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Analysing crisis situations of seedlings and crisis conditions in palmyra palm stands in Burkina Faso

Babou SOGUÉ[1], Burhan OZKAN[2]

[1]University of Nazi BONI, Legal, Political, Economic, and Management Training and Research Unit Sciences, Bobo-Dioulasso, Burkina Faso
[2]Akdeniz University, Faculty of Agriculture, Department of Agricultural Economics, 07070, Antalya, Türkiye

Corresponding author: B. Sogué, e-mail: babousogue@gmail.com
Author(s) e-mail: bozkan@akdeniz.edu.tr

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ABSTRACT

The regeneration system of Borassus aethiopum in Burkina Faso is the subject of several hypotheses. However, it is challenging to implement appropriate conservation strategies due to the lack of usage of bioeconomic approaches to support this or that perspective. The objective of this study is to settle this debate by assessing the status of palm tree stands using a bioeconomic model based on a dynamic equilibrium price. The data used in the study was gathered from thirty farming households in the study area in 2010, 2015, and 2020, as well as from monitoring thirty farm sites. The results show that, on average, there is an equilibrium between the rate of harvesting and the rate of regeneration of the palmyra palm. Nonetheless, market prices do not reflect the species' value, as they are between 28% and 166% below their implicit level. To ensure a proportionality coefficient between the equilibrium price and the resource constraint, a dynamic Pigouvian tax should be applied, taking into account the gap, the rate of exploitation, and regeneration.

1. Introduction

Borassus aethiopum is a species of dioecious palm native to Africa, where it grows in savannahs and forests (Bayton 2007). It is particularly abundant in eastern Burkina Faso in the Kompienga watershed. The province of Kompienga spans 7280 km^2 and is located in the far eastern region of Burkina Faso. However, since the 1990s, it has been experiencing accelerated degradation due to the exploitation of young shoots for their roots (hypocotyls) (Guinko and Ouédraogo 2005), leading to the ageing of the palm stand. The species' regeneration system is therefore affected by these practices, while there is virtually no appropriate mechanism for internalising the external effects of the actions of local populations.

The social cost of overexploitation of in situ seedlings in certain localities is characterised by the perceptible ageing of palm stands, the fragmentation of their plant formations and the decline in their productivity, on the one hand, but also by the fall in agricultural yields and the income of farmers dependent on forestry, the silting up of watercourses and the destruction of crops located downstream of the banks, on the other. This is a case of the presence of negative externalities specific to common goods. It is also accepted that the market fails in the presence of externalities, common goods, and collective goods, as in the present case (IRP 2020). For the time being, decisions on the preservation of the species combine Ronald Coase and Pigouvian approaches, i.e. the organisation of neighbouring populations and the application of a flat-rate tax on the exploitation of hypocotyls. Coase (1960) was highly critical of standard neo-classical theory, which emphasised public solutions to the harmful effects of activities. Instead, he put forward private solutions to deal with so-called externalities. The "Coase theorem" states that "the final result is independent of the legal system if the pricing system is assumed to work". So, in the absence of transaction costs, property rights are sufficient to achieve the social optimum. Unfortunately, in the hypocotyl market, prices do not work in the way Coase wants (Chu 2022) and there are no property rights over the resource. However, local people have put in place strategies to conserve the resource, such as the development of seeding to reduce the extraction of seedlings in situ, and the protection of banks overgrown with palm trees. Although this decision takes into account the ecological footprint, i.e. the equalisation between exploitation and regeneration rates, its effectiveness is ignored. Several methods of economic evaluation of the degradation of renewable resources have been proposed for this purpose. Among others, the Chevassus-au-Louis (2009) report proposes valuing biodiversity on the basis of the ecosystem services from which society benefits. Gastineau et al. (2023) used a multi-criteria approach to discuss the modalities of ecological compensation measures in response to environmental damage when ecological, economic, and societal criteria are taken into account Gastineau et al. (2021). They showed that it is necessary to find a compromise between ecological criteria and criteria that take into account the preservation of the quality of life of inhabitants, which they call the "social well-being" criterion (IRP 2020). The principle of monetarisation was used to evaluate, in monetary terms, the impact of a variation in the quantity of an environmental good on the well-being of an individual consisted in determining how much an individual would be prepared to pay to avoid the degradation of an element of his environment. However, this method itself contains intrinsic biases linked to the moral hazard of actors. L'Écuyer-Sauvageau (2022) analysed the supply and demand of water-related ecosystem services in the agricultural sector in Quebec using the benefit transfer method and methods derived from market prices. This approach has certainly provided a picture of the value of ecosystem services associated with agricultural environments, but it does not take into account the imperfect nature of markets, which makes the price incapable of internalising the externalities associated with the exploitation of environmental heritage. Similarly, several studies have addressed the degradation of palm trees in eastern Burkina Faso (Sogué 2010; Yaméogo 2016). However, all these studies have merely presented the results obtained without explicitly developing the techniques, methods and hypotheses. Njomgang (2002) developed an innovative dynamic method based on the equilibrium price between the resource constraint and human activity. This approach seems better suited to our context and is used in this study to analyse the crisis situation and the crisis state of plant exploitation in the Kompienga watershed, with variances. We integrated the price of a perfect substitute for hypocotyl as the social opportunity cost of the depletion of the palm tree stock, to determine the crisis situation and the state of crisis of the economic exploitation of this natural good. In what follows, the methodology used is first presented, then the results of the data analysed are presented and discussed, and finally, we drew the inherent conclusion and recommendations.

