w}{P_2A(1-\alpha)} \Leftrightarrow \left(\frac{L_2^*}{S_2^*}\right)^{(1-\alpha)} = \left\{\frac{P_2A(1-\alpha)}{w}\right\}^{\frac{(1-\alpha)}{\alpha}}. \tag{9}$$

From equations (3) and (9), we have the following result

$$(P_2A)^{\frac{1}{\alpha}}\alpha\left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}} = \lambda + \Phi(A)C'(S_2^*) = \lambda + \gamma\Phi(A)S_2^*. \tag{10}$$

From equations (8) and (10) lead to

$$(P_2A)^{\frac{1}{\alpha}}\alpha\left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}} - P_1^{\frac{1}{\alpha}}\alpha\left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}} = \gamma[\Phi(A)S_2^* - S_1^*]. \tag{11}$$

Assume λ strictly positive, in this case $S_1^* + S_2^* = V$ and collaborate with equations (8) and (10), we obtain

$$P_1^{\frac{1}{\alpha}}\alpha\left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}} > \gamma S_1^* \tag{12}$$

$$(P_2A)^{\frac{1}{\alpha}}\alpha\left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}} > \gamma\Phi(A)S_2^*. \tag{13}$$

Basing on equations (12) and (13), it can be seen that $Q(P_1, P_2, \alpha, w, \Phi, \gamma, A) > S_1^* + S_2^*$.

(i) If $V \geqslant Q(P_1, P_2, \alpha, w, \Phi, \gamma, A)$. In addition, from equation (8) lead to

$$\frac{\alpha}{\gamma} P_1^{\frac{1}{\alpha}} \left\{ \frac{1-\alpha}{w} \right\}^{\frac{(1-\alpha)}{\alpha}} = \frac{\lambda}{\gamma} + S_1^*. \tag{14}$$

It comes from equation (10) that

$$\frac{\alpha}{\gamma \Phi(A)} (P_2 A)^{\frac{1}{\alpha}} \left\{ \frac{1-\alpha}{w} \right\}^{\frac{(1-\alpha)}{\alpha}} = \frac{\lambda}{\gamma \Phi(A)} + S_2^*. \tag{15}$$

From equations (14) and (15), we have

$$\frac{\alpha}{\gamma} P_1^{\frac{1}{\alpha}} \left\{ \frac{1-\alpha}{w} \right\}^{\frac{(1-\alpha)}{\alpha}} + \frac{\alpha}{\gamma \Phi(A)} (P_2 A)^{\frac{1}{\alpha}} \left\{ \frac{1-\alpha}{w} \right\}^{\frac{(1-\alpha)}{\alpha}} = \frac{\lambda}{\gamma} \left\{ 1 + \frac{1}{\Phi(A)} \right\} + S_2^* + S_1^*. \tag{16}$$

Recall that

$$Q(P_1, P_2, \alpha, w, \Phi, \gamma, A) = \frac{\alpha}{\gamma} P_1^{\frac{1}{\alpha}} \left\{ \frac{1-\alpha}{w} \right\}^{\frac{(1-\alpha)}{\alpha}} + \frac{\alpha}{\gamma \Phi(A)} (P_2 A)^{\frac{1}{\alpha}} \left\{ \frac{1-\alpha}{w} \right\}^{\frac{(1-\alpha)}{\alpha}}.$$

If $\lambda > 0$ then $V = S_1^* + S_2^*$ that is a contradiction. Indeed, calculation from equation (16) shows that

$$V = Q(P_1, P_2, \alpha, w, \Phi, \gamma, A) = \frac{\lambda}{\gamma} \left\{ 1 + \frac{1}{\Phi(A)} \right\} + V > V.$$

Therefore, $\lambda = 0$, then we have

$$\begin{aligned}
\text{land of conventional product} \quad S_{1a}^* &= \frac{\alpha}{\gamma} P_1^{\frac{1}{\alpha}} \left\{ \frac{1-\alpha}{w} \right\}^{\frac{(1-\alpha)}{\alpha}}, \\
\text{labor of conventional product} \quad L_{1a}^* &= \frac{\alpha}{\gamma} P_1^{\frac{2}{\alpha}} \left\{ \frac{1-\alpha}{w} \right\}^{\frac{(2-\alpha)}{\alpha}}, \\
\text{land of organic product} \quad S_{2a}^* &= \frac{\alpha}{\gamma \Phi(A)} (P_2 A)^{\frac{1}{\alpha}} \left\{ \frac{1-\alpha}{w} \right\}^{\frac{(1-\alpha)}{\alpha}}, \\
\text{labor of organic product} \quad L_{2a}^* &= \frac{\alpha}{\gamma \Phi(A)} (P_2 A)^{\frac{2}{\alpha}} \left\{ \frac{1-\alpha}{w} \right\}^{\frac{(2-\alpha)}{\alpha}}.
\end{aligned}$$

