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Precision Cotton Agriculture and Strategic Commercial Policies: An Analysis in Terms of Duopoly by Quality

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ABSTRACT – *We study a Hotelling's duopoly in world cotton market to examine the effects of Precision Agriculture's (PA) adoption in term of strategic international trade between the United-States and Central and West Africa (CWA). We prove that US producers should be well advised to adopt PA to offer "environmental quality" cotton whereas CWA producers have a natural comparative advantage that allows them to offer a "product quality" cotton. We also argue that if the USA subsidizes PA in order to protect environment, this measure can be considered as a strategic international policy. We determine a critical subsidy level, which ousts CWA producers from the cotton market. At this subsidy level, US policy can be thought of unfair even if this policy enables them to improve the environment*

KEY WORDS: *strategic commercial policy, precision farming, Hotelling's duopoly, quality's differentiation, environment, welfare, cournot, nash equilibrium, subsidies*

Introduction

The adoption of precision agriculture (PA) is now considered an essential objective for sustainable agriculture, as has been shown by the many programs implemented by governments. In fact, PA decreases pollution (Lambert and Lowenberg-DeBoer 2000, Schumacher et al., 2000, Whitley et al., 2000, Lowenberg-DeBoer, 2004) while increasing productivity gains (Bronson et al., 2003, Yu et al., 2000, and Yu et al., 1999).

Moreover, PA is an issue for international trade because it enables the countries that adopt it to differentiate their products qualitatively as is the case for the cotton sector. PA enables the production of cotton that is of a better environmental quality than traditional cotton. However, the impact of PA on the quality of the cotton fibres remains uncertain so it may be beneficial for countries with a natural advantage in terms of fibre quality to differentiate their product without necessarily adopting it (Yu et al. 1999).

In this context, PA may be a support to the implementation of strategic international trade policies based on granting subsidies for its adoption. Recent studies show that, in the United States, PA has caused a double impact on international cotton exchanges (Pan et al., 2004; World *Cotton Model* from Pan, Malaga and Kulkarni, 2008). First of all, we have seen a decrease in world cotton prices and secondly, an increase in American exports and in decrease in exports from Central and Western African countries (CWA) that are unable to

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adopt PA (Oberthür et al. 2006). Such policies are even more easily justifiable since, from an environmental point of view, PA enables a decrease in pollution. With respect to international trade, it looks as if certain States should switch traditional trade policies for strategic environmental policies which cannot easily be condemned by the WTO although they have exactly the same effects. In fact, restrictions imposed by the GATT or the WTO on traditional trade policies have led many governments to increase strategic environmental policies to promote their exports and protect their agricultural sectors from international competition (Bureau and Mougeot, 2004, Bouët, 1992, 1998, 1999, 2001, Ulph, 1996, Barrett, 1992) without any risk of being condemned for these actions.

The purpose of this article is to evaluate international trade issues of PA in the cotton sector by analyzing United States (US) policies as opposed to CWA[1] countries. Two reasons justify this problem. The first resides in the United States', the world's main cotton producer, role of "price-maker" on the market (Parmentier, 2006). The second involves CWA countries for which the cotton sector in the main source of agricultural riches (Perrin and Lagandre, 2005) while there is very little chance that PA will be developed in these countries because of its cost and the technical knowledge necessary for its implementation (Oberthür et al., 2006). Therefore, the States that are unable to adopt PA are at risk of losing their natural advantage.

In order to answer this question, we will develop a horizontal differentiation model "à la Hotelling" between US cotton and CWA cotton, in order to evaluate the strategic effects on international trade that result from the adoption of PA. We will show under which conditions CWA countries can or cannot retain a portion of their revenues from international trade if the US agent produce cotton of a high environmental quality by using PA. We will considerer the fact that American and African cottons possess both qualities: environmental and fibre. The US produces cotton that is of a high environmental quality, because they use PA, and low fibre quality while the CWA countries offer cotton with high fibre quality that results from their natural advantage.

Our analysis is based around three sections. The first describes the model by explaining the demand for cotton (1.1), the behaviour of growers (1.2) and the architecture of the proposed issues between the US and the CWA countries (1.3). The second part shows how cotton consumers are spread over the international market according to whether they prefer "environmental" quality or "fibre" quality (2.1). We will determine the Nash-Hotelling balance for "environmental quality" (2.2) and for "fibre quality" (2.3) which allows CWA countries to remain competitive when US cotton producers develop PA. We will evaluate the level of welfare on the international cotton market (2.4). In the third part, we infer that the US implements a commercial subsidy policy for PA so that their growers will produce "environmental quality" cotton. We will determine the levels of "environmental quality" and "fibre quality" of the cotton that results from this type of policy (3.1). The results show an improvement in "fibre quality" in US cotton with relation to "fibre quality" of cotton from CWA countries so that cotton fibre consumers do not care if they use cotton fibre from the US or cotton fibre from CWA. The competitive advantage of CWA countries is thus decreased. We will then demonstrate that this policy improves the welfare of the United States and CWA countries, but, over a certain level of subsidy, the US trade policy is unfair

[1] The main countries involved here are Benin, Burkina Faso, Mali and Tchad.

because the CWA countries are at risk of being crowded out of the international cotton market (3.2).

The model

We look at two countries, the US and CWA countries, as a duopoly on the international cotton market that competes for quality on the third market. We look at the fact that the competition is supported by the qualities of the cottons offered knowing that the cotton has two characteristics: one "environmental" and the other "fibre". The US produces cotton with high "environmental quality", noted as $q_{E,e}$, due to PA. This qualitative characteristic is justified by the fact that PA induces strong environmental benefits. US cotton also has "fibre quality" of lower quality than the cotton produced in CWA countries. Manual cotton production allows them to produce cotton with a high "fibre quality", noted as $q_{A,p}$. CWA cotton fibre is qualitatively superior to American cotton.

- *Hypothesis 1*: PA is adopted by all of the American cotton growers but not by CWA countries.
- *Hypothesis 2:* Since the "environmental quality" of CWA cotton is stable because they do not possess adapted technology, it is not considered as an exogenous variable noted as $q_{A,e} = \overline{q}$.

Demand for cotton

We infer a heterogeneous demand composed of two categories of consumers. On one hand, consumers who are concerned with preserving the environment and who maximise a utility function, noted as μ_E, and who only use cotton characterized by a high "environmental quality" q_e. On the other hand, consumers who maximise a utility function, noted as μ_A, who only use "fibre quality" cotton q_p.