2. Materials and Methods

2.1. Method

We started from the work of Njomgang (2002) to define the crisis in relation to the equilibrium, symbolized by: $\mu = \omega t \omega o^{-1} = 1$. Where: μ is the rate of depletion of the palmyra palm wood resource, ωt is the effective rate of exploitation of the forest capital Wt in t, ωo is the optimal exploitation rate, i.e. the rate compatible with forest regeneration.

To determine ωo in practice, we conducted an inventory of a dozen hectares of natural palmyra palm tree stands, which we compared to the stratum of young palmyra palm trees ranging in age from six months to six years at 30 logging sites selected based on the density of the stands and their accessibility. This stratum is considered by Guinko and Ouédraogo (2005) and Yaméogo et al. (2016) as the regenerated palmyra palm franche. If, for example, the inventory yields 60 six-month-old to six-year-old seedlings per hectare out of a total of 300 palmyra palm trees, then the regeneration rate will be 60/300. And if the net natural regeneration (dead seedlings and surviving saplings) from harvesting sites yields 2 out of 300 trees per hectare per year, then the regeneration cycle (equal, in equilibrium, to the rotation period) is:

$T = 60(300)^{-1}(2(300))^{-1} = 30$ years. We will then have $\omega o = 1 * T^{-1} = 1 * 30^{-1}$ (1)

That is to say, the forest formation considered can be divided into thirty equal parcels, of which one can be exploited each year without danger to the forest capital. The effective rate of extraction is defined as the ratio between the quantity of seedlings harvested Qt and the forest capital Wt, i.e.

$$\omega_t = Q_t W_t^{-1} \quad (2)$$

The equilibrium situation (the crisis condition) is thus symbolized by:

$$\mu = \omega t \omega o^{-1};\ \mu = 1, \text{ i.e. } \omega t = \omega o \text{ or } Q_t W_t^{-1} = 1 * T^{-1} \quad (3)$$

The indicator μ makes it possible to distinguish between the two types of planting crisis that occur in the Kompienga watershed: The over-exploitation crisis, characterized by μ>1, is prevalent in the Kompienga watershed. The under-exploitation crisis, characterized by μ<1, is rampant in the forestry sector.

