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Pricing agricultural inputs from biodiversity-rich ecosystems and habitats without input markets

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Abstract

Purpose – The purpose of this paper is to focus on the analysis of an understudied problem in the economic literature. It proposes a valuation methodology for inputs that come from biodiversity-rich ecosystems/habitats and are used in agro-food production at zero input cost because there is not a market for such inputs.
Design/methodology/approach – Following Onofri *et al.* (2017), the authors computed the value of the marginal productivity of different inputs in three selected case studies (Angola, Mozambique and Brazil). Results are theory based and rigorous but show a strong contingency, case based, relative dimension that is captured, in the framework, by the "relativity ratio." The ratio expresses the relative weight of the value generated by the input that comes from biodiversity-rich ecosystems/habitats in the per capita monthly available income of the farmer and aims at conveying additional insights to the economic valuation.
Findings – In this paper, the assessment of agricultural inputs value (price) in the absence of inputs markets is done, with an application to three different case studies. The inputs are peculiar since they come from habitats and ecosystems that are very biodiversity-rich.
Originality/value – The paper proposes a practical, though rigorous, methodology for the assessment of the value (price) of agricultural inputs in absence of inputs markets. Markets do not exist since the inputs come from biodiversity-rich habitats and ecosystems.

Keywords Biodiversity, Agricultural input, Economic valuation, Marginal productivity of inputs, Missing markets

Paper type Case study

1. Introduction

Agricultural sectors are major users of biodiversity since they manage terrestrial, freshwater and marine areas on Earth. Agricultural sectors can contribute to important ecosystem functions if managed in a sustainable way. These functions include maintenance of water quality, nutrient cycling, soil formation and rehabilitation, erosion control, carbon sequestration, resilience, habitat provision for wild species, biological pest control and pollination. In agricultural ecosystems, in fact, maintenance of biological diversity[1] is important both for food production and conservation of the ecological foundations necessary to sustain life and rural livelihoods. In this perspective, biodiversity is key to food security and

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nutrition. It is needed to sustainably produce enough nutritious food in the face of challenges, such as climate change and growing populations with changing diets (FAO, 2018, p. 6).

Agricultural biodiversity can be defined as the "sum of all the components of biological diversity of relevance to food and agriculture together with the components of biological diversity that constitute the agro-ecosystem: the variety and variability of animals, plants and micro-organisms, at the genetic, species and ecosystem levels, that sustain the functions, structure and processes of the agro-ecosystem" (FAO, 2018, p. 1). This diversity was shaped by farmers and communities for millennia and remains a key element of the small-scale farmers throughout the world. Agricultural biodiversity, including wild relatives of genetic resources, is a fundamental resource for the continued improvement of varieties and breeds and is needed to cope with changes (FAO, 2018, p. 4).

In this perspective, good governance, enabling frameworks and stewardship incentives are needed to facilitate mainstreaming of biodiversity in agro-food sectors. Good governance includes a careful pricing mechanism of agricultural biodiversity.

Within such a framework, the paper focuses on the analysis of an understudied problem in the economic literature. It tackles the issue on how to price agricultural biodiversity input[2] when they are used in agro-food production and there is not an underlying market for those inputs.

In economic theory, firms produce outputs by using a set of inputs, according to a determined technology that is mathematically summarized by a production function. Inputs are generally (but not exclusively) purchased in input markets. However, when production inputs are natural resources (water, genetic material, flowers, plants, fruits and so on), they are often used for agro-food (or industrial) production without being acquired or purchased in the input markets. Those kinds of production inputs, in fact, are directly supplied by nature "for free," at zero cost. This process generates several types of impacts. The price for the natural resources-based input, in such perspective, cannot be determined according to the rules and drivers that inspire market dynamics. The supplier's (nature) production costs (that contribute to determining the price of inputs on the supply side in neoclassical economics frameworks) are not strictly economic. Nature does not supply goods and services according to the theory of the firm but in accordance with biophysical and ecological laws. The opportunity cost generated by the choice of using the natural resource in the marketplace has mostly an ecological dimension. The demanded quantity of the input, on the other hand, assumes different values/importance, according to the peculiar and contextual use of the resource. In this perspective, the natural resource can be both used for subsistence consumption (e.g. for producing food in poor rural villages) or for profit-maximizing production (e.g. cosmetic and pharmaceutical multinationals that use natural resources in the production of their outputs). However, the benefits (subsistence or profits) derived from the use of the resource are not traded off by the costs for the use of the very same resource. There is not an underlying input market for the resource and the price cannot be determined according to market dynamics.