There is a continuum of mass 1 consumers distributed according to a linear Hotelling model on a segment representing the possible cotton qualities where US growers are situated in 0 and CWA growers are situated in 1. Consumers go to American or African cotton growers depending on whether they prefer cotton with high "fibre quality" or high "environment quality". "Environmental quality" and "fibre quality" cotton consumers are noted as n_E and n_A respectively, with $n_E + n_A = 1$. We admit that American and African growers sell at world cotton prices, supposedly fixed and noted as $p = \overline{p}$. We use an x to indicate the location of an agent according to his preferences for one or the other quality of cotton such as: $x \in [0;1]$. We define the mass of consumers who prefer high "environmental quality" cotton as $n_E \in [0;x[$ and the mass of consumers who prefer cotton with high "fibre quality" as $n_A \in]x;1]$. The utility functions are noted as follows:

$$U_x = \begin{cases} \mu_E = r + q_{E,e} + q_{E,p} - tx - \overline{p} \\ \mu_A = r + \overline{q} + q_{A,p} - t(1-x) - \overline{p} \end{cases} \quad (1)$$

In the previous expression, r (r > 0) represents the utility of each consumer no matter what the quality of the cotton. The consumers choose one quality or the other so that the entire market is covered, in order that in the balance, all the consumers obtain a positive utility no matter what type of cotton they buy. The expression tx (resp. $t(1-x)$) represents the disutility of consumers when they want to acquire the cotton q_e (resp. q_p). The term x (resp. $(1-x)$ represents the market segment covered by "environmental quality" US cotton q_e (resp. CWA "fibre quality" cotton q_p). The parameter t represents the cost of transportation traditionally used to formalise the differentiation between the two types of product. It is linear and represents the cost for a consumer to purchase environmental quality or fibre quality cotton.

Profit functions

The term $q_{E,e}$ (resp. $q_{E,p}$) represents the "environmental quality" (resp. "fibre quality) of American cotton with: $q_{E,e} > q_{E,p} > 0$[1]. The term $q_{A,p}$ represents the "fibre quality" level of African cotton with $q_{A,p} > \bar{q} > 0$[2]. American growers (resp. Africans) determine the "environmental quality" of cotton (resp. the "fibre quality") which maximises their profit function. We note as c_E and c_A the cost functions, which are supposedly quadratic, of American and African cotton as:

$$c_E = \frac{1}{2}\bar{q}^2_{E,p} + n_E \times q_{E,e} \text{ and } c_A = \frac{1}{2}\bar{q}^2 + n_A \times q_{A,p}$$

The profit functions of US and CWA growers are then noted as follows:

$$\pi_{q_e,q_p} = \begin{cases} \pi_E = n_E \cdot \bar{p} - \frac{1}{2}q^2_{E,p} - n_E \cdot q_{E,e} = n_E\left(\bar{p} - q_{E,e}\right) - \frac{1}{2}q^2_{E,p} \\ \pi_A = n_A \cdot \bar{p} - \frac{1}{2}\bar{q}^2 - n_A \cdot q_{A,p} = n_A\left(q_{A,p} - \bar{p}\right) - \frac{1}{2}\bar{q}^2 \end{cases} \quad (2)$$

π_E represents the profit function of the US while the adoption of PA allows them to produce "high environmental quality" cotton, and π_A represents the profit function of CWA countries that, being unable to adopt PA, produce "high fibre quality" cotton.

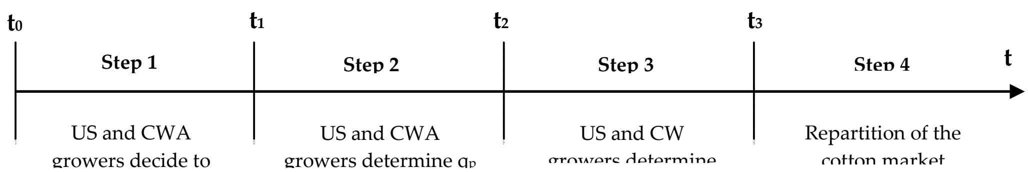
In order to evaluate how PA modifies the terms of competition between American and African growers, and determine under what conditions the African growers maintain their competitive advantage despite the diffusion of PA, we will resolve the following issue using backwards induction.

The architecture of the issue

The objective of the model is to explain how the adoption of PA by the US can be profitable from the point of view of international trade to both American growers and growers in CWA countries, therefore resulting in qualitative environmental gains. This is how we justify optimal quality research strategies when growers maximize their profits. Their objective is to corner the demand of consumers who are concerned with one quality of cotton or the other. The issue includes four steps:

[1, 2] This relation is justified by the specialization in the cotton quality.

Figure 1. Sequence of issue



- In t0 the price of cotton is fixed by the world market as $\overline{p} = p_A = p_E$. American and African growers decide whether or not to produce.
- In t1 American and African growers fix the "fibre quality" q_p.
- In t2 American growers fix their "environmental quality" $q_{E,e}$. The "environmental quality" of supposedly exogenous CWA cotton is noted as $\overline{q}$ such as $\overline{q} \leq \overline{p}$
- In t3 US producers adopt PA. American and African producers determine their profits and market shares.

Resolution of the issue: determine the balances in optimal qualities

The issue is resolved using fait par backward induction. We successively determine the market shares for growers, the "fibre quality" and "environmental quality" of the American cotton and the "fibre quality" of the CWA cotton.

Determining narket shares between the United States and the CWA countries

In t3 we determine how the two categories of consumers are divided along the $[0;1]$ axis. We infer that a representative consumer, indifferent as to q_e cotton and q_p cotton situated at point $\hat{x}$ verifying $\mu_E = \mu_A$ such as:

$$r + q_{E,p} + q_{E,e} - t\hat{x} - \overline{p} = r + q_{A,p} + \overline{q} - t(1-\hat{x}) - \overline{p}$$

After resolving the previous expression with relation to $\hat{x}$, we obtain:

$$\hat{x} = \frac{t + \Delta_e + \Delta_p}{2t} \quad (3) \qquad \text{where } \Delta_e = q_{E,e} - \overline{q} \text{ and } \Delta_p = q_{E,p} - q_{A,p}$$

If $0 < \hat{x} < 1$, there is a consumer who is indifferent to the two qualities of cotton available. Consumers belonging to the $0 < x < \hat{x}$ range want q_e cotton grown by the US. Consumers belonging to the $\hat{x} < (1-x) < 1$ range prefer q_p cotton grown by the CWA countries.