The equilibrium price is an implicit price. That is to say, it results from the process of maximizing, under the constraint of the scarcity of young shoots, the net social benefit provided by the regeneration of palmyra palm trees, instead of being a parameter (market price or public price) in this process (Njomgang 2002). It indicates the price of a unit of resource in terms of net social benefit when the constraint is varied by one unit. It is therefore a decision variable in our problem of rationalizing reforestation or natural regeneration policies, allowing us to assess the impact of human activities on the palmyra palm seedlings and not an exogenous variable. In the context of the study, the research on the equilibrium price aims at providing a criterion for quantitative analysis of the interface exploitation of the seedlings (hypocotyl), and the regeneration of the species. These seedlings are viewed in terms of their dual function as a source of food and income on the one hand, and as a factor in future ecosystem regulation on the other. This is an implicit macro-price (Njomgang 1993), in the sense that it results from a joint maximisation in the ecosystem and in the economic exploitation of the young shoots, under the hypothesis of proportionality between the economic value of the palmyra palm tree and its regeneration cycle. As assumptions**,** we place ourselves in the eyes of the state, whose objective it is to maximise the satisfaction of the needs for non-wood forest products under the constraint of ecological balance, i.e., with natural regeneration. The only way to increase the stock of palmyra palm tree stands is through natural regeneration. We consider that the rate of assisted regeneration of the palmyra palm tree asset is very weak because of the absence of action for reforestation of the palmyra palm trees on the site. The policy of natural regeneration is taken into account through the rate of replacement of the old or dead Borassus aethiopum each year by the survivors of the young palmyra palmer shoots. The first relationship is a defining relationship of cut replacement:

$$R_t = r\, Q_t \quad (4)$$

Where R_t is the number of trees to be retained in the harvested area to ensure stand regeneration, and Q_t is the number of seedlings removed for their roots. The rate r is constant (the mortality rate is considered to be identical in the whole area). The second relationship is a relation of definition of the forest capital.

$$W_t = W_0 - \left(\int_0^t Q\tau\, d\tau - \int_0^t R\tau\, d\tau\right) \quad (5)$$

Expression in which: W_t and W_0 denote, respectively, the stand capital of the palmyra palm tree at t and the initial stand capital of the palmyra palm tree. The sums in parentheses denote the quantities harvested and retained to t, respectively. This is again written as:

$$W_t = W_0 - \left(\omega \int_0^t W\tau\, d\tau - r\omega \int_0^t W\tau\, d\tau\right) \quad (6)$$

$$W_t = W_0 - \omega(1-r)\int_0^t W\tau\, d\tau \quad (7)$$

In this expression, (1-r) denotes the effective exploitation rate in the presence of natural regeneration. One has in effect:

$$\omega(1-r) = \frac{Q_t}{W_t}\left(1-\frac{R_t}{Q_t}\right) = \frac{Q_t - R_t}{W_t} \quad (8)$$

The definition of the net social benefit provided by the operation of palmyra palm seedlings is:

$$B_s = U(Q) - C_s \quad (9)$$

Where: U(Q) is the social utility of a seedling. This utility is defined, in the context of the study, as the sum of the income of the hypocotyl producers and the consumption and production services rendered by the palmyra palm in the various uses. These include food, energy, handicrafts, fertilisation of agricultural soils, etc. However, in this study, the utility will be summarized as the income provided to hypocotyl producers because of the difficulties in evaluating the other services provided by the palmyra palm to society. Thus, the utility is underestimated (Yaméogo 2008). C_s is the social cost of the palmyra palm tree. This cost includes environmental costs and opportunity costs measured in terms of the comparative yield of alternative uses of non-wood palmyra products (timber, in particular, food, medicine, etc.) and substitutes for hypocotyls in food uses (tubers and agricultural roots, in particular). The social costs were assessed in this study through the value of substitutes for hypocotyls in food uses, including yam, sweet potato, and cassava. According to Sogué (2010), cassava is the closest substitute to hypocotyl with a cross-price elasticity equal to +1.16. That is, a 1% increase in the price of cassava leads to a 1.16% increase in the consumption of hypocotyl. Thus, the social cost of hypocotyl is equal to its opportunity cost, i.e., the price of cassava times the quantity. U(Q) measures the sum of the utility flows Pt (q), where q denotes the flow of wood production. Thus we have:

$$U(Q) = \int_0^q Pt(q)\, dt \quad (10)$$

The problem thus amounts to maximizing: $B_s = U(Q) - C_s$.