Since $S_{1a}^* + S_{2a}^* = Q(P_1, P_2, \alpha, w, \Phi, \gamma, A)$, we have $S_{1a}^* + S_{2a}^* < V$ if $V > Q(P_1, P_2, \alpha, w, \Phi, \gamma, A)$ and $S_{1a}^* + S_{2a}^* = V$ if $V = Q(P_1, P_2, \alpha, w, \Phi, \gamma, A)$.

(ii) Consider $V < Q(P_1, P_2, \alpha, w, \Phi, \gamma, A)$, if $\lambda = 0$ then $S_1^* + S_2^* = Q(P_1, P_2, \alpha, w, \Phi, \gamma, A)$, and $\lambda = 0$ is absurd. Thus, we have $\lambda > 0$. This implies $S_1^* + S_2^* = V$. Recall that

$$\begin{aligned}
R &= (P_2 A)^{\frac{1}{\alpha}} \alpha \left\{ \frac{1-\alpha}{w} \right\}^{\frac{(1-\alpha)}{\alpha}} - P_1^{\frac{1}{\alpha}} \alpha \left\{ \frac{1-\alpha}{w} \right\}^{\frac{(1-\alpha)}{\alpha}} \\
&= \left[(P_2 A)^{\frac{1}{\alpha}} - P_1^{\frac{1}{\alpha}} \right] \alpha \left\{ \frac{1-\alpha}{w} \right\}^{\frac{(1-\alpha)}{\alpha}}.
\end{aligned}$$

From equation (11), we have

$$R = \gamma[\Phi(A)S_2^* - S_1^*] = \gamma\Big[\Phi(A)V - S_1^*(1+\Phi(A))\Big]. \tag{17}$$

From equation (17), we get

$$\gamma S_1^*(1+\Phi(A)) = \gamma\Phi(A)V - R. \tag{18}$$

From equation (18), we obtain

$$\begin{aligned}
S_1^* &= \frac{\gamma\Phi(A)V - R}{\gamma(1+\Phi(A))} \text{ if } \gamma\Phi(A)V - R \geqslant 0\\
S_1^* &= 0 \text{ if } \gamma\Phi(A)V - R \leqslant 0\\
S_2^* &= \frac{\gamma V + R}{\gamma(1+\Phi(A))} \text{ if } \gamma V + R \geqslant 0\\
S_2^* &= 0 \text{ otherwise.}
\end{aligned}$$

(ii.a1) If $\frac{R}{\gamma\Phi(A)} < V < Q(P_1, P_2, \alpha, w, \Phi, \gamma, A)$. $S_1^* \geqslant 0$ if and only if $\gamma\Phi(A)V - R \geqslant 0$ or $\gamma\Phi(A)V \geqslant R$. We have

$$\begin{aligned}
\gamma\Phi(A)V &> (P_2A)^{\frac{1}{\alpha}}\alpha\left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}} - P_1^{\frac{1}{\alpha}}\alpha\left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}}\\
\Leftrightarrow V &> \frac{\alpha}{\gamma\Phi(A)}(P_2A)^{\frac{1}{\alpha}}\left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}} - \frac{\alpha}{\gamma\Phi(A)}P_1^{\frac{1}{\alpha}}\left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}}\\
\Leftrightarrow V &> \frac{R}{\gamma\Phi(A)},
\end{aligned}$$

with the condition $V < Q(P_1, P_2, \alpha, w, \Phi, \gamma, A)$ or equivalently

$$V < \frac{\alpha}{\gamma}P_1^{\frac{1}{\alpha}}\left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}} + \frac{\alpha}{\gamma\Phi(A)}(P_2A)^{\frac{1}{\alpha}}\left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}}.$$

We find the land of conventional product $S_{1a}^{**} = \frac{\gamma\Phi(A)V - R}{\gamma(1+\Phi(A))} > 0$.

From equation (7), we obtain $L_{1a}^{**} = \left[\frac{\gamma\Phi(A)V - R}{\gamma(1+\Phi(A))}\right]\left\{\frac{P_1(1-\alpha)}{w}\right\}^{\frac{1}{\alpha}} > 0$.