The problem is exacerbated when the natural resource, used as a production input, comes from a biodiversity-rich ecosystem or habitat. In this case the resource generates a wide range of extra benefits in the production of goods and services (TEEB, 2010) and may increase agricultural and ecosystems productivity (Tilman and Downing, 1994; Palatnik and Nunes, 2015; Onofri *et al.*, 2017). Biodiversity can guarantee survival in poor contexts (CBD, 2010). Besides, biodiversity generates positive externalities in production (Tilman *et al.*, 1997) and presents public goods features. More precisely, it is "what has been called a privately produced public good" (Heal, 2000). The supply of natural resources that are used as production input (especially if belonging to biodiversity-rich ecosystems and habitat) is not so large as to exceed the amount that could be demanded at any price. Such resources, in fact, can be depleted and/or overharvested/over-exploited. This does not occur because supply is much larger than demand, as in the water-diamond paradox. It occurs because the production input is directly supplied by nature and not by a profit-maximizing firm. It is, again, straightforward that the economic exploitation of such resource provides many (private) benefits at no (private) cost.

In this context, the paper is an attempt to economically assess the value (in monetary terms) of natural resources that are provided by biodiversity-rich habitat and ecosystems, when they are used as production inputs of agro-food outputs, which are traded in the markets. The setting includes that the underlying input markets do not exist, and the natural resource inputs are not priced. We apply a proposed assessment methodology in three different selected pilot sites (Namibe Region in Angola, outskirts of the city of Maputo in Mozambique, and the area of Sao Francisco do Sertao in Brazil). The choice of the pilot locations is based on several commonalities. The sites are semi-arid areas and habitats that are, nonetheless, rich in natural resources and biodiversity. They are characterized by high levels of poverty, since the socio-economic structure is mostly organized in rural economies where Portuguese is the common language.

The paper is organized as follows. Section 2 provides socio-economic valuation contexts. Section 3 describes the proposed methodology. Section 4 presents the methodology applications. Section 5 presents the valuation results and the relativity index. Section 6 discusses the results and concludes.

2. Context analysis

The section provides a synthetic description of the settings where the valuation exercise is performed. The proposed methodology is applied to three selected pilot sites: the region/area of Namibe in Angola; the Maputo outskirts in Mozambique and the region/area of Sao Francisco do Sertao in Brazil. Boxes 1–3 shortly summarize the main socio-economic characteristics of the selected pilot sites.

Table I shows economic indicators that summarize selected socio-economics figures of the studied territories.

Despite the differences that we have shortly highlighted, the selected pilot sites share six types of commonalities:

(1) They are located in semi-arid areas.

(2) They are characterized by high levels of poverty.

(3) They are rural economies.

(4) They are Portuguese speaking-areas.

(5) They are natural resources and biodiversity-rich areas (areas rich in natural capital).

(6) They adopt agriculture as an important economic activity to support local livelihoods. Local natural resources, coming from biodiversity-rich ecosystems, are inputs in the agro-food production processes, whilst agro-food outputs are expressions of local culture and economies.

Box 1. Region of Namibe, Angola

The Namibe territory is the agricultural region in the South-West of Angola. The local economy is mostly based on agriculture and fishery and heavily depends on natural resources. The human capital employed in agro-food sectors is highly unskilled. The livestock and seafood processing and conservation sectors present a higher productivity of labor (Onofri *et al.*, 2017). The agri-food sector is mostly supported by state intervention to modernize and innovate. The regional government has intensively invested in the provision of more modern pieces of machinery (e.g. tractors and boats) and subsidies to the farmers and fishers. Angola government owns the land and leases pieces of land to the farmers with short term contracts (three to five years). Within the Namibe region, there is the Mopane area, where nomad populations live and where resources that come from biodiversity-rich ecosystems and habitat are used and transformed in final products with techniques and methods inspired by traditional knowledge.