Under the ecological equilibrium constraint ω= ωo, where R_t= rQ_t in terms of replacement, r= 1. The Lagrangian is written:

$$V(Q,\lambda,t) = (U(Q) - C_s) - P'_t Q_t - \lambda(t)(Q_t - R_t) \quad (11)$$

Where again:

$$V(Q,\lambda,t) = (U(Q) - C_s(Q)) - P'_t Q_t - \lambda(t)(1-r)Q_t \quad (12)$$

By canceling the partial derivatives, we obtain:

$$\frac{\partial V}{\partial Q} = U'(Q) - P'_t - \lambda(t)(1-r) = 0 \quad (13)$$

and

$$\frac{\partial V}{\partial \lambda} = Q_t(1-r) = 0 \quad (14)$$

The relation (13) gives:

$$U'(Q) = P'_t + \lambda(t)(1-r) \quad (15)$$

With P'_t the price of cassava. Again, knowing that:

$$U(Q) = \int_0^q Pt(q)\, dq. \text{ And } P_t = P'_t + \lambda(t)(1-r) \quad (16)$$

Where (t) is a time-dependent Lagrange multiplier, playing the role of a proportionality coefficient between the equilibrium price and the resource constraint. According to equation (8) $\omega(1-r) = \frac{Q_t}{W_t}\left(1-\frac{R_t}{Q_t}\right) = \frac{Q_t-R_t}{W_t}$ hence $\lambda(t) = \omega(t) = \frac{Q_t}{W_t}$ i.e. the effective rate of hypocotyl extraction. Here, P_t is the inverse demand expression for hypocotyl with λ(t) (1-r) as the quantity demanded. (1-r) being constant, the increase in quantity demanded depends on (t) which in turn is a function of the rate of resource depletion which is analytically positive $\lambda(t) = \mu^* \omega_0$. This is consistent with the economic theory of natural resource depletion where P_t is an increasing function of time and depletion of the palmyra palm resource in the situation of overexploitation of the resource (μ>1), and decreasing in the situation of under exploitation of the resource (μ<1), and roughly equal to $P'_t + (1-r)$ in the equilibrium situation. To summarise, regardless of the resource's exploitation crisis, its price must be higher than its closest substitute in order to reduce demand.

2.2. Data

Secondary and primary data were used in this research. For this purpose, the study reports of the environmental institutions established in the study area were consulted. Part of the data was extracted from the master's thesis of Sogué (2010) and supplemented by a survey of households growing palmyra palm from 2010 to 2020; because of the remoteness of the households' compounds, insecurity in the area and the recent presence of armed groups in the area, the sample size was reduced to thirty households. In addition, in 2010, twelve control sites were identified and the Borassus aethiopum was inventoried by age group. The exploitable seedlings are those between 1 and 3 months old. At this age, they have one to two leaves. Seedlings over one meter in height are considered regenerated. The same approach was adopted for thirty harvesting sites in 2010, 2015, and 2020. Of the thirty sites monitored, 17 were close to the concessions (2 to 3 km) and were considered "high accessibility" while those located between 3 and 5 km were considered "medium accessibility", of which there were seven. Finally, the remaining six were either on the riverbank or on the other side of the riverbank. They were accessible only in the dry season after January or March. They were qualified as sites with low accessibility.

3. Results and Discussions

The average density of the park is 436 mature palmyra palm trees per hectare in the inventory areas. If the youngest individuals are taken into account, the average density increases to 3876 trees ha^{-1}, of which 430 seedlings are extracted per year on each site, i.e., an exploitation rate of 0.11. This density is well above that of agroforestry parks in southwestern Burkina Faso (Cassou and Depommier 1997).