When $S_2^* + S_1^* = V$, we obtain $S_{2a}^{**} = \frac{\gamma V + R}{\gamma(1+\Phi(A))}$.

From equation (9), we obtain $L_{2a}^{**} = \left[\frac{\gamma V + R}{\gamma(1+\Phi(A))}\right]\left\{\frac{P_2A(1-\alpha)}{w}\right\}^{\frac{1}{\alpha}}$.

(ii.a2) If $V \leqslant \frac{R}{\gamma\Phi(A)}$. We have $\gamma\Phi(A)V - R \leqslant 0$ or $\gamma\Phi(A)V \leqslant R$. The optimal solution for S_{1a}^{**} cannot be anymore strictly positive. Hence, $S_{1a}^{**} = 0$. We easily obtain

$$S_{1a}^{**} = 0,\ S_{2a}^{**} = V,\ L_{1a}^{**} = 0,\ L_{2a}^{**} = V\left\{\frac{P_2A(1-\alpha)}{w}\right\}^{\frac{1}{\alpha}}.$$

(ii.b1) If $R < 0$ and $-\frac{R}{\gamma} < V < Q(P_1, P_2, \alpha, w, \Phi, \gamma, A)$ then by the same computations as in (ii.a1), we obtain

$$\begin{aligned}
S_{1a}^{**} &= \frac{\gamma\Phi(A)V - R}{\gamma(1+\Phi(A))} > 0, \\
L_{1a}^{**} &= \left[\frac{\gamma\Phi(A)V - R}{\gamma(1+\Phi(A))}\right]\left\{\frac{P_1(1-\alpha)}{w}\right\}^{\frac{1}{\alpha}} > 0, \\
S_{2a}^{**} &= \frac{\gamma V + R}{\gamma(1+\Phi(A))} > 0, \\
L_{2a}^{**} &= \left[\frac{\gamma V + R}{\gamma(1+\Phi(A))}\right]\left\{\frac{P_2 A(1-\alpha)}{w}\right\}^{\frac{1}{\alpha}} > 0.
\end{aligned}$$

(ii.b2) If $V \leqslant -\frac{R}{\gamma}$ (observe that $Q(P_1, P_2, \alpha, w, \Phi, \gamma, A) + \frac{R}{\gamma} > 0$) then S_{2a}^{**} cannot be anymore non-negative. We have

$$S_{2a}^{**} = 0,\ S_{1a}^{**} = V,\ L_{2a}^{**} = 0,\ L_{1a}^{**} = V\left\{\frac{P_1(1-\alpha)}{w}\right\}^{\frac{1}{\alpha}}.$$

□

4.3 Appendix 3: Proof of Lemma 2.2

Proof.

(i) The proof is obvious.

(ii.1) We have

$$\begin{aligned}
Q(P_1, P_2, \alpha, w, \Phi, \gamma, A) &= \frac{\alpha}{\gamma} P_1^{\frac{1}{\alpha}} \left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}} + \frac{\alpha}{\gamma\Phi(A)} (P_2 A)^{\frac{1}{\alpha}} \left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}} \\
&= \frac{\alpha}{\gamma} P_1^{\frac{1}{\alpha}} \left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}} \left[1 + \frac{1}{\Phi(A)}\left(\frac{A}{A_1}\right)^{\frac{1}{\alpha}}\right] \\
&= V_1 \times \left[1 + \frac{1}{\Phi(A)}\left(\frac{A}{A_1}\right)^{\frac{1}{\alpha}}\right].
\end{aligned}$$

Hence,

$$\begin{aligned}
V < Q(P_1, P_2, \alpha, w, \Phi, \gamma, A) \quad &\Leftrightarrow \quad \left[\frac{V}{V_1} - 1\right] < \frac{1}{A_1^{\frac{1}{\alpha}}} \times \frac{A^{\frac{1}{\alpha}}}{\Phi(A)} \\
&\Leftrightarrow \quad \frac{A^{\frac{1}{\alpha}}}{\Phi(A)} > A_1^{\frac{1}{\alpha}} \times \left[\frac{V}{V_1} - 1\right].
\end{aligned}$$

Let

$$\phi(A) = \frac{A^{\frac{1}{\alpha}}}{\Phi(A)}.$$

Since Φ is concave, the function ϕ is increasing. Let A_2 be defined by

$$\frac{{A_2}^{\frac{1}{\alpha}}}{\Phi(A_2)} = A_1^{\frac{1}{\alpha}} \times \left[\frac{V}{V_1} - 1\right].$$