Condition 1a: *The cotton market is totally covered if r is big enough.* In this case, consumers have the choice between one or the other qualities of cotton which implies that: $r + q_{E,e} + q_{E,p} - t\hat{x} - \overline{p} > 0$ and/or that: $r + \overline{q} + q_{A,p} - t(1-\hat{x}) - \overline{p} > 0$.

Condition 1b: *The model which supposes a configuration of the market such as $\hat{x} \in]0;1[$, t must satisfy the following necessary and sufficient condition: $t > \Delta_e + \Delta_p$. This condition ensures a balance in which US and CWA growers are faced with positive demands.*

Condition 1c: *The previous condition implies that the degree of horizontal differentiation between the two types of cotton is high enough for US and CWA cotton growers to coexist on the market. In other words, it is necessary for:* $q_{E,e} > \bar{q}$ and $q_{A,p} > q_{E,p}$

By hypothesis, condition (1b) is satisfactory because consumer preferences are evenly distributed on the market. Consumers situated to the left of $\hat{x}$ prefer "high environmental quality" while consumers situated to the right of $\hat{x}$ prefer "high fibre quality". Condition (1c) is equally satisfactory because cotton growers are differentiated by the competitive advantage that they possess.

From (3), we can write the functions of demand that are addressed to each grower:

$$\begin{cases} n_E = \hat{x} = \dfrac{t + \Delta_e + \Delta_p}{2t} \\ n_A = 1 - \hat{x} = \dfrac{t - \Delta_e - \Delta_p}{2t} \end{cases} \tag{4}$$

By replacing (4) in (2), we obtain the following US and CWA profits:

$$\pi_{q_E,q_A} = \begin{cases} \pi_E = \dfrac{\left(\bar{p} - q_{E,e}\right)}{2t}\left(\Delta_e + \Delta_p\right) + \dfrac{\left(\bar{p} - q_{E,e}\right)}{2} - \dfrac{1}{2}q_{E,p}^2 \\ \pi_A = \dfrac{\left(q_{A,p} - \bar{p}\right)}{2t}\left(\Delta_e + \Delta_p\right) + \dfrac{\left(q_{A,p} - \bar{p}\right)}{2} - \dfrac{1}{2}q_{E,p}^2 + \bar{p} - \dfrac{1}{2}\bar{q}^2 - q_{A,p} \end{cases} \tag{5}$$

Determination of the "environmental quality" balance

By t_2, US cotton growers define the optimal "high environmental quality" of their cotton by maximising their profit function (first rate conditions)[2]:

$$\max_{q_{E,e}} \pi_E = \frac{\partial \pi_E}{\partial q_{E,e}} = 0 \Leftrightarrow \frac{\bar{p}}{2t} - \frac{q_{E,e}}{t} + \frac{\bar{q}}{2t} - \frac{\Delta_p}{2t} - \frac{1}{2} = 0 \tag{6}$$

After resolving equation (6), we obtain the level of "high environmental quality" $q_{E,e}^*$ produced by the US: $q_{E,e}^* = \dfrac{1}{2}\left(\bar{p} + \bar{q} + q_{A,p} - q_{E,p} - t\right)$ (7)

The "environmental quality" level proposed to the US depends negatively on t. Therefore, when t decreases, the differentiation with CWA cotton is accentuated. The reverse observation can be proposed if t increases. Likewise, if t increases, $q_{E,e}^*$ decreases, with induced a decrease in US profits. The effect on the profits is reversed with t decreases.

For CWA growers, the "environmental quality" of their cotton was exogenous $q_{A,e}^* = \bar{q}$.

The balance noted (E_e) in terms of "environmental quality" on the cotton market is determined by the following expression: $E_e = \left\{ q_{E,e}^* = \dfrac{1}{2}\left(\bar{p} + \bar{q} + q_{A,p} - q_{E,p} - t\right); q_{A,e}^* = \bar{q} \right\}$ (8)

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[2] We verified that at the balance the second order conditions are verified: $\dfrac{\partial^2 \pi_E}{\partial^2 q_{E,e}} = -\dfrac{1}{t} < 0$.

Determining the optimal "fibre qualities" on the cotton market

In t_1, the African and American producers define the level of "fibre quality" of their cotton which maximizes their profits. The derivatives of the profit function (first order condition)[3] are expressed in the following way:

$$\max_{q_{E,p},q_{A,p}} \pi = \begin{cases} \max\limits_{q_{E,p}} \pi_E = \dfrac{\partial \pi_E}{\partial q_{E,p}} = 0 \\ \max\limits_{q_{A,p}} \pi_A = \dfrac{\partial \pi_A}{\partial q_{A,p}} = 0 \end{cases} \Leftrightarrow \begin{cases} \dfrac{\overline{p}}{2t} - \dfrac{q_{E,e}}{2t} - q_{E,p} = 0 \\ \dfrac{\overline{p}}{2t} + \dfrac{q_{E,e}}{2t} + \dfrac{q_{E,p}}{2t} - \dfrac{q_{A,p}}{2t} - \dfrac{\overline{q}}{2t} - \dfrac{1}{2} = 0 \end{cases} \tag{9}$$

The reaction functions in terms of "fibre quality" of US and CWA growers are written respectively:

$$\begin{cases} q_{E,p} = \dfrac{1}{2t}\left(\overline{p} - q_{E,e}\right) \\ q_{A,p} = \dfrac{1}{2}\left(\overline{p} + q_{E,e} + q_{E,p} - \overline{q} - t\right) \end{cases} \tag{10}$$

After the resolution of the equation system (10), we obtain a balance of US and CWA "fibre qualities" which are noted respectively $q^*_{E,p}$ and $q^*_{A,p}$ such as:

$$\begin{cases} q^*_{E,p} = \dfrac{1}{2t}\left(\overline{p} - q_{E,e}\right) & 11.a \\ q^*_{A,p} = \dfrac{1}{2}\left[\overline{p}\left(1 + \dfrac{1}{2t}\right) + q_{E,e}\left(1 - \dfrac{1}{2t}\right) - \overline{q} - t\right] & 11.b \end{cases} \tag{11}$$

We notice, as previously for relation (7), that the "fibre quality" level of CWA cotton depends negatively on t. The utility of the consumer preferring "fibre quality" improves particularly as t decreases like CWA profits which depend positively on $q^*_{A,p}$. The effects are reversed if t increases.