Box 2. Outskirts of Maputo, Mozambique

The Maputo city area experiences high levels of poverty in a spread rural dimension (even within the city), as a common denominator with the country. Around 80 percent of the total population of Maputo is rural and survives thanks to agricultural products. Labor is highly unskilled and people live in extreme poverty conditions. The land belongs to the Mozambique Government that leases small pieces to the farmers and provides both production inputs (like seeds) and technological transfer/formation (i.e. how to efficiently use water) through the farmers' associations. In the City of Maputo, the agricultural sector employs most of the labor force, since agricultural production systems are labor intensive. Labor productivity is low, most probably because of the poor conditions faced by farm workers. Poverty affects the characteristics and performance of human capital, generating a vicious cycle in which poverty generates poverty (CBD, 2010). Production is traded locally, in informal markets, at trifling prices. The bulk of the production is supplied independently by individual growers to distributors. It emerges a system characterized by strong inequalities, where small local farmers are not able to fully internalize the benefits resulting from farming.

Box 3. Region of Sao Francisco do Sertao, Brasil

The Region of Sao Francisco do Sertao is a semi-arid territory in the State of Bahia, located in the North of Brazil. Local communities have broadly adapted to the arid climate and habitat by defining and implementing peculiar cultivation methods and techniques (especially irrigation methods). The local economy, highly subsidized and planned by the national and local governments, is family based and grounded on a system of cooperation and social integration. Agricultural activities occur in socio-economic contexts, in which the outputs and production inputs are the results of adaptation to the climate and the semi-arid territory. Agricultural products are mostly (but not exclusively) produced and traded in regulated markets. Local governments provide start-up subsidies and purchase the output that is not sold in markets. Local governments implement many policies that aim at improving the conditions of access to credit; the distribution of plots of land to farmers; the optimization of irrigation systems; and the creation of small processors of the product, the government seeks to improve the conditions of the supply and to ensure that the supply of the product is managed by resident populations in the area – the Brazilian semi-arid landscape.

Region	Total population	Rural population (% of total population)	Per capita GDP (2015 US$)	(% of population below poverty line)
Namibe	471,613	36.4	225	80
Sao Francisco do Sertao	494,624	28	1,823	74
City of Maputo	1,194,121	80	18	87

Source: Own elaboration with local data

Table I. Synthetic indicators of regional socio-economic characteristics

3. Valuation methodology

The proposed valuation follows (part of) the methodology created by Onofri *et al.* (2017) and aims to the quantification of the value of the inputs that come from biodiversity-rich ecosystems and that are used for agro-food production, without an underlying input market. Even in case of an implicit zero-input cost condition, inputs have value and contribute to producing value (the final output). Such value is not recorded nor computed in the production chain. To fill this important informative gap, our methodology covers two steps:

(1) We compute the marginal productivity (MP) of the input that comes from biodiversity-rich ecosystems. We want to assess, in physical terms, the impact of marginal increments of the selected input on produced quantity of the agro-food output.

This computation is usually performed through the estimation of a production function. However, it can also rely on other methods (see Onofri *et al.*, 2017).

(2) We compute the value of the marginal productivity (VMP) of the input. The VMP is a measure of how much the selected input is worth (in monetary terms) when used to produce a determined agro-food output. To compute the indicator, we multiply the MP times by the market price of the final agro-food output. The VMP represents a monetary value of the market "use value" of the input that comes from a biodiversity-rich ecosystem, in a context where there is not an input market and the price of the input cannot be determined according to the standard market dynamics.