Then obviously,

$$V \leqslant Q(P_1, P_2, \alpha, w, \Phi, \gamma, A) \Leftrightarrow A \geqslant A_2.$$

If $\dfrac{A_1^{\frac{1}{\alpha}}}{\Phi(A_1)} < A_1^{\frac{1}{\alpha}} \times \left[\dfrac{V}{V_1} - 1\right]$ or equivalently $\dfrac{1}{\Phi(A_1)} < \left[\dfrac{V}{V_1} - 1\right]$ then $A_2 > A_1$ since function ϕ is increasing. If $\dfrac{1}{\Phi(A_1)} = \left[\dfrac{V}{V_1} - 1\right]$ then $A_2 = A_1$ and obviously $\dfrac{1}{\Phi(A_1)} > \left[\dfrac{V}{V_1} - 1\right]$ then $A_2 < A_1$.

(ii.2) Let

$$\psi(A) = \frac{A^{\frac{1}{\alpha}} - A_1^{\frac{1}{\alpha}}}{\Phi(A)} \times \frac{1}{A_1^{\frac{1}{\alpha}}}.$$

Function ψ is increasing since ϕ is increasing. It satisfies $\psi(0) = -\infty$, $\psi(A_1) = 0$. Therefore $A_3 > A_1$ since $\psi(A_3) = \dfrac{V}{V_1}$. Now, observe that

$$\frac{A_3^{\frac{1}{\alpha}}}{\Phi(A_3)} = A_1^{\frac{1}{\alpha}} \times \frac{V}{V_1} + \frac{A_1^{\frac{1}{\alpha}}}{\Phi(A_3)}$$

while A_2 verifies

$$\frac{A_2^{\frac{1}{\alpha}}}{\Phi(A_2)} = A_1^{\frac{1}{\alpha}} \times \left[\frac{V}{V_1} - 1\right],$$

hence $A_3 > A_2$.

Since

$$R = (P_2 A)^{\frac{1}{\alpha}} \alpha \left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}} - P_1^{\frac{1}{\alpha}} \alpha \left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}},$$

we get,

$$\frac{R}{\gamma\Phi(A)} = \frac{1}{A_1^{\frac{1}{\alpha}}} \times \left[\frac{A^{\frac{1}{\alpha}} - A_1^{\frac{1}{\alpha}}}{\Phi(A)}\right] V_1.$$

We have

$$\begin{aligned}
\frac{R}{\gamma\Phi(A)} < V \quad &\Leftrightarrow \psi(A) < \frac{V}{V_1} = \psi(A_3) \Leftrightarrow A < A_3, \\
\frac{R}{\gamma\Phi(A)} = V \quad &\Leftrightarrow \psi(A) = \frac{V}{V_1} = \psi(A_3) \Leftrightarrow A = A_3.
\end{aligned}$$

(ii.3) Since

$$R = (P_2 A)^{\frac{1}{\alpha}} \alpha \left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}} - P_1^{\frac{1}{\alpha}} \alpha \left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}},$$

we have

$$-\frac{R}{\gamma} = V_1 \times \left[1 - \left(\frac{A}{A_1}\right)^{\frac{1}{\alpha}}\right].$$

Hence,

$$V+\frac{R}{\gamma} = V-V_1\times\left[1-\left(\frac{A}{A_1}\right)^{\frac{1}{\alpha}}\right]=V-V_1+V_1\left(\frac{A}{A_1}\right)^{\frac{1}{\alpha}}$$
$$> V-V_1>0.$$

Thus, $V+\frac{R}{\gamma}>0$, and we find $V>-\frac{R}{\gamma}$.

(iii.1) Since (ii.3), we have

$$-\frac{R}{\gamma}=V_1\times\left[1-\left(\frac{A}{A_1}\right)^{\frac{1}{\alpha}}\right].$$

Hence

$$\begin{aligned} V\leqslant-\frac{R}{\gamma} &\Leftrightarrow V\leqslant V_1\times\left[1-\left(\frac{A}{A_1}\right)^{\frac{1}{\alpha}}\right]\\ &\Leftrightarrow \left(\frac{A}{A_1}\right)^{\frac{1}{\alpha}}\leqslant\left[1-\frac{V}{V_1}\right]\\ &\Leftrightarrow A\leqslant A_1\times\left[1-\frac{V}{V_1}\right]^{\alpha}=A_0\Leftrightarrow A\leqslant A_0. \end{aligned}$$

(iii.2) Let

$$\psi(A)=\frac{A^{\frac{1}{\alpha}}-A_1^{\frac{1}{\alpha}}}{\Phi(A)}\times\frac{1}{A_1^{\frac{1}{\alpha}}}.$$

