ISSN 0798 1015

REVISTA ESPACIOS

Vol. 38 (Nº 23) Año 2017. Pág. 11

Implicit Price for Pollination Services: Improving Coffee Yield in Risaralda, Colombia

Precio Implícito de los Servicios de Polinización: Mejorando el Rendimiento del Café en Risaralda, Colombia

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Recibido: 24/11/16 • Aprobado:13/12/2016

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ABSTRACT:
Pollination is a critical link in the functioning of ecosystems, and it is essential for the production of a wide range of crops. This paper shows the economic role of pollination services to support the production of coffee crops by rural farmers in Risaralda, Colombia. The Production function approaches seems to be the best model since it is particularly useful for ecosystem services that support economic activities. In order to estimate the contribution of pollination to coffee growing, two steps were developed. First, the physical effects of changes in the coffee plantation by the pollination services were assessed. Second, the impacts of these changes are valued in terms of the corresponding change in the marketed output of coffee. Using 300 coffee farms and a Cobb-Douglas Model, the study estimated the value of pollination as well as other inputs on the production coffee in Risaralda. The results show an increase of yield production by hectare that correspond to each input. As expected, the contribution of pollination factor is significant to the production of coffee. 1% increase in the fruit – set by hectare is

RESUMEN:
El servicio de polinización es importante para el funcionamiento de los ecosistemas, y es esencial para la producción de una amplia gama de cultivos agrícolas. Este artículo muestra la influencia económica que el servicio de polinización tiene en la producción del cultivo de café para los agricultores de Risaralda, Colombia. Fue usada la técnica Función de Producción, ya que es el mejor modelo econométrico para la valorización de servicios ecosistémicos que soportan actividades agrícolas. Con el objetivo de estimar la contribución de la polinización en la producción de café, dos métodos fueron usados. Primero, fueron calculados los efectos biofísicos de los cambios en la producción de café ante la presencia de la polinización de abejas Apis Melífera. Segundo fueron valorados monetariamente estos cambios, usando precios de mercado de café en la región. A través de una muestra de 300 fincas cafeteras y usando la función de produccion Cobb-Douglas, el estudio estimó el valor de polinización así como de otras variables en la producción de café en Risaralda. Los resultados muestran que existe un incremente del

correlated with a 31% increase in yield. Contrary to the expectation, fertilizer and pesticides almost no impact on coffee yield. The study contributes to acknowledge of econometric valuation of pollination services and can be used for valuing other crops. Furthermore, it gives the basis for further studies in the value of pollination services at a national scale.
Keywords: Cobb-Douglas Model, Ecosystem Services, Coffee Production Function, Apis Mellifera, Value, Monoculture.

rendimiento de la cosecha por hectárea correspondiente a cada variable contemplada. Como esperado, la contribución del factor de polinización es significativo para la producción de café, ya que el aumento de 1% en el factor de polinización conlleva a un aumento de 31% en el rendimiento de la produccion de café. Contrario a lo esperado, los fertilizantes y pesticidas tienen un impacto casi nulo en la producción de café. Este estudio contribuye a la ciencia de la valoración económica del servicio de polinización y puede ser replicado en otros cultivos agrícolas diferentes al café. Además, este artículo proporciona las bases para estimar el valor de la polinización en el café en escala nacional.
Palabras clave: Modelo Cobb-Douglas, Servicios Ecosistemicos, Función de Produccion, Apis Mellifera, Monocultura.

1. Introduction

Coffee is a widely-grown commodity, and extensive research indicates that both the Arabica and Robusta varieties can yield a greater quantity and quality of harvested fruit after pollination by bees (Vernon G. 2012). Animal pollinators, and particularly the honeybees, provide an essential ecosystem service in facilitating the reproduction of a large number of agricultural crops (Aizen et al. 2009). However, much coffee production does not recognize, explicitly, a role for insect pollination (Vernon G. 2012)

A recent review on the importance of pollination in crops worldwide shows that 87 out of 124 leading food crops are dependent on animal pollination (Klein et al. 2007). In particular, tropical crop species seem to rely on pollen vectors even more, as 70% of the species have at least one variety where production is improved with animal pollination (Roubik 1995). However, the estimated value that pollination by bees brings to production is unknown in many developing countries. In addition, production declines due to poor pollination are also ignored.

The recognition that pollinators have gained came after the identification of a global “pollinators crisis” (Buchmann and Nabhan 1997). There are many reports on local extinctions and decrease of natural populations of wild bees (Williams 1989, Williams 1991).