Determining "environment" and "fibre" qualities on the cotton narket

In t_0, the growers must decide of they grow, in view of the balance qualities determined in (8) and (11) at the world price $\overline{p}$. By replacing (11) in (7), we obtain the "environmental quality" level that US growers propose:

$$q^{**}_{E,e} = \overline{p} + \frac{2t\overline{q} - 6t^2}{6t - 1} \tag{12}$$

Likewise, by replacing (12) in (11.b) we obtain the optimal "fibre quality" level for CWA cotton produced in the balance:

[3] By considering 1.b the second order conditions are respected if: $\dfrac{\partial^2 \pi_E}{\partial^2 q_{E,p}} = -1 < 0$ and $\dfrac{\partial^2 \pi_A}{\partial^2 q_{A,p}} = -\dfrac{1}{t} < 0$.

$$q_{A,p}^{**} = \bar{p} + \frac{t\left(2-2\bar{q}\right)-6t^2}{6t-1} \tag{13}$$

Finally, by replacing (12) in (11.a), we obtain the optimal "fibre quality" level for US cotton:

$$q_{E,p}^{**} = \frac{3t-\bar{q}}{6t-1} \tag{14}$$

The optimal level of demand n_E^{**} (resp. n_A^{**}), for US growers (resp. CWA) is obtained by replacing (12), (13) and (14) in (4). Or after calculation:

$$\begin{cases} n_E^{**} = \hat{x}^{**} = \dfrac{3t-\bar{q}}{6t-1} \\ n_A^{**} = 1-\hat{x}^{**} = \dfrac{3t-\bar{q}-1}{6t-1} \end{cases} \tag{15}$$

Proposition 1: *The growers undertake their production if the level of qualities (environment and fibre) is positive or nul.*

This proposition is verified if the following conditions are realized:

- $q_{E,e}^{**} = \bar{p} + \frac{1}{6t-1}\left(2t\bar{q}-6t^2\right) \geq 0$ which implies that: $\bar{p} \geq \frac{\left(2t\bar{q}-6t^2\right)}{6t-1}$. Since $\bar{p} > 0$ we verify that: $2t\bar{q}-6t^2 > 0$. We deduct that: $q_{E,e}^{**}$ if and only if $\bar{p} > t \in \left[0; \frac{1}{3}\bar{q}\right]$
- $q_{A,p}^{**} = \bar{p} + \frac{2t-2t\bar{q}-6t^2}{6t-1} \geq 0$ implies that: $\bar{p} > \frac{2t-2t\bar{q}-6t^2}{6t-1}$. Since $\bar{p} > 0$ we verify that: $t\left(2-2\bar{q}\right)-6t^2 > 0$. We deduce that: $q_{E,p}^{**} \geq 0$ if and only if $\bar{p} > t \in \left[0; \bar{q} \leq 1\right]$.
- $q_{E,p}^{**} = \frac{3t-\bar{q}}{6t+1} \geq 0$ which implies that: $3t-\bar{q} \geq 0$. We deduce that: $q_{E,p}^{**} \geq 0$ if and only if $t \geq \frac{1}{3}\bar{q}$. (16)

According to condition 1.b and proposition 1, if we want the combined levels of quality to be positive, we must restrict our study to the case where t respects the following condition: $t \geq \frac{1}{3}\bar{q}$ with $\bar{q} < 1$ (17.a). Proposition 1 also highlights the fact that the world price verifies the following condition: $\bar{p} > t$ (17.b).

By replacing the optimal demand defined by (15) and the balance qualities defined by the relations (12), (13) and (14) in the profit functions (4), we obtain, in t_0, the following profit balances:

$$\begin{cases} \pi_E^{**} = n_E^{**}(\overline{p} - q_{E,e}^{**}) - \frac{1}{2}q_{E,p}^{**2} = \hat{x}^{**}\left(\overline{p} - q_{E,e}^{**}\right) - \frac{1}{2}q_{E,p}^{**2} \\ \pi_A^{**} = n_A^{**}(\overline{p} - q_{A,p}^{**}) - \frac{1}{2}\overline{q}^2 = \hat{x}^{**}(q_{A,p}^{**} - \overline{p}) - \frac{1}{2}\overline{q}^2 + \overline{p} - q_{A,p}^{**} \end{cases} \quad (18)$$

The growing decision is not undertaken unless the t_0 profits are positive.

Proposition 2: *According to (18), in order for the profits to be positive, we must be able to verify that:*

$\overline{p} - q_{E,e}^{**} > 0 \; and \; \overline{p} - q_{A,p}^{**} > 0$

This proposition implies that $\overline{p}$ is sufficiently large. Therefore: $\overline{p} \in \left]\left(q_{E,e}^{**}, q_{A,p}^{**}\right); +\infty\right[$ (19).

When conditions (17.a), (17.b) and (19) are satisfied, the profits of US and CWA growers are positive so that both countries share the cotton market.

In other terms, the previous developments show that if American growers adopt PA and opt for an "environmental quality" strategy of cotton production, CWA cotton growers remain competitive if they adopt a "fibre quality" cotton development strategy.

It is now necessary to assess the impact of the previous strategies in terms of welfare by determining, first of all, at what level the welfare is set when all the growers adopt PA and, secondly, show that public intervention, to ensure the distribution of PA to all of the US growers, can impact quality levels to the detriment of CWA countries.

Subsidies for the adoption of PA: a study in terms of welfare

Two scenarios are considered. The first consists in determining welfare when PA is distributed to the US (*hypothesis 1*). The goal of the second is to determine welfare when PA is used as a support for an international trade policy of subsidies to assist the adoption of PA for the US who want to acquire a competitive advantage. Two arguments are brought forth to justify such a policy: the first concerns environmental protection and the second concerns assistance for innovation. In this case, we show how, first of all, the US obtain international trade revenue by improving their two cotton qualities, and secondly, how such a policy can be unfair if it continues to crowd CWA countries out of the cotton market since they have no way to retaliate.