Function ψ is increasing since ϕ is increasing. It satisfies $\psi(0)=-\infty$, $\psi(A_1)=0$. Therefore $A_3>A_1$ since $\psi(A_3)=\frac{V}{V_1}$. Since

$$\frac{R}{\gamma\Phi(A)}=\frac{1}{A_1^{\frac{1}{\alpha}}}\times\left[\frac{A^{\frac{1}{\alpha}}-A_1^{\frac{1}{\alpha}}}{\Phi(A)}\right]V_1,$$

we have

$$\frac{R}{\gamma\Phi(A)}\leqslant V \quad\Leftrightarrow\psi(A)\leqslant\frac{V}{V_1}=\psi(A_3)\Leftrightarrow A\leqslant A_3.$$

□

4.4 Appendix 4: Proof of Proposition 2.3

Proof.

(i.1) We have $A_0<A_1$, hence $A\leqslant A_0\Rightarrow A<A_1\Leftrightarrow R<0$ (see (i) of Lemma 2.2). From (iii.1) of Lemma 2.2 we have $A\leqslant A_0\Leftrightarrow V\leqslant-\frac{R}{\gamma}$. From (ii.b2) of Proposition 2.1, we get

$$S_{2a}^{**}=0,\ S_{1a}^{**}=V,\ L_{2a}^{**}=0,\ L_{1a}^{**}=V\left\{\frac{P_1(1-\alpha)}{w}\right\}^{\frac{1}{\alpha}}.$$

(i.2) We have $A_1 < A_3$ (see (iii.2) of Lemma 2.2). First suppose $A_0 < A < A_1$. We know that $A < A_1 \Leftrightarrow R < 0$ from (i) of Lemma 2.2, and $A_0 < A \Leftrightarrow V > -\dfrac{R}{\gamma}$ from (iii.1) of the same lemma. We have

$$-\frac{R}{\gamma} < V \leqslant V_1 < Q(P_1, P_2, \alpha, w, \Phi, \gamma, A).$$

Use (ii.b1) of Proposition 2.1. Now suppose $A_1 \leqslant A < A_3$. If $A_1 \leqslant A \Leftrightarrow R \geqslant 0$ from (i) of Lemma 2.2 and $A < A_3 \Leftrightarrow \dfrac{R}{\gamma\Phi(A)} < V$. We have

$$R \geqslant 0,\ \frac{R}{\gamma\Phi(A)} < V \leqslant V_1 < Q(P_1, P_2, \alpha, w, \Phi, \gamma, A).$$

Use (ii.a1) of Proposition 2.1. Both cases imply

$$\begin{aligned}
S^{**}_{1a} &= \frac{\gamma\Phi(A)V - R}{\gamma(1+\Phi(A))} > 0,\\
L^{**}_{1a} &= \left[\frac{\gamma\Phi(A)V - R}{\gamma(1+\Phi(A))}\right]\left\{\frac{P_1(1-\alpha)}{w}\right\}^{\frac{1}{\alpha}} > 0,\\
S^{**}_{2a} &= \frac{\gamma V + R}{\gamma(1+\Phi(A))} > 0,\\
L^{**}_{2a} &= \left[\frac{\gamma V + R}{\gamma(1+\Phi(A))}\right]\left\{\frac{P_2A(1-\alpha)}{w}\right\}^{\frac{1}{\alpha}} > 0.
\end{aligned}$$

(i.3) We know that $A_3 > A_1$ (see (iii.2) of Lemma 2.2). Hence $A \geqslant A_3 \Rightarrow A > A_1 \Leftrightarrow R > 0$. But $A \geqslant A_3 \Leftrightarrow V \leqslant \dfrac{R}{\gamma\Phi(A)}$ (see (ii.2) of Lemma 2.2). Use (ii.a2) of Proposition 2.1 to get the results

$$S^{**}_{1a} = 0,\ S^{**}_{2a} = V,\ L^{**}_{1a} = 0,\ L^{**}_{2a} = V\left\{\frac{P_2A(1-\alpha)}{w}\right\}^{\frac{1}{\alpha}}.$$

(ii) We distinguish two cases:

(ii.a) $V \geqslant V_1\left\{1 + \dfrac{1}{\Phi(A_1)}\right\} \Leftrightarrow A_2 \geqslant A_1$,

(ii.b) $V_1 < V < V_1\left\{1 + \dfrac{1}{\Phi(A_1)}\right\} \Leftrightarrow A_1 > A_2$.