Worldwide production is facing terrible decline. In Brazil, farmer are in the midst of a severe drought. In Indonesia, Robusta beans, is having production difficulties as well, with coffee output projected to come in 10% to 15% lower year-on-year. For other side, Colombia is fronting similar problems, in 2014 the government halted subsidies to coffee farmers. While not a negative development in and on itself, the impact of this policy change will be hard felt. Also important to mention that in 2013, up to 50% of Colombian coffee farmers’ income came from government subsidies (Reynoso, 2014).

In fact Colombian Coffee production is sharply decreasing in the last years (FNC, 2011) as a result of rising temperatures and more intense and unpredictable rains, phenomena that many scientists link partly to global warming. Besides, Colombian coffee, costs in 2012 $168-204 per 60-kilogramme bag to produce, however, the average price paid to growers in 2012 was, $103 per bag, or 78 cents per pound (FNC, 2015).That mean that even after government support payments of some $38 per bag, equivalent to 29 cents per pound, "the subsidy falls short of ensuring that growers will earn a profit or even break even.

In that regards, it is necessary to identify the influence of input in coffee production and also determine the economic role of pollination services to support the production of coffee crops in Risaralda rural farmers - Colombia. The main aim is to estimate the marginal elasticity of the pollination service in the coffee crop. In the case of private goods or services traded in the market, price is the measure of marginal willingness to pay and it can be used to derive an estimate of the economic value of an ecosystem service (Hufschmidt et al. 1983 Freeman, 1993).

The study is divided in 3 sections. Section 2 identifies the main valuation method of pollination function, section 3 shows how the production function approach could determine the economic influence of pollination services in crops, and section 4 outlines the results and discussion of using production function approach in the coffee field.

2. Methodology/approach

2.1. Area

This work was carried out in the Risaralda state (208450 S, 458520 W), located in Colombia. Figure 1 show the municipalities where the data was collected. In total 12 of 14 municipalities are using the land for coffee production (there is 54.000 hectares of land use for coffee) Experiment were collect in the municipalities of Quinchía, Santuario, La Celia, Balboa, Guática, Apia and Belen de Umbria.