The economic theory that spurs the proposed methodology is strictly microeconomic-based (see Varian, 2010). The VMP is interpreted as the firm's marginal revenue. In perfect competition, this should equal the input price, as highlighted in the following equation:

$$\text{MP}\times\text{Output price} = \text{VMP} = \text{Marginal Revenue} = \text{Input price}. \quad (1)$$

If and only if the output agro-food markets are in perfect competition, then the VMP is the correct value for the input price. Otherwise, the VMP is interpreted as the value of the marginal revenue and the economic contribution that a single input is able to produce on the margin[3].

Finally, we can highlight two main components of the VMP of the input that come from biodiversity-rich ecosystems. The following equation describes what variables affect those components:

$$\text{VMP} = \underbrace{\frac{\partial \text{Qagro} - \text{Food}_{\text{output}}}{\partial i_{\text{input}}}}_{\text{Variations in the production technologies and use of the input}} \times \overbrace{p_{\text{output}}}^{\text{Variations in the price of the final output (e.g. demand and supply conditions)}} \quad (2)$$

4. Valuation applications

The section presents the application of the proposed valuation methodology to selected inputs and agro-food outputs in the three sites. After many meetings, structured as *in loco* visits organized by the local GLoB (*Governace Local para a Biodiversidade*) Project Partners, with local policymakers, producers and experts in different disciplines, spanning from botany to economics, from ecology to agricultural engineering, we have decided to apply the methodology to those inputs and outputs that are listed in Tables II and III.

Difficulties in gathering quantitative information have influenced the choice of the valuation approach. Onofri *et al.* (2017, p. 119) suggest three alternative types of methods for the computation of the input MP:

(1) estimation of production functions[4];

(2) empirical information provided by experts/literature; and

(3) computation derived by the application of microeconomic theory.

We were not able to econometrically estimate production functions for the computation of the MP of the selected inputs, as in other cases (Table IV)[5], given a substantial lack of quantitative and qualitative data. We, therefore, adopted the methodology suggested by Points (2) and (3) in the Onofri *et al.* (2017) paper.

The study by Urso *et al.* (2013) has provided figures for the value of the MP of *mumpeke* seeds (to produce the *mumpeke* oil), as in Point (2).

Region	Outputs	Biodiversity-rich input
Namibe (Mopane area)	*Mumpeke* oil[a]	*Mumpeke* (plant/bush) seeds
	Dry edible worms[b]	*Maungo* (edible worm)
Sao Francisco do Sertao	*Maracuja* jelly[c]	*Maracuja de Caatinga* (*Caatinga* passion fruit)
City of Maputo	Traditional food[d]	*Amboa leaves/Tseke leaves* (edible leaves)

Notes: [a]In the Mopane area of the Namibe region, local tribes use the seeds of the *Mumpeke* bush for the production of a cosmetic oil that is sold in local markets. The production of the oil follows a very (female) labor-intensive process that involves picking up the seeds; crush them in a mortar; boiling the dough for hours; filtering and bottling the oil; [b]in the same area, the Mopane trees host the *maungo*, an edible worm, that is collected, dried or smoked, packed and commercialized locally, nationally and internationally (mostly Belgium and France); [c]in the Sao Francisco do Sertao area, a species of passion fruit, the *Caatinga* passion fruit grows spontaneously. Local populations pick the fruits and partially sell them unprocessed. They also process part of the harvest to produce (mostly) jellies and juices that are marketed locally; [d]in the Maputo outskirts, a whole selection of edible leaves grows spontaneously. Farmers pick and sell the leaves in local markets. The leaves are used for the preparation of traditional food
Source: Our elaboration

Table II. Products and biodiversity-rich inputs

Region	Input	Output	MP[a]	VPM[b] (US$)
City of Maputo	*Tseke* leaves	Traditional food	1	From 0.04 to 0.2
	Amboa leaves	Traditional food	1	From 1.44 to 1.60
Sao Francisco do Sertao	Maracuja de *Caatinga* (*Caatinga* passion fruit)	Jellies	2	4.4
Namibe (Mopane Area)	*Maungo*	Smoked/dried worm	1	From 3.75 to 5.25 (Namibe Market) From 1.25 to 2.25 (Bibala Market) 15 (Afrika Market, African Supermarket Chains in Brussels)
	Mumpeke oil	*Mumpeke* oil	0.16	0.75 (Mopane) 1.5–1.9 (Namibe market)