First scenario: evaluation of the welfare without a strategic subsidy

We note as AS_e^{**} the surplus of consumers concerned with environmental protection and as AS_p^{**} the surplus of the consumer who prefers "fibre quality". The surplus of growers corresponds to the level of profits π_E^{**} and π_A^{**} previously calculated. We note as W_1^{**} welfare on the cotton market such as: $W_1^{**} = AS_e^{**} + \pi_E^{**} + AS_p^{**} + \pi_A^{**}$. The following expression determines the level of welfare on the cotton market as t_0:

$$W_1^{**} = \int_{x=0}^{\hat{x}^{**}} \left(r + q_{E,e}^{**} + q_{E,p}^{**} - t\hat{x} - \overline{p}\right)\partial x + \int_{x=\hat{x}^{**}}^{1} \left(r + q_{A,p}^{**} + \overline{q} - t\left(1 - \hat{x}\right) - \overline{p}\right)\partial x + \pi_E^{**} + \pi_A^{**}$$

or, $\tilde{x}^{**} = \dfrac{3t - \bar{q}}{6t - 1}$

After calculations we obtain the following expression:

$$W_1^{**} = \frac{-18t^3 + t^2\left(10\bar{q}^2 - 36\bar{q} + 15\right) + t\left(2\bar{q} - 1\right) - \bar{q}^2}{2(6t-1)^2} + r + \bar{q} - \frac{1}{2}\bar{q}^2 \qquad (20)$$

Proposition 3: *Cotton production is undertaken only if the welfare is positive or nil. For all values of* $t > \Delta_e + \Delta_p$ *(1.c), and knowing that r is sufficiently large, we verify that* W_1^{**} *is always positive for* $t \in \left]\Delta_e + \Delta_p; +\infty\right[$ (21).

If condition (21) is satisfactory the welfare is positive. This expression implies that all the American cotton growers must adopt PA. It this is not the case, the entire American cotton production will not benefit from the "high environmental quality" characteristic which implies that certain consumers μ_E will not be satisfied and will see no difference between US and CWA cotton. In this case, the surplus of consumers AS_e^{**} and the welfare W_1^{**} decrease and a regulator is necessary, in this case the American government, to ensure that all American growers adopt PA in order to respect the result (20).

Second scenario: the implications in terms of welfare of a public policy for assistance to the adoption of PA

In this paragraph, we abandon the hypothesis in which all of the US growers adopt PA, which implies that some growers are unable to produce "high environmental quality" cotton so that their cotton's level of "environmental quality" may be noted as $q_{E,e} \le \bar{q}$. Because PA is a "green" technology, we infer that the American State decides to subsidise it without running the risk of being liable of illegal subsidy policies. We note as "s" the marginal public subsidy such as: $\dfrac{\partial\left(q_{E,e} - s\right)}{\partial s} < 0$ (22)

The impact of such a policy can be measured by evaluating its effect on the level of American cotton qualities $q_{E,e}^{**}$ and $q_{E,p}^{**}$ and on the level of profits. From an economic point of view, taking into consideration PA subsidies is done at the level of "environmental quality cotton production costs which can be expressed as follows: $n_E \times (q_{E,e} - s)$.

In sub-section 3.2.1, we will evaluate the impact of such a policy on the levels of "environmental quality" and "fibre quality" of US and CWA cotton. We will deduct the impact of the levels obtained on the level of profits made. Sub-section 3.2.2 will evaluate the effects of subsidies on welfare.

Subsidy policies to assist the adoption of PA in the US: a study in terms of competitiveness

We note as $q_{(s)E,e}^{**}, q_{(s)E,p}^{**}, q_{(s)A,p}^{**}, \pi_{(s)E}^{**}$ and $\pi_{(s)A}^{**}$ respectively, the optimal level of "environment" and "fibre" qualities produced by US growers when they are subsidised; the "fibre" quality offered by CWA growers when US growers are subsidised, and the US and

CWA profits with subsidies. After calculating, and applying the method of backward induction as was used previously, we obtain the following values:

$$q^{**}_{(s)E,e} = \overline{p} + \frac{1}{6t-1}\left[2t\overline{q} + s(4t-1) - 6t^2\right] \quad \text{(a)}$$

$$q^{**}_{(s)E,p} = \frac{3t+s-\overline{q}}{6t-1} \quad \text{(b)}$$

$$q^{**}_{(s)A,p} = \overline{p} + \frac{1}{6t-1}\left[-6t^2 - 2t\overline{q} + 2t + 2st\right] \quad \text{(c)}$$

The levels of "quality" balance obtained depend differently on the parameter t, which brings us to make several comments.

Comment 1: The balance represented by the relation showed that the variation in the level of "environmental quality" in US cotton, when the growers are subsidised, depends on t. The quality also depending on s, both cases can be distinguished to appreciate the impact of a variation of t on (A).

- ***Case 1:*** If $s > \frac{3}{2}t$ and t decreases, then the level of "environmental quality" balance decreases towards $\overline{q}$, so that the differentiation with "environmental quality" CWA cotton decreases and disappears. The disutility related to using CWA cotton decreases.

- ***Case 2:*** If $s < \frac{3}{2}t$, the scenario is reversed. A decrease of t induces an improvement of "environmental quality" for US cotton which accentuates the differentiation of the cottons. The disutility related to using CWA cotton increases.

Comment 2: We can compare the effects of a t variation between levels of quality between (b) and (c).

- *Case 1 bis:* If $s > 3t$ an increase of t, if $\overline{q} < 1$, induces an increase in the level of "fibre quality" of US and CWA cotton. The improvement is greater for US cotton.

- ***Case 2 bis:*** If $s < 3t$ an increase of t improves the "fibre quality" of US cotton and decreases that of CWA cotton. The differentiation between the two cottons decreases so that growers in the CWA countries no longer have as much of their natural advantage. If, to the contrary, t decreases, the induced effect is reversed to the previous to that the improvement of "fibre quality" in US cotton induced by PA is lower.

Comments 1 and 2 show that a variation of t can cancel the positive effects that subsidies produce on US and CWA cotton's level of balance qualities. We can also see that a variation of t can minimise the anticipated effects on the qualities of US cotton that result from the adoption of PA.