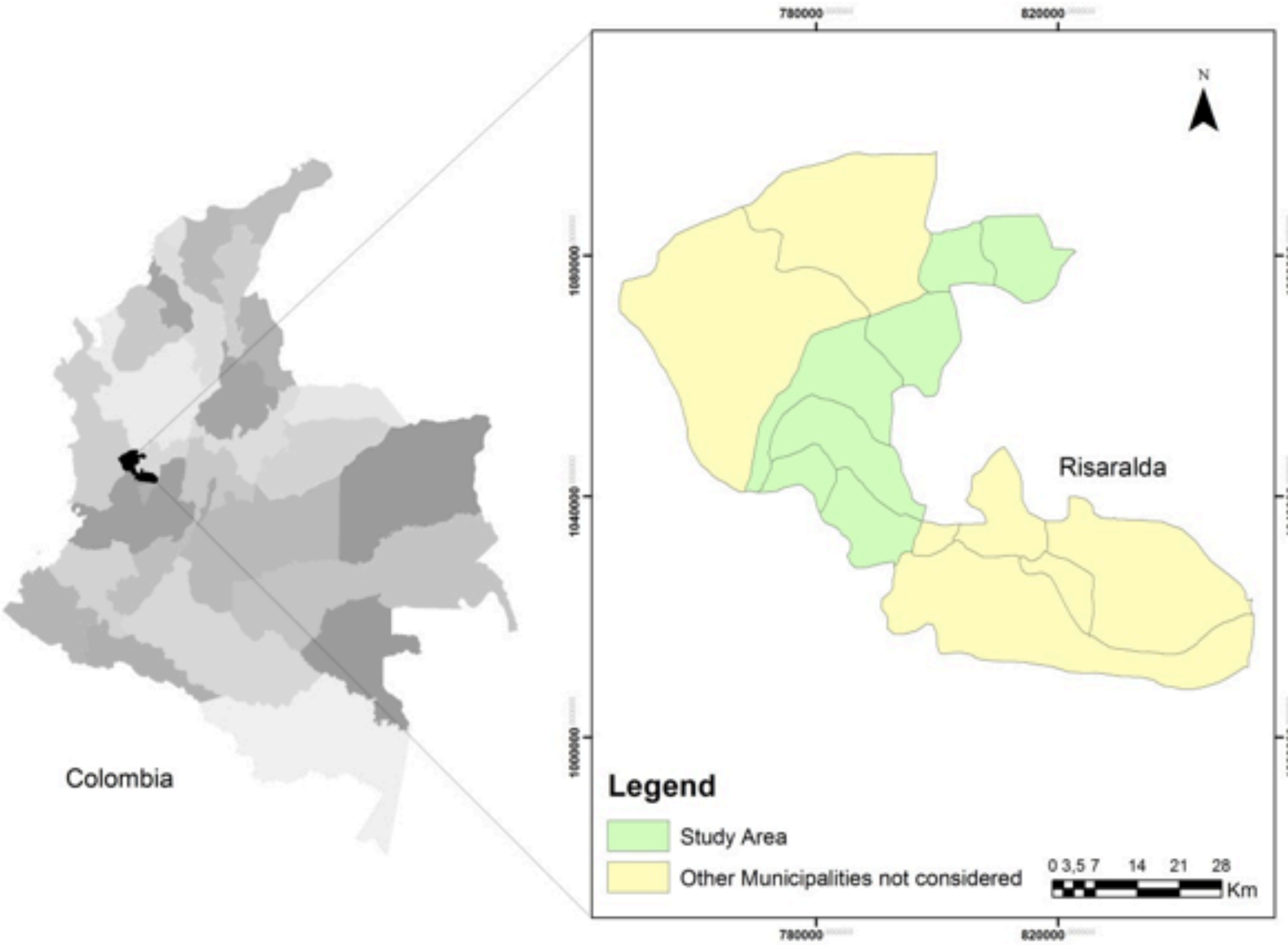

Figure 1 Municipalities where data was collected

In this study, two types of coffee planting method will be compared: Monocultures with full sun and shaded system, which is associated to the culture bananas trees constituting an agro-silvicultural system.

Tetragonisca angustula, known in Colombia as “angelita” is the stingless bee most widely distributed in the country, found in all natural regions below 1800 m elevation (Nates-Parra 2011). However, *Apis mellifera* is the dominant species on flower visits and presented an efficiency of 43% on the pollination process. Furthermore, Roubik (2002) suggested that *Apis mellifera* (the introduced honey bee) plays the most important role in coffee pollination in this area, but also native bees could be involved.

2.2. Valuation Methods.

According to FAO (2006) there are a number of approaches that can be followed to value the pollination service. These include (i) using market prices; (ii) the damage cost method; and (iii) the production factor method. These three principal methods suitable for valuation of the pollination service are reviewed below. The methods selected for further review are all indirect (revealed preference) methods.

Market Price: In the case of perfectly functioning markets (full information, no transaction costs, etc.) and no distortion through taxes or subsidies, the market prices paid by farmers to commercial beekeepers reflect the marginal value of the pollination service. In order to calculate the total value of the pollination service, for instance in a country, the consumer's and producer's surplus have to be calculated. The consumer's surplus is reflected in the demand curve that represents farmer's willingness to hire commercial bee-hives. Clearly, data on marginal or total value of the pollination service using a market prices approach are only available for pollinators that have been domesticated including honeybees and, recently, bumblebees.

The large majority of bees that are used commercially for pollination are European honey bees (*Apis melifera*). However, a range of other bees are also used, for instance bumble bees (especially for high value greenhouse crops including tomatoes) and leafcutter bees (for US alfalfa crops)

Cost-based methods (preventive expenditure/damage costs avoided /replacement costs): The preventive expenditure, damage costs avoided and replacement cost methods are related methods that estimate values of ecosystem services based on either the costs of avoiding damages due to lost services, the cost of replacing ecosystem services, or the cost of providing substitute services. In the case of the pollination service, damage costs result from a reduction in agricultural production following a reduction in the amount of pollinators available. In some cases, a complete loss of pollinators may cause only a reduction in the production (as in the case of coffee), in other cases this may lead to a complete loss of the production of a specific crop. The methods are most appropriately applied in cases where damage avoidance or replacement expenditures have actually been, or will actually be, made.

Production function: Production function approaches are particularly useful for ecosystem services that support economic activities. It consists of a two-step procedure. First, the physical effects of changes in a biological resource or ecological function on an economic activity are assessed. This means that the precise impact of the pollination service on agricultural output has to be determined. The impact of pollination on crop yields varies per crop, ranging from over 90% in mango and almonds to between 10 and 20% for peanuts and grape ((Morse and Calderone, 2000; Roubik, 2002).

Second, the impact of these environmental changes needs to be valued in terms of the corresponding change in the marketed output of the corresponding activity. In other words, the ecosystem service is treated as an'input' into the economic activity, and, like any other input, its value can be equated with its impact on the productivity of the marketed output.

In a formal manner (following Freeman, 1993), consider an agricultural production process in which output (y) depends on purchased inputs (x), ecosystem services such as pollination (q), and another fixed factor (k) representing the fixed costs such as land and capital investments. In this case,

$$y = f(x, q, k) \qquad (1)$$

Hence, in a situation with perfectly functioning markets, the value of the pollination service can be determined by analysis of how the production of agricultural commodity y changes following a change in the supply of the pollination service q. A critical point in this equation is that y represents the increase in y that would occur if all other inputs are held constant (Freeman, 1993).