Notes: [a]The marginal productivity is interpreted as the output variations (measured in kilos) when using and additional unit (kilo) of an input that is taken from biodiversity-rich ecosystems; [b]the agricultural products market prices are taken as data, for the sake of the study objectives. The analysis of the determinants of those prices are left to further research and is useful for the refinements of the assessment exercise
Source: Own elaboration with local data

Table III. Value of the marginal productivity of biodiversity-rich inputs of production

Explanatory variables	(Log)Sheep	(Log)Goats
(Log)Labor	1.58***	0.96***
(Log)Land	–	0.39***
Constant	1.87	1.09
R^2	0.75	0.82

Note: ***Significant at 1 percent

Table IV. Pooled OLS results

The MP of the other inputs was computed as in Point (3), by following microeconomic reasoning and the relationship between marginal and average measures. We only got data on the average product (computed as the ratio of total output and total input) of the selected inputs in selected years (*maungo*, *tseke/amboa* leaves and *Catinga* passion fruit). We used the very simple and general mathematical rule that links marginal and average measures.

In synthesis, if the marginal is larger than the average, then the average increases. If the marginal is smaller than average, then the average decreases. If the marginal equals the average, then the average does not change. Such general rules also apply to economic concepts, including marginal and average productivity of inputs (see Varian, 2010).

Our data, scarce and fragmented, shew empirical regularity in the average productivity of the selected inputs[6]. In this perspective, we interpret the data as describing a situation, where the average product equals MP.

More formally, let us assume a production function where the only input comes from biodiversity-rich ecosystems. The quantity of agro-food output (Q) is a function of the input i_b and describes the technical relationship that links input i_b and output Q, as described in the equation as follows:

$$Q = f(i_b). \tag{3}$$

The average productivity measures the total output divided the total input, as described in the following equation. It provides information on how total production varies when changing total input:

$$\mathrm{AP} = Q/i_b. \tag{4}$$

Finally, MP measures the variation of output when changing the input on the margin (a small amount), as described in the following equation. It is a derivative of the production function with respect to the selected input marginal variations and conveys information on additional increases in the input use:

$$\mathrm{MP} = \frac{dQ}{di}, \tag{5}$$

when $\mathrm{AP}_{t1}=\mathrm{AP}_{t2}= \ldots =\mathrm{AP}_{tn}$ then we can conclude that $\Rightarrow$ AP=MP.

This means that when average productivity is constant over a selected period (spanning from t_1 to t_n), then, applying the mathematical rule, we can derive that average productivity equals the MP. In economic terms, this also means that the selected input presents constant marginal returns.

5. Results

The section presents the valuation results and their interpretation in a contextualized setting, through the computation of a "relativity ratio." Table III summarizes the selected results.

Column 3 reports the MP of each selected biodiversity-rich input. The MP of *tseke* and *amboa* leaves is 1. This means that an additional kilo of leaves produces an additional kilo of food. The MP of the *Caatinga* passion fruit is 2. Therefore, an additional kilo of passion fruit produces 2 additional kilos of jelly. The MP of the *maungo* is 1, and therefore, an additional kilo of worms produces an additional kilo of smoked/dried product. Finally, the MP of *mumpeke* seeds is 0.16. This implies that an additional kilo of seeds produces 160 grams of *mumpeke* oil.

Column 4 reports the VMP selected biodiversity-rich input[7]. In Maputo the VMP generated by selling an extra kilo of leaves equals few dollars/dollar cents. The amount is very low in absolute terms. In San Francisco do Sertao the VMP is $4.4. In the Namibe area, the *maungo*'s VMP changes according to the variation of the output price in different markets. It spans from a few dollars, when traded in Namibe and Bibala markets, to $15 per kilo, when traded in Brussels supermarkets.