At the balance, the repartition of the demand for each cotton quality of given by:

$$\begin{cases} \hat{x}^{**}_s = n^{**}_{s,E} = \dfrac{3t+s-\overline{q}}{6t-1} \\ 1-\hat{x}^{**}_s = n^{**}_{s,A} = \dfrac{3t+\overline{q}-s-1}{6t-1} \end{cases} \quad (23)$$

Likewise with regards to the profits we obtain:

$$\pi^{**}_{(s),q_E,q_A} = \begin{cases} \pi^{**}_{(s),E} = \hat{x}^{**}_s \bar{p} - \frac{1}{2}\left(q^{**}_{(s)E,p}\right)^2 - \hat{x}^{**}_s \left(q^{**}_{(s)E,e} - s\right) \\ \pi^{**}_{(s),A} = \hat{x}^{**}_s \left(q^{**}_{(s)A,p} - \bar{p}\right) - \frac{1}{2}\bar{q}^{2} + \bar{p} - q^{**}_{(s)A,p} \end{cases} \tag{24}$$

Proposition 4: *According to expression (24) public policy induced an increase in profits if the level of subsidies verifies the following condition:* $q^{**}_{(S),E,e} - s \geq 0$. *Or if:*

$$0 \leq s \leq \bar{q} + 3\bar{p} - 3t - \frac{\bar{p}}{2t} \tag{25}$$

The effects of subsidies for the adoption of PA on optimal "environment" and "fibre" qualities for US and CWA growers can be expressed as follows:

$$\frac{\partial q^{**}_{(s)E,e}}{\partial s} = \frac{4t-1}{6t-1} > 0 \; ; \; \frac{\partial q^{**}_{(s)E,p}}{\partial s} = \frac{1}{(6t-1)} > 0 ; \frac{\partial q^{**}_{(s)A,p}}{\partial s} = \frac{2t}{(6t-1)} > 0$$

Proposition 5: *Subsidies to assist the adoption of PA induce a positive effect on the "environmental quality" and "fibre quality" levels of American cotton with a greater positive effect on "environmental quality".*

The previous results show that when subsidies allow American producers to improve the "fibre quality" of their cotton, they can compete with the growers in CWA countries, who then see their market share decrease because consumers of "fibre quality" cotton are may buy American "fibre quality" cotton which meets, or closely meets, their demand.

The effects of public policy on the demand for American and African cotton can be expressed as follows:

$$\begin{cases} \frac{\partial n^{**}_{S,E}}{\partial s} = \frac{1}{6t-1} > 0 \\ \frac{\partial n^{**}_{S,A}}{\partial s} = \frac{-1}{6t-1} < 0 \end{cases}$$

Proposition 6: *Subsidies paid to US growers for the adoption of PA cause an increase in American demand and a decrease in African demand.*

The results stated in proposition 4 confirm those of proposition 5. Profits resulting from PA on the "fibre quality" of American cotton, which can be confirmed by certain empirical works that explain that PA can induce positive effects on the intrinsic quality of the product, result in the fact that some consumers who are concerned with this will meet their needs by buying "fibre quality" cotton from the US and not from CWA countries. The closer the level of American "fibre quality" cotton is to CWA cotton, the more indifferent consumers are as to the origin of the cotton.

The profit functions can now be expressed in the following way:

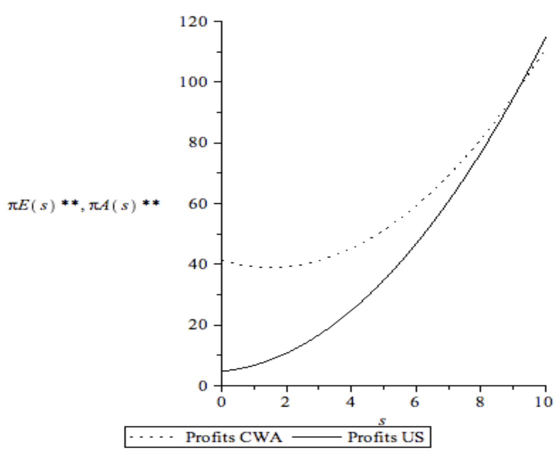
$$\begin{cases} \pi^{**}_{E,s} = \dfrac{36t^3 + t^2\left(24s - 24\bar{q} - 9\right) + t\left(4s^2 - 6s - 8s\bar{q} + 6\bar{q} + 4q^2\right) + 2\bar{q}s - s^2 - \bar{q}^2}{2\left(6t-1\right)^2} \\ \pi^{**}_{A,s} = \dfrac{18t^3 + t^2\left(12\bar{q} - 12s - 12\right) + t\left(2s^2 + 4s + 2 + 2\bar{q}^2 - 4\bar{q} - 4s\bar{q}\right)}{\left(6t-1\right)^2} + \bar{p} - \dfrac{1}{2}\bar{q}^2 \end{cases}$$

From numerical values that respect the hypotheses defined in the model (r sufficiently large; $\bar{p} > t$; $t \geq \frac{1}{3}\bar{q}$; $\bar{q} \leq 1$; and $0 < s < 3t + \bar{q} - 1$, we verify that $\pi^{**}_{E,s} > 0$ and $\pi^{**}_{A,s} > 0$[1]. The study on the impact of public policy on profits verifies that:

$$\begin{cases} \dfrac{\partial \pi^{**}_{E,s}}{\partial s} = \dfrac{24t^2 + t\left(8s - 8\bar{q} - 6\right) + 2\bar{q} - 2s}{2\left(6t-1\right)^2} > 0 \quad (26.a) \\ \dfrac{\partial \pi^{**}_{A,s}}{\partial s} = \dfrac{-12t^2 + 4st + 4t - 4t\bar{q}}{\left(6t-1\right)^2} > 0 \quad (26.b) \end{cases} \qquad (26)$$

The expression (26) shows that, no matter what the level of the subsidy, growers' profits increase. The following graphic illustrates our results:

Graphic 1. Evolution of US and CWA profits according to levels of subsidies



Proposition 7: *American subsidies have a positive impact of the profits of cotton growers in this country and those in CWA countries, although the impact is greater on American profits. It is an optimal subsidy level s_m when US profits are greater than CWA profits. This level optimal level of profits is determined after profit maximisation with regard to s. We obtain it by equalizing equations (26.a) and (26.b). Or:*

$$\frac{-12t^2 + 4st + 4t - 4t\bar{q}}{\left(6t-1\right)^2} = \frac{24t^2 + t(8s - 8\bar{q} - 6) + 2\bar{q} - 2s}{2\left(6t-1\right)^2} \Leftrightarrow 2s = 48t^2 - 4t\bar{q} - 7t + \bar{q}$$