There is little variation in density at the plot level as indicated by coefficients of variation (CV) ranging from 22% to 33%. However, there are more intermediate strata in the sparse sites generally closer to the concessions than in the dense, inaccessible

Table 1. Descriptive statistics of the data

Variables	Unit	Average	Median	SD[a]	CV[b]
Seedlings	feet	3440.23	3146.50	1123.19	0.33
Palmyra palm	feet	435.74	417.50	96.77	0.22
W_t	feet	3875.98	3542.50	1204.56	0.31
Q_t	feet	429.90	420.00	109.20	0.25
ω_t	-	0.11	0.11	0.02	0.17
ω_0	-	0.11	0.11	0.04	0.33
$\mu = \omega_t \omega_o^{-1}$	-	1.00	0.97	0.17	0.17
Price of hypocotyl	USD	0.25	0.21	0.11	0.00
Cassava price	USD	0.54	0.36	0.69	0.00

a; standard deviation, b; coefficient of variation.

areas. The results in Table 1 also show a natural regeneration rate in the control areas of $\omega o = 0.11$ giving a seedling depletion rate of $\mu = 1$. This is an equilibrium situation that ensures compatibility between the regeneration cycle of the resources and the rotation rate. Overall, there is no seedling crisis condition in the study area. Table 2 shows that the situation is not static. In 2010, the natural asset was facing an overexploitation crisis with a depletion rate of $\mu = 1.07$, i.e. an overexploitation of 7%. Of the 30 plots monitored, 53.3% were overexploited compared to 43.3% and 26.7%, respectively, in 2015 and 2020. In addition, the table 2 shows that the plots wereincreasingly under-exploited over time. The security crisis has caused the displacement of populations from the areas and reduced the accessibility of production sites. However, this generates a crisis of under-exploitation where the potential resources are enormous, but the poor accessibility of the deep forest limits the exploitable resources and has accentuated the over-resourcing around the concessions and refusal areas and the generalisation of the production of hypocotyl in germinators. The result is a scarcity of hypocotyls that is as constraining in its effects on prices and the environment as the over-exploitation crisis. Njomgang (1993, 2005) found similar results in the context of fuelwood exploitation in Cameroon.

In addition to the safety measures that slowed down the overexploitation of palm trees, the awareness-raising actions of rural development actors has promoted the awareness of the existence of damage on an even larger scale, such as global warming, the disruption of ecosystems, the occurrence of extreme weather events, etc. In this perspective, the analysis of

Table 2. Interannual seedling exploitation crisis situation

Years	Under-exploited	Over-exploited	µ
2010	46.7%	53.3%	1.07
2015	56.7%	43.3%	0.98
2020	73.3%	26.7%	0.96

the interactions between human activities and nature has become crucial. Indeed, Figure 1 shows a gradual shift of human pressure on stands towards highly accessible areas and the substitution of in-situ sapling extraction for controlled agricultural production of hypocotyls. The determination of equilibrium prices of hypocotyls recorded in Table 3 shows the extent of hypocotyl undervaluation over time. These prices observed in 2010, 2015 and 2020 are respectively 0.13 USD, and USD 0.24, USD 0.37 per hypocotyl. They should be USD 0.35, USD 0.40 and USD 0.48 per hypocotyl to take into account the social cost of their depletion. The social cost generated represents an undervaluation of the producer price of hypocotyls of 166%, 70%, and 28% of their current price.

Baral et al. (2008) used a contingent valuation method to determine the price of entry into Nepal's largest protected area, Annapurna. Taking into account biodiversity conservation, ecosystem protection and sustainable development, they found that the proposed fees ranged from USD 30 to USD 120, with a survey price of USD 27. The study indicates that the entry fee may well be increased incrementally from USD 27 to USD 50. Thus, the implicit prices of environmental assets are generally reservation prices for the consumers and therefore reduce their surplus to zero.