5.1 Contextualizing valuation results: the "relativity ratio"

The VMP indicates how much additional revenues are generated using an additional amount of the input. Such a figure is very important and, if correctly computed, conveys information on market structure and performance. VMP contains information on the marginal impact of the input on the productive technology (MP) and it signals how (and how much) such value can change when the output price changes.

Such values, however, should be interpreted in the context where they are computed. In this perspective, we have computed a "relativity ratio," the ratio between per capita monthly GDP and VMP of the selected inputs. The ratio indicates the proportion between per person monthly availability of money and the VMP. The ratio is useful to contextualize the value of selected inputs and outputs in relative terms. It synthetically indicates how much an extra sale of output weights in the person monthly available budget.

For instance, in Mozambique, the annual per capita GDP is $74 (e.g. 6.16 monthly GDP). This means that every additional revenue generated by selling an extra kilo of *amboa* leaves produces almost a fourth of the monthly GDP of the poor. The sale of an additional kilo of *tseke* leaves generates revenue that is the 154th part of the monthly per capita GDP of the representative Maputo farmer. These examples provide insights for the computation and contextualization of the value of the inputs that are taken from biodiversity-rich ecosystems to the market. In Angola, a farmer selling an additional kilo of dry/smoked *maungo* (produced with an additional unit of the input that comes from biodiversity-rich ecosystems) may get a revenue up to one-fifth of his monthly per capita GDP. However, the *maungo*'s VPM changes according to the variation of the output prices in international (Brussels), urban (Namibe) and provincial (Bibala) markets. In Brazil, the trade of an additional kilo of jelly, prepared with *Caatinga* passion fruit, equals up to a 34th of the monthly per capita GDP. Table V summarizes the results.

6. Conclusive remarks

In the paper, we have valued inputs that come from biodiversity-rich ecosystems and are used in agro-food production at zero input cost because there is not a market for such inputs. Following Onofri *et al.* (2017), we have computed the VMP of different inputs in three selected case studies (Angola, Mozambique and Brazil). Results are theory based and rigorous but

Region	Input	Monthly per capita GDP (US$)	VMP (US$)	Relativity ratio
City of Maputo	*Tseke* leaves	6.16	From 0.04 to 0.2	From 154 to 30.8
	Amboa leaves		From 1.44 to 1.60	From 4.27 to 3.85
Sao Francisco do Sertao	*Maracuja de Caatinga* (*Caatinga* passion fruit)	152	4.4	34.54
Namibe (Mopane Area)	*Maungo*	18.75	From 3.75 to 5.25 (Namibe market) From 1.25 to 2.25 (Bibala market) 15 (Afrika Market, African supermarket in Brussels, Belgium	From 5 to 3.5 (Namibe) From 15 to 8.33 (Bibala) 1.23 (Brussels) Belgium
	Mumpeke oil		0.75 (Mopane) 1.5–1.9 (Namibe Market)	25 (Mopane) 12.5–9.8 (Namibe Market)

Source: Own elaboration with local data

Table V. Relativity ratio and value of the marginal productivity of biodiversity-rich inputs of production show a strong contingency, case based, relative dimension that is captured by the "relativity ratio." The ratio expresses the relative weight of the value generated by the input use in the per capita monthly available income of the farmer. Our empirical valuation results offer hints for critical discussion, based on three main points.

First, the VMP is an important indicator of the economic value that inputs from biodiversity-rich ecosystems can generate. However, such indicator must be contextualized and interpreted "with care." Different prices of the same agro-food output (e.g. the *maungo* price in local Bibala markets or international Brussels supermarkets) vary and affect the value of the input VMP. In this perspective, a "risky" interpretation of the input VMP would be instrumental to opportunistically increase the "value of biodiversity" through some market strategies or even public policies. For instance, one can claim that since VMP of the *maungo* worm is higher in Brussels (because the price of dried *maungo* is higher there), this should indicate that *maungo*'s value is higher internationally and the supply should be increased in international markets. This could spur production and exports at the detriment of resource conservation and sustainable harvest.