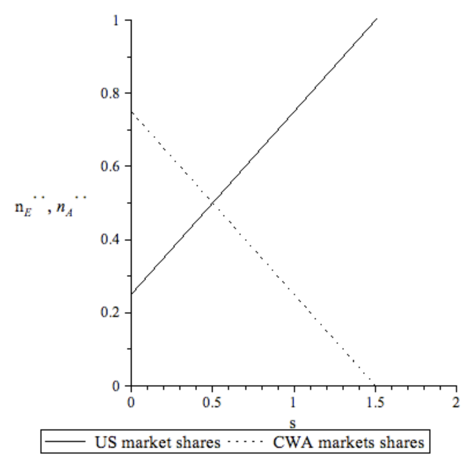
[1] We verify, using numerical values ($p = 10; r = 20; q = 1; t = 0,36; s = 0,5$) that the profits are positive.

$$\Leftrightarrow s_m = 24t^2 + t\left(-4\overline{q} - 7\right) + \overline{q} \qquad (27)$$

Therefore, on a profit level, for any amount of $s \geq 0$, US and CWA profits increase. However, according to proposition 6, subsidies induce an increase in the US market and a decrease in CWA market shares. This means that there is a critical level of subsidy, noted as s_c from where CWA growers are crowded out of the market. This level is defined as: $n_A^{**} = 0 \Leftrightarrow 3t + \overline{q} - s - 1 = 0 \Leftrightarrow s_c = 3t + \overline{q} - 1$

For a subsidy amount that is greater or equal to s_c we can consider that the US trade policy becomes unfair, without necessarily being condemnable, in the sense that, under the pretext of protecting the environment, they contribute to crowding CWA growers out of the cotton market. Graphic 2 explains this eventuality:

Graphic 2. Evolution of cotton market shares with relation to subsidies in place



What effects do public subsidies have on overall "environmental quality" $Q_e^{**} = q_{(s)E,e}^{**} + q_{(s)A,e}^{**} = q_{(s)E,e}^{**} + \overline{q}$ and overall "fibre quality" quality" $Q_p^{**} = q_{(S)E,p}^{**} + q_{(S)A,p}^{**}$?

These impacts can be evaluated from the following derivatives:

$$\frac{\partial Q_e^{**}}{\partial s} = \frac{4t-1}{6t-1} > 0 \quad \frac{\partial Q_p^{**}}{\partial s} = \frac{2t+1}{6t-1} > 0$$

***Proposition** 8: Subsidies to assist with the adoption of PA increase the total levels of "environmental" and "fibre" qualities. This implies that subsidies to assist the adoption of PA induce an increase in benefits to all consumers.*

In this paragraph we were able to show that the implementation of the American public policy of subsidies to assist the adoption of PA induces positive effects for growers and consumers. Although African growers lose market shares, subsidies induce and increase in their profits. The results also highlight the fact that such a policy can exclude CWA cotton growers from the market even though they have a comparative advantage.

It is now time to evaluate the level of welfare that results from subsidies for the adoption of PA.

The impact of a subsidy for the adoption of PA in terms of welfare

The objective of this section is to identify the level of subsidy that ensures the complete circulation of PA. To do so, we will establish under what conditions the profits, qualities and welfare are at least equal to those obtained in the first scenario.

We note as $S = s \times n_E^{**}$ the amount of the subsidies paid by the US government. Total welfare is defined as the surplus amount from consumers and profits minus the level of subsidies.

The public authorities decide to allocate subsidies so that:

(i) The subsidies have a positive impact for US and CWA growers and for cotton consumers, which we have highlighted in section 3.2.1.

(ii) The amount of the subsidies S is compensated by the increase in the level of consumers purchasing US cotton and profits made by US growers. In this case the new level of welfare be at least equal to the previous level.

We will determine the amount of the subsidies that is necessary to maximize US profits so that welfare in not inferior to that which was obtained without subsidies.

The level of welfare with subsidies noted as W_2^{**} is determined by the following expression: $W_2^{**} = AS_{e,s}^{**} + AS_{p,s}^{**} + \pi_{E,s}^{**} + \pi_{A,s}^{**} - S^{**}$

$$\Leftrightarrow W_2^{**} = \int_{x=0}^{\hat{x}_s^{**}} \left(r + q_{(s)E,e}^{**} + q_{(s)E,p}^{**} - t\hat{x} - \overline{p} \right) \partial x + \int_{x=\hat{x}_s^{**}}^{1} \left(r + q_{(s)A,p}^{**} + \overline{q} - t(1-\hat{x}) \right) \partial x + \pi_{E,s}^{**} + \pi_{A,s}^{**} - s \cdot \hat{x}_s^{**}$$

with: $\tilde{x}_s^{**} = \dfrac{3t + s - \overline{q}}{6t-1}$;

$$\pi_{E_s}^{**} = \frac{3t - \overline{q}}{6t-1} \left[\frac{-12t^2 + t\left(4\overline{q} - 3\right) + \overline{q}}{2\left(6t-1\right)} \right] + s;$$

$$\pi_A^{**} = \frac{18t^3 + t^2\left(12\overline{q} - 12\right) + t\left(4\overline{q}^2 - 4\overline{q} + 2\right)}{\left(6t-1\right)^2} - \frac{1}{2}\overline{q}^2.$$

After calculation, the value of welfare is given by:

$$W_2^{**} = \frac{18t^3 + t^2\left(36s - 36\overline{q} + 3\right) + t\left(10s^2 + 2\overline{q} + 10\overline{q}^2 + 1 - 20s\overline{q} - 2s\right) + 2\overline{q}s - s^2 - \overline{q}^2}{2\left(6t-1\right)^2} - \frac{1}{2}\overline{q}^2 + r + \overline{q}$$

We verify, by taking relevant numerical values[1] that respect our hypotheses (r sufficiently large; $\overline{p} > t$; $t \in \left]0; \frac{1}{3}\overline{q}\right[$; $\overline{q} \le 1$; and $0 < s < 3t + \overline{q} - 1$ as the welfare $W_2^{**} > 0$. We also verify

[1] For $p = 10; r = 20; q = 1; t = 0,3; s = 0,3$ the profits are positive.