(ii.a1) We have $A \leqslant A_2 \Leftrightarrow V \geqslant Q(P_1, P_2, \alpha, w, \Phi, \gamma, A)$. From (i) of Proposition 2.1, we get

$$\begin{aligned}
S^{*}_{1a} &= \frac{\alpha}{\gamma}P_1^{\frac{1}{\alpha}}\left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}},\\
L^{*}_{1a} &= \frac{\alpha}{\gamma}P_1^{\frac{2}{\alpha}}\left\{\frac{1-\alpha}{w}\right\}^{\frac{(2-\alpha)}{\alpha}},\\
S^{*}_{2a} &= \frac{\alpha}{\gamma\Phi(A)}(P_2A)^{\frac{1}{\alpha}}\left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}},\\
L^{*}_{2a} &= \frac{\alpha}{\gamma\Phi(A)}(P_2A)^{\frac{2}{\alpha}}\left\{\frac{1-\alpha}{w}\right\}^{\frac{(2-\alpha)}{\alpha}},\\
V &> S^{*}_{1a} + S^{*}_{2a}.
\end{aligned}$$

(ii.a2) If $A > A_2$ then $A > A_1 \Rightarrow R > 0$. Also

$$\begin{aligned} A > A_2 &\Leftrightarrow V < Q(P_1, P_2, \alpha, w, \Phi, \gamma, A) \\ A < A_3 &\Leftrightarrow \frac{R}{\gamma\Phi(A)} < V. \end{aligned}$$

Use (ii.a1) of Proposition 2.1 to get

$$\begin{aligned} S_{1a}^{**} &= \frac{\gamma\Phi(A)V - R}{\gamma(1+\Phi(A))} > 0, \\ L_{1a}^{**} &= \left[\frac{\gamma\Phi(A)V - R}{\gamma(1+\Phi(A))}\right]\left\{\frac{P_1(1-\alpha)}{w}\right\}^{\frac{1}{\alpha}} > 0, \\ S_{2a}^{**} &= \frac{\gamma V + R}{\gamma(1+\Phi(A))} > 0, \\ L_{2a}^{**} &= \left[\frac{\gamma V + R}{\gamma(1+\Phi(A))}\right]\left\{\frac{P_2 A(1-\alpha)}{w}\right\}^{\frac{1}{\alpha}} > 0. \end{aligned}$$

(ii.a3) If $A \geqslant A_3$ then $A > A_1 \Rightarrow R > 0$ and $V \leqslant \dfrac{R}{\gamma\Phi(A)}$ (see (ii.1) of Lemma 2.2). Use (ii.a2) of Proposition 2.1 to obtain

$$S_{1a}^{**} = 0,\ S_{2a}^{**} = V,\ L_{1a}^{**} = 0,\ L_{2a}^{**} = V\left\{\frac{P_2 A(1-\alpha)}{w}\right\}^{\frac{1}{\alpha}}.$$

(ii.b1) We have $A \leqslant A_2 \Leftrightarrow V \geqslant Q(P_1, P_2, \alpha, w, \Phi, \gamma, A)$. From (i) of Proposition 2.1, we get

$$\begin{aligned} S_{1a}^{*} &= \frac{\alpha}{\gamma} P_1^{\frac{1}{\alpha}} \left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}}, \\ L_{1a}^{*} &= \frac{\alpha}{\gamma} P_1^{\frac{2}{\alpha}} \left\{\frac{1-\alpha}{w}\right\}^{\frac{(2-\alpha)}{\alpha}}, \\ S_{2a}^{*} &= \frac{\alpha}{\gamma\Phi(A)} (P_2 A)^{\frac{1}{\alpha}} \left\{\frac{1-\alpha}{w}\right\}^{\frac{(1-\alpha)}{\alpha}}, \\ L_{2a}^{*} &= \frac{\alpha}{\gamma\Phi(A)} (P_2 A)^{\frac{2}{\alpha}} \left\{\frac{1-\alpha}{w}\right\}^{\frac{(2-\alpha)}{\alpha}}, \\ V &> S_{1a}^{*} + S_{2a}^{*}. \end{aligned}$$

(ii.b2) We first consider the case $A_2 < A \leqslant A_1$. We have successively

$$\begin{aligned} A \leqslant A_1 &\Leftrightarrow R \leqslant 0 \text{ (see (i) of Lemma 2.2)} \\ A > A_2 &\Leftrightarrow V < Q(P_1, P_2, \alpha, w, \Phi, \gamma, A) \text{ (see (ii.1) of Lemma 2.2)} \\ V > V_1 &\Rightarrow V > -\frac{R}{\gamma} \text{ (see (ii.3) of Lemma 2.2).} \end{aligned}$$