Second, an economic value, expressed in monetary terms, if not carefully balanced by context analysis, including relativity indices, is just a stand-alone figure that is not very meaningful if not conceptualized and interpreted in the real, concrete valuation context. In this perspective, we would have a "bad" interpretation and application of "good" (because theoretically based) economic valuation in monetary terms. In our opinion, a "stand-alone monetary figure" loses its informative role and content if it is not conceptualized and interpreted in the real, concrete valuation context. Qualitative, context-based economic valuation should complement and enrich technical economic valuation expressed in monetary units. This aims both at capturing the relativity of the valuation exercise and at intellectually avoiding "the Night in which all Cows are Black." The colorful expression, borrowed from Hegel's criticism of Schelling's philosophy, expresses a concept, and a future research path that, in our opinion, applies to economic valuation of biodiversity. Neoclassical economic theory, valuation methods and concepts are powerful instruments but still are not fully able to capture the value of natural resources (see Gowdy, 1997). They, however, convey important economic concepts, like marginalism, relativity, trade-offs balancing that are embodied and expressed by "contextualized" monetary values. It is also important to highlight the theoretical concept of opportunity cost (and related monetary dimension) of alternative uses of the very same input. A typical example and application come from the competition between biofuel feedstock and food production, especially in developing countries, as pointed out in the recent paper by Herrmann *et al.* (2018).

Third, the monetary value of inputs from biodiversity-rich ecosystems does not represent the unique economic valuation dimension. In Maputo/Mozambique, biodiversity is a driver that guarantees subsistence for the poor. *Amboa* and *tseke* leaves are traded in small quantities (*molhinhos*, small bunches, few hundred grams), with other products, in local markets. The leaves are the expression of the local biodiversity. Poor people use them to prepare traditional food and daily meals. In this perspective, it is important to highlight that the value of inputs, in such a context of poverty, is also determined by the capacity of natural resources to ensure human survival. Typical products of local biodiversity, like the leaves of *tseke* and *amboa*, are essential for survival. Such characteristic is not fully captured by the economic dimension measured in monetary units. In a context where the typical leaves' consumer, the farmworker, earns around \$6.5–\$13 a month (with about 30 days of work, 11 h a day on average), a *molhinho* (bunch) of *amboa* and/or *tseke* takes a consistent part of the monthly available income. Additional measures, like the calculation of calories and nutrients, and health indicators might be a more appropriate measure of the economic value of inputs that are taken from biodiversity-rich ecosystems. In this perspective and socio-economic context, the value of those inputs is extremely high. In Mozambique, biodiversity is interpreted as a driver to alleviate poverty. In Brazil, in the territory of Sao Francisco do Sertao, the support of local communities through a (controlled) economic exploitation of inputs that come from biodiversity-rich ecosystems allows and guarantees the survival and economic development of local populations. It helps to protect local biodiversity through the cultivation of a traditional input that produces traditional agro-food products. It encourages farmers to conserve the culture whilst respecting the natural cycles. In Brazil, the value of biodiversity is interpreted as a driver to support well-adapted local communities and to increase their welfare. Finally, in Angola, the economic exploitation of inputs that are taken from biodiversity-rich ecosystems is a source, among the other, of female empowerment. The ecosystem of Mopane economic performance depends mainly on women's work. Women prepare the *mumpeke* oil and pick the *maungo* worm from the Mopane trees. Women contribute (together with men) to perform the procedures aiming at drying and packaging the product. Women keep and transmit important traditional production methods. In Angola, biodiversity is interpreted as a driver to conserve traditional knowledge.

Such final, critical remarks mostly highlight that much work must be done along those lines to mainstream biodiversity in agricultural and agro-food markets. In this perspective, the assessment of the value of agricultural biodiversity (FAO, 2018), and the methods to contextualize that value, will generate a large basin of stimulus and debates for future research.