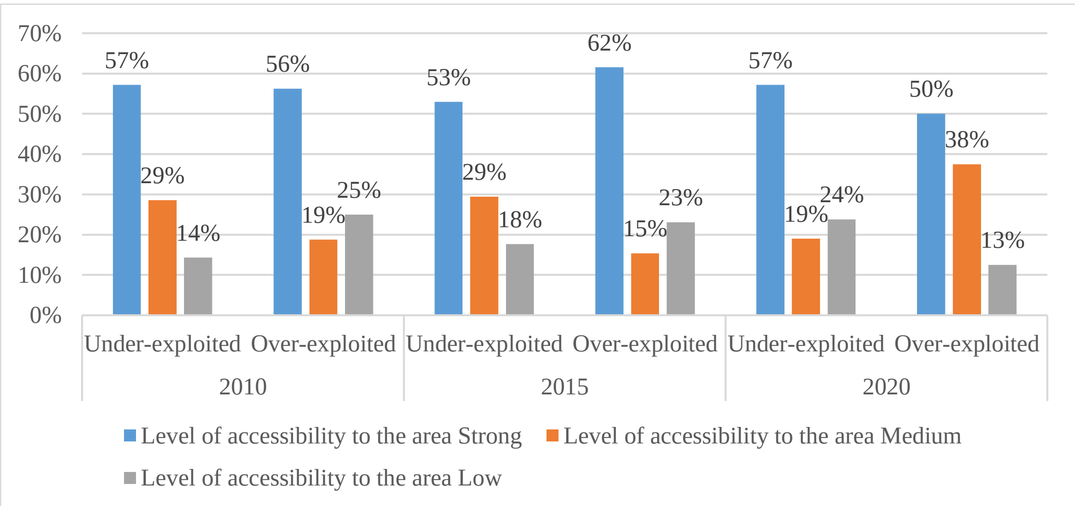

Figure 1. Dynamics of the nature of the crisis.

Figure 2 provides a comparative view of price structures over this decade. A visualisation of the implicit prices of hypocotyls shows little difference with those of their direct substitute over time. This implies a transition to green and sustainable growth of palmyra palm tree services. However, this requires taking the analysis further and looking beyond production as described above by requiring the asset base to remain intact. Indeed, the current depletion of the asset base poses a risk to growth, and this type of risk must be avoided. Until now, the price of hypocotyls on the market essentially integrated private costs, i.e., the costs borne by those involved in the young growth sector of the palmyra palm tree for the production and marketing of hypocotyls. The social costs include forestry taxes and fees, taxes and other regulatory costs whose objective is to reduce harvesting and safeguard forest resources are derisory (Sogué 2010) to dissuade consumers. As shown in Table 3, these taxes should represent 166%, 70% and 28% of the market price of hypocotyl in 2010, 2015 and 2020, respectively, in order to reflect the real use value of the seedlings and to preserve the regeneration of the species, whereas Sogué (2010) reported that the tax represented only 6% of the price of hypocotyl in 2010.

As shown in Figure 2, implicit prices are variable both intra- and inter-annually. Similar results were found by Revéret et al. (2019). Indeed, he conducted a case study in the Tioga classified forest in Burkina Faso on a sample of 300 surveyed households. The author shows two types of average Willingness To Pay (WTP) for riparian households: an average monthly WTP of USD 1.03 to obtain a field in the forest (alternative use), and an average WTP of USD 0.80 for forest maintenance. In the same vein, Ouédraogo (2015), based on the work of Yaméogo et al. (2016), showed that between 1985 and 1995, the real price of firewood sold to consumers increased by 28.54%. However, this increase in the price of fuelwood is explained by simultaneous increases of 124.96% in real transport costs, 39.87% in real retail costs, and 42.16% in real wholesale profit margins; real retail profit margins have decreased by 16.27% between 1985 and 1995, and not by the price of the social costs of producing fuelwood. Finally, Figure 2 shows the evolution of observed prices at an increasing rate from 2015 and the possibility of convergence of the three prices if this 2015 growth rate is maintained. Observed prices rose on average from USD 0.13 in 2010 to USD 0.24 in 2015, and to USD 0.37 in 2020. This represents a 2010-based price index of 100; 181.25; and 287.68 respectively, a tripling of prices in a decade. In addition, in some sites where the depletion rate is very low, the observed price is higher than that determined.