Hence

$$-\frac{R}{\gamma} < V < Q(P_1, P_2, \alpha, w, \Phi, \gamma, A).$$

Use (ii.b1) of Proposition 2.1. Now, consider the case $A_1 < A < A_3$. We have successively

$$\begin{array}{lll} A > A_1 & \Leftrightarrow & R > 0 \text{ (see (i) of Lemma 2.2)} \\ A > A_1 & \Rightarrow & A > A_2 \Leftrightarrow V < Q(P_1, P_2, \alpha, w, \Phi, \gamma, A) \text{ (see (ii.1) of Lemma 2.2)} \\ A < A3 & \Leftrightarrow & V > \dfrac{R}{\gamma\Phi(A)} \text{ (see (ii.2) of Lemma 2.2).} \end{array}$$

To sum up

$$R > 0,\ \frac{R}{\gamma\Phi(A)} < V < Q(P_1, P_2, \alpha, w, \Phi, \gamma, A).$$

Use (ii.a1) of Proposition 2.1. Both cases give

$$\begin{aligned} S_{1a}^{**} &= \frac{\gamma\Phi(A)V - R}{\gamma(1+\Phi(A))} > 0, \\ L_{1a}^{**} &= \left[\frac{\gamma\Phi(A)V - R}{\gamma(1+\Phi(A))}\right]\left\{\frac{P_1(1-\alpha)}{w}\right\}^{\frac{1}{\alpha}} > 0, \\ S_{2a}^{**} &= \frac{\gamma V + R}{\gamma(1+\Phi(A))} > 0, \\ L_{2a}^{**} &= \left[\frac{\gamma V + R}{\gamma(1+\Phi(A))}\right]\left\{\frac{P_2 A(1-\alpha)}{w}\right\}^{\frac{1}{\alpha}} > 0. \end{aligned}$$

(ii.b3) Now assume $A \geqslant A_3$. If $A \geqslant A_3$ then $A > A_1 \Rightarrow R > 0$ and $V \leqslant \dfrac{R}{\gamma\Phi(A)}$ (see (ii.2) of Lemma 2.2). Use (ii.a2) of Proposition 2.1 to obtain

$$S_{1a}^{**} = 0,\ S_{2a}^{**} = V,\ L_{1a}^{**} = 0,\ L_{2a}^{**} = V\left\{\frac{P_2 A(1-\alpha)}{w}\right\}^{\frac{1}{\alpha}}.$$

□

4.5 Appendix 5: Proof of Proposition 2.6

Proof. We have

$$Y_2^* = \widehat{Y_2} \Leftrightarrow A S_2^{*\alpha} L_2^{*1-\alpha} = \widehat{Y_2} \Leftrightarrow A L_2^{*1-\alpha} = \widehat{Y_2} S_2^{*-\alpha}.$$

The problem of the producer is

$$\max\{P_1 S_1^\alpha L_1^{1-\alpha} - wL_1 - C(S_1) + P_2\widehat{Y_2} - w\left\{\frac{\widehat{Y_2}}{A}\right\}^{\frac{1}{(1-\alpha)}} S_2^{-\frac{\alpha}{(1-\alpha)}} - \Phi(A)C(S_2)$$

using the constraints

$$S_1 \geqslant 0,\ S_2 \geqslant 0,\ L_1 \geqslant 0,\ S_1 + S_2 \leqslant V.$$

Assume the optimal values of land and labor are strictly positive. Let $\mathfrak{L}$ denote the Lagrangian. We have

$$\begin{aligned} \mathfrak{L} &= \Big\{P_1 S_1^\alpha L_1^{1-\alpha} - wL_1 - C(S_1) + P_2\widehat{Y_2} \\ &\quad - w\left\{\frac{\widehat{Y_2}}{A}\right\}^{\frac{1}{(1-\alpha)}} S_2^{-\frac{\alpha}{(1-\alpha)}} - \Phi(A)C(S_2) - \lambda(S_1 + S_2 - V)\Big\} \end{aligned}$$

with $\lambda \geqslant 0,\ \lambda(S_1 + S_2 - V) = 0.$

We obtain the following First Order Conditions (FOC)

$$\frac{\partial \mathfrak{L}}{\partial S_1} = 0 \Leftrightarrow P_1 \alpha \left(\frac{L_1^*}{S_1^*} \right)^{1-\alpha} - C'(S_1^*) - \lambda = 0 \tag{19}$$