Notes

1. "Biological diversity means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems." Art 2 of the Convention of Biological Diversity.
2. For the sake of the research, agricultural biodiversity inputs are those production inputs that derive from peculiar biodiversity-rich ecosystems.
3. To our knowledge, the literature on input-pricing models with implicit assumptions of zero input costs is mostly related to the labor markets and the trade-off between opportunity cost of labor and leisure (see Posnett and Jan, 1996; Becker, 1965; DeSerpa, 1971).
4. Production functions describe in functional, mathematical terms, the technical relationship between produced output (Q) and used inputs (in) $\Rightarrow$ $Q=f(\text{in})$.
5. The statistical office of the regional government of the Namibe province has produced an economic outlook (Governo Provincial do Namibe, 2014), containing data and information that allowed us to perform some econometric exercise. In particular, we could gather the economic performance of 187 farms in the period 2008–2013 for the goats and sheep breeding sector. Given the available data, we have chosen to estimate a Cobb-Douglas (CB) production function. The CB log-log production function takes the (general) empirical form, as described in the following equation:

$$\text{lnOutput} = \alpha_0 + \sum_{n=1}^{N} \beta_n \text{lnInput}_n + \varepsilon_n. \quad (1)$$

Agricultural output (in logs) depends on a log-linear combination of n production inputs and an error term. The empirical specification is derived from a theoretical model, where Output=A Input1^b $\times$ Input2^c. The dependent variable is agricultural output, A is the total factor productivity (the change in output not caused by the inputs, e.g. by technology change or weather), and Input 1 and Input 2 are inputs, typically labor (L) and capital (K). The exponents, b and c, are to be estimated. Since the CD is a multiplicative model, not a linear model, taking the logarithms of the data is necessary to estimate the function using OLS linear regression. The standard log-log linear model is the generic model expressed in Equation (1). The CB empirical model is easy to estimate and interpret and requires estimation of few parameters. Main disadvantages are the (stringent) assumptions that firms operate in a setting of perfect competition, with all firms having the same production elasticities (and that substitution elasticities equal 1). This is why, our results have to be interpreted with care, as an exploratory empirical exercise. In the case at issue, we have selected to test the empirical CB specification that is as expressed in the following equation:

$$(Log)\text{Output}_{i,t} = \alpha_0 + \beta_1(\log)\text{Labor}_{i,t} + \beta_2(\log)\text{Land}_{i,t} + \varepsilon_{i,t}. \quad (2)$$

In Equation (2), the dependent variable (Log)Output is the logarithm of the outputs (goats and sheep, respectively) of the ith farm at time t. Production inputs are the logs of labor and land, of the ith farm at time t. The model includes a constant and an error term. The model has been estimated with a pooled OLS estimation routine. Pooled OLS is an estimation method that is used when the data set is obtained by collecting random samples from a large population independently of each other at different points in time. The fact that the random samples are collected independently of each other implies that they need not be of equal size and will usually contain different statistical units at different points in time. Pooled OLS is a more appropriate estimator for randomly sampled cross-sections of individuals at different points in time, like in the case at study. Pooled OLS differs from balanced and unbalanced panel data. Balanced panel data record all different points in time for all individuals. Unbalanced panel data do not record the same/all different points in time for all individuals in the data set (see Green, 2002). The model was estimated with STATA 12. Table IV reports selected econometric results.

Labor is a very important input in the production of cattle. A 1 percent labor increase generates a 1.58 percent increase in the number of sheep and a 0.96 percent increase in the number of goats, respectively. A 1 percent increase in land generates a 0.39 percent increase in the number of goats. The goodness-of-fit is relatively high. The Wald statistic based on the pooled OLS estimate is 13,576.

6. For instance, Brazilian producers of jelly have reported that in 2009 they used 150 kilos of passion fruit for producing 300 kilos of jelly. In 2010, 140 kilos of passion fruit have produced 280 kilos of Jelly, and in 2011, 175 kilos of passion fruit have generated 350 kilos of jelly. The average product for the three years is 2. On average a kilo of *Catinga* passion fruit produces 2 kilos of jelly. This is also a very straightforward marginal measure. An additional kilo of jelly produces 2 kilos of jelly.
7. The computation of the VMP has required information on prices of the selected final outputs. These were collected by local researchers in local markets and were highly incomplete

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