4. Conclusion

Our approach to developing this methodology has been based on the most recent developments in the economic evaluation of environmental degradation. We started with the work of Claude Njomgang (1993, 2002) to determine an equilibrium price for young palmyra palm tree shoots in the Kompienga watershed. The exploitation of seedlings is in equilibrium. In fact, at equilibrium, the rate of depletion (μ) of wood resources is equal to 1 and ensures compatibility between the regeneration cycle of the resources and the rotation rate. Moreover, with the generalisation of germination and the deterioration of the security situation in eastern Burkina Faso since 2015, the demand for hypocotyl has decreased, also leading to a reduction in the rate of exploitation of seedlings in natural formations. While these two phenomena have helped to rebalance the flow of energy in the ecosystem, they also create situations of under-exploitation crises which, like over-exploitation, constitute an inefficiency from an economic point of view. The prices observed during the three periods do not allow for optimal exploitation of the resource. Producer prices are between 28% and 166% lower than their implicit level. The Pigouvian tax currently applied by the public

Table 3. Determination of equilibrium prices of the hypocotyl

Years	Average prices determined in USD	Average prices observed in USD	Differences in USD	Extent of price underpricing
2010	0.35	0.13	0.22	166%
2015	0.40	0.24	0.16	70%
2020	0.48	0.37	0.10	28%

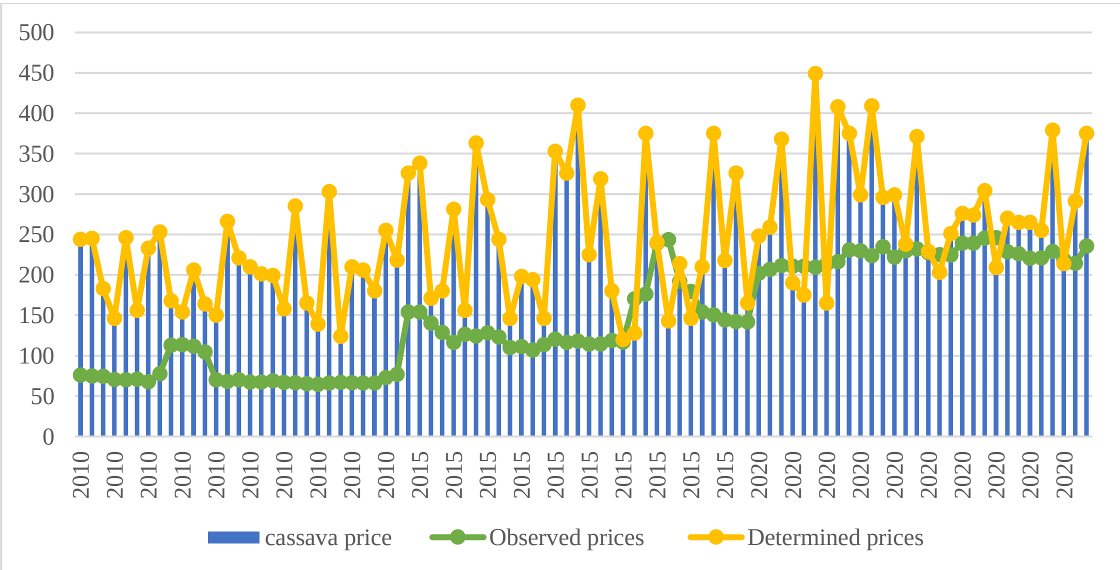

Figure 2. Evolution of observed and determined prices of hypocotyl and cassava in space.

administration to ensure price convergence is modest enough to be effective. It is barely 6% of the observed price, whereas it should have been 166% in 2010, 70% in 2015, and 28% in 2020 of the price of the producer of the hypocotyl in order to reflect the unit use value of the seedlings and to preserve the regeneration of the species. The convergence of the observed prices and the determined prices is accidental because it is essentially created by the security situation, which reduced the accessibility of the operators of the zones of production and generated a supply of hypocotyls lower than their demand. It is recommended that the public administration should apply a tax that varies over time according to the rate of exploitation and natural regeneration of palmyra palm tree seedlings. This dynamic tax should act as a proportionality coefficient between the equilibrium price and the resource constraint.

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