that $W_2^{**} \geq W_1^{**}$. The impact of public subsidies for the adoption of PA on the welfare is expressed as follows: $\frac{\partial W_2^{**}}{\partial s} = \frac{36t^2 - 2t + s(20t - 2) - 20\bar{q}t + 2\bar{q}}{2(6t-1)^2}$

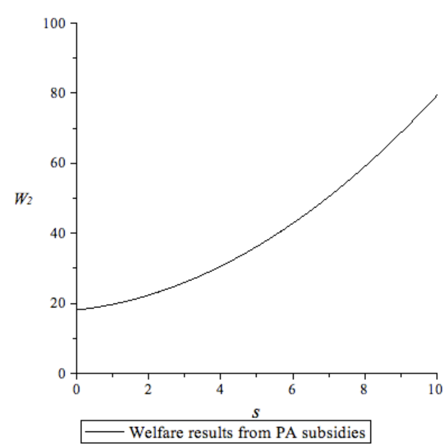
Proposition 9: *An increase in the value of the marginal subsidy "s" has a positive impact on the collective welfare. It this case we verify that:* $\partial W_2^{**} / \partial s > 0$

In this situation, the US public authorities optimize the welfare by determining the optimal level of subsidies such as:

$$\frac{\partial^2 W_2^{**}}{\partial^2 s} = \frac{20t - 2}{2(6t-1)^2} > 0$$

The previous expression signifies that, no matter what the level of subsidy, the welfare is improved. The following graphic illustrates this conjecture that welfare increases *in fine:* $W_2^{**}(s) \in]0;+\infty[$, for all values of $s > 0$.

Graphic 3. Evolution of welfare according to level of subsidies



In the first case, the policy for subsidies to assist the adoption of PA allows American growers to decrease their production cost for "environmental quality". The goal of the public authorities is to evaluate the optimal subsidy that will be beneficial to all of the US actors. Several conditions must be respected in order to make it so.

- Condition (25) must be respected: $s^{**} \leq \bar{q} + 3\bar{p} - 3t - \frac{\bar{p}}{2t}$

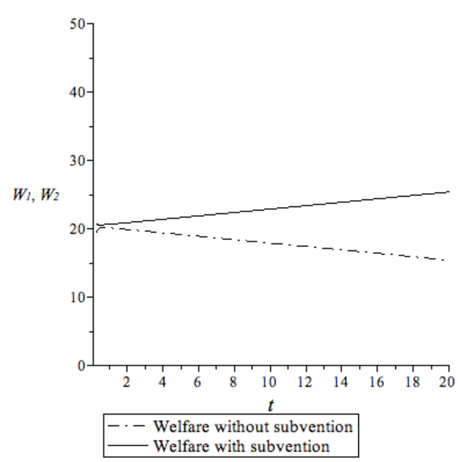
- The public authorities must take into consideration the gains of African growers because, according to the hypotheses retained, they must not be crowded out of the market (I).

Graphic 2 highlights the fact that there is a level of subsidy where African growers are crowded out of the market. Nevertheless, as by hypothesis, r is large enough so that no actor is crowded out of the market, the level of subsidies that are granted must meet the following condition: $\bar{q}-\frac{1}{2}<s^{**}<3t+\bar{q}-1$ (28)

There is a level of subsidy that is optimal and profitable for all the actors on the market. Its value, in t_0, when condition (25) is respected, is given by the following expression: $s^{**}=\bar{q}-\frac{1}{2}$.

For this subsidy amount, the welfare is positive and superior to the welfare when PA is not subsidised. The strategic policy undertaken by the American government enables an increase in American market shares and an improvement in the qualities of cotton that is produced. The American and African growers also remain competitive (proposition 7). In this case, the public policy is justified economically because the welfare is positive and superior to W_1^{**}(graphic 4), and also because it induces an increase in American market shares.

Graphic 4. Evolution of Welfare according to t with and without PA subsidies



We have shown that public policy to distribute PA to the cotton sector enables in increase in welfare and an increase in market shares for American growers. This policy can be considered to be a strategic commercial policy combined with an environmental policy for the reduction of pollutants caused by agriculture. The American cotton sector becomes profitable without harming CWA growers who have a natural advantage in this sector. However, we have shown that there is a critical subsidy level that causes CWA countries to be crowded out of the cotton market. This situation would obviously be contrary to the US commitment regard ding policies to aid development in countries such as those in CWA. We have finally highlighted the fact that subsidies improve both cotton qualities, which would place CWA countries at a disadvantage because their natural competitive advantage would be blurred.

Conclusion

Although the quality of the cotton produced by CWA countries is undeniably superior to cotton from other countries, distributing PA could reverse this state of affairs. Many studies recognize that PA enables optimal soil management, positively influences cotton quality and induces a positive impact on the environment (Bradow et al., 1999a. and 1999b., Johnson et al., 2002, Ping et al., 2004). If PA should, in the future, become a support for the implementation of strategic trade policy combined with environmental policies, it would be clear that CWA countries would be faced with a new challenge because their competitiveness would be jeopardized (Gergely, 2005).

The previous model shows that such a situation could be considered under certain conditions. The balances obtained (section 3), the result of a subsidy policy for the adoption of PA, are higher to those determined when the hypothesis is made that US growers have access to PA but are not subsidized (section 2). In other terms, aid for the adoption of PA implemented by the US would result in an improvement of welfare of the US and welfare of CWA countries. They also analytically confirm studies by Yu et al., (1999), Yu, 2000, Bongiovanni and Lowenberg-DeBoer, (2000), Whitley et al., (2000), Schumacher et al., (2000) Bronson et al. (2003,) regarding the use of PA, which confirms an increase in yields and profitability and a decrease in pollutants. They also agree with the studies that highlight the fact that PA enables the quality of cultivated products to be improved. (Long et al., 1998, Bradow et al., 2000, Johnson et al., 2000, Ping et al., 2004a). However, we have shown that there is a critical level of subsidy that crowds out CWA countries from the market. For subsidy amounts that are greater or equal to this level, a strategic commercial policy can be considered unfair because CWA countries are unable to react by a trade war.

Finally, in as much as American profits and welfare are not susceptible to variations in cotton prices, strategic trade policies implemented by the US to support PA have every reason to be initiated at the risk of harming CWA countries.

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