$$\frac{\partial \mathfrak{L}}{\partial L_1} = 0 \Leftrightarrow P_1(1-\alpha) \left(\frac{S_1^*}{L_1^*} \right)^{\alpha} - w = 0 \tag{20}$$

$$\frac{\partial \mathfrak{L}}{\partial S_2} = 0 \Leftrightarrow w \left\{ \frac{\widehat{Y_2}}{A} \right\}^{\frac{1}{(1-\alpha)}} \frac{\alpha}{(1-\alpha)} S_2^{-\frac{1}{(1-\alpha)}} - \Phi(A) C'(S_2^*) - \lambda = 0 \tag{21}$$

$$\lambda(S_1^* + S_2^* - V) = 0. \tag{22}$$

From equation (20), we have

$$\left(\frac{S_1^*}{L_1^*} \right)^{\alpha} = \frac{w}{P_1(1-\alpha)} \Leftrightarrow \left(\frac{L_1^*}{S_1^*} \right)^{(1-\alpha)} = \left\{ \frac{P_1(1-\alpha)}{w} \right\}^{\frac{(1-\alpha)}{\alpha}}. \tag{23}$$

From equations (19) and (23), we get

$$P_1^{\frac{1}{\alpha}} \alpha \left\{ \frac{1-\alpha}{w} \right\}^{\frac{(1-\alpha)}{\alpha}} = \lambda + \gamma S_1^*. \tag{24}$$

From equation (21), we obtain

$$\frac{\alpha}{(1-\alpha)} w \left\{ \frac{\widehat{Y_2}}{A} \right\}^{\frac{1}{(1-\alpha)}} S_2^{-\frac{1}{(1-\alpha)}} = \lambda + \gamma \Phi(A) S_2^*. \tag{25}$$

Assume λ equal to zero. From equation (24) and equation (25), we obtain

$$P_1^{\frac{1}{\alpha}} \alpha \left\{ \frac{1-\alpha}{w} \right\}^{\frac{(1-\alpha)}{\alpha}} = \gamma S_1^* \tag{26}$$

$$\frac{\alpha}{(1-\alpha)} w \left\{ \frac{\widehat{Y_2}}{A} \right\}^{\frac{1}{(1-\alpha)}} S_2^{-\frac{1}{(1-\alpha)}} = \gamma \Phi(A) S_2^*. \tag{27}$$

From equations (26) and (27), we get

$$\frac{\alpha}{\gamma} P_1^{\frac{1}{\alpha}} \left\{ \frac{1-\alpha}{w} \right\}^{\frac{(1-\alpha)}{\alpha}} = S_1^* \tag{28}$$

$$\frac{\alpha}{(1-\alpha)} \frac{w}{\gamma \Phi(A)} \left\{ \frac{\widehat{Y_2}}{A} \right\}^{\frac{1}{(1-\alpha)}} = S_2^{*\frac{(2-\alpha)}{(1-\alpha)}}. \tag{29}$$

Summing up:

$$\text{land of conventional product } S_{1c}^* = \frac{\alpha}{\gamma} P_1^{\frac{1}{\alpha}} \left\{ \frac{1-\alpha}{w} \right\}^{\frac{(1-\alpha)}{\alpha}},$$

$$\text{labor of conventional product } L_{1c}^* = \frac{\alpha}{\gamma} P_1^{\frac{2}{\alpha}} \left\{ \frac{1-\alpha}{w} \right\}^{\frac{(2-\alpha)}{\alpha}},$$

$$\text{land of organic product } S_{2c}^* = \left\{ \frac{\alpha}{(1-\alpha)} \frac{w}{\gamma \Phi(A)} \right\}^{\frac{1-\alpha}{(2-\alpha)}} \left\{ \frac{\widehat{Y_2}}{A} \right\}^{\frac{1}{(2-\alpha)}},$$

$$\text{labor of organic product } L_{2c}^* = \left\{ \frac{\alpha}{(1-\alpha)} \frac{w}{\gamma \Phi(A)} \right\}^{-\frac{\alpha}{(2-\alpha)}} \left\{ \frac{\widehat{Y_2}}{A} \right\}^{\frac{2}{(2-\alpha)}}.$$

We have $S^*_{1c} + S^*_{2c} \leqslant V$ from the assumption stated in the proposition. Hence, the values S^*_{1c}, L^*_{1c}, S^*_{2c}, L^*_{2c} are optimal. $\square$

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