The Production function approaches seems to be the suitable method to value the pollination services as an input of the coffee production. In that regard, above mention step 1 and 2 were addressed.

To follow the step 1, experiments were done to collect the variable Fruit-set (the proportion of female flowers which developed into a fruit). It was assess the quantity of flowers and the beginning and in the end of flowering. Around one (1) month was necessary to collect the fruit set variable in each farm.

The main flowering occurs in August, with secondary peaks in September. The experiment was conducted in 30 farm properties. In each farm was selected five (5) coffee plants distributed uniformly in the lines of the culture, and at least 5 m distant to the edge to avoid possible edge effects in the production. One of the branches placed in the same height was wrapped up in a mesh net (1.5 mm pore size), making it impossible for possible pollinators to visit the flowers. We count the number of flowers present and the number of fruit produced on each marked branch in August and September. From this data the proportion of fruit produced was calculated as the ratio of number of fruits and number of flowers present per branch.

The results indicate that the branches with free access to pollinators produced a higher proportion of fruits than the plants wrapped. Fruit set did not differ between coffee fields but between pollination treatments. Accordingly, bee pollination caused from 12 to 28% increase in fruit set, compared to wind pollination plus autogamy by hectare.

Following this, second step was conducted. Using a sample of 300 coffee farms in the central area of Colombia (Risaralda), was estimated the implicit price of pollination service as well as other factors that affect Arabic coffee production (Table 1.) Taking into account that the value of crop pollination cannot be seen separately from the agricultural production process.

In total, six categories of data were collected to carry out an analysis of the economic value of pollination: Pollination Factor: Fruit- set, Proximity to natural forest, Inputs: Quantity of fertilizer and pesticides, Labor force: days per hectare, and Type of coffee planting.

Table 1 Variables used in the production function approach

Type	Variables	Units per ha	Average Quantity
Output	Yield: (kg/ha)	Kg	2217
Inputs	Fe: Fertilizer (kg / ha) X: Pesticide (kg / ha)	Kg Kg	670 706
Fixed Cost.	S: Planting Seedling kg/ha) L: Labor days used on the farm (Days/ha)	kg Man days	0,25 580
Pollination factor	P: Fruit - Set	% Fruit set	12-28%
Proximity to forest	Fo: Dummy.	1 if is near to 500 mts, 0 if it more than 500mts	1: 197 0: 103
Type of coffee planting	C: Dummy	1 monocultures full sun, 0 shaded.	1: 187 0: 113

Source: Author

Three different sources of information were employed in this study. The primary source comes from the experiment in order to find the fruit set. Labor cost, inputs, type of coffee planting and yield production was directly surveyed and geographically coded using Arcmap®. The proximity to forest was include in order to identify is there are any spatial pattern in coffee crops, coordinates (latitude and longitude) of the centroids of the farm and the near forest assessed.

2.3. Model Specification

The following is the Cobb-Douglas model considered in this research:

$$Ln(Y) = Ln(\beta 0) + \beta 1Ln(fe) + \beta 2Ln(x) + \beta 3Ln(s) + \beta 4Ln(L) + \beta 5Ln(P) + \beta 6\ (Fo) + \beta 7\ (C) + e \quad (2)$$

In this study the Cobb- Douglas model is favored over other linear or other specification form because it is widely used to represent the technological relationship between the amounts of two or more inputs, particularly physical capital and labor, and also because of the best fit of the sample data.

The pollination factor relies on the measures for fruit-set and it would depend of location from 12 to 28 %. Type of coffee planting is a dummy variable, which take value of 1, when the farm type of planting is monoculture grown under full sun, and 0 when the farm type of planting is shaded (frequently with other crops such as plantains and bananas).

Proximity to forest refers to the distance between each farmer from forest patch, it take the value of 1 when the distance is from 0 to 500mt and takes value of 0 when distances is from more than 500mts. The native forest proximity can provide resources to the pollinators in the periods in which the coffee culture is not flowered, and, mainly, provide a variety of nesting sites and material for nest building. The local diversity and landscape heterogeneity are extremely important here, considering that many species build their nests in tree hollows, not found in coffee plantations (Matheson et al. 1996).

The distance between the farm and the forest was estimated using GIS mapping. In a spatial context, there is an evidence of heterogeneity in this variable, showing that the variance is not constant and the classic OLS regression bias the estimation. In that sense was incorporate a weight matrix into de spatial regression.

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3. Results

For the purpose of this study, yield is considered to be a function of Labor force, Inputs: Quantity of fertilizer and pesticides, Fruit- set, Proximity to natural forest, and Type of coffee planting.

Based on examination of parameters estimates, standard errors and goodness of fit measures, it was decided that the Cobb – Douglas Log-Log function was more appropriate to these data than the linear form. All the coefficients in the Cobb-Douglas form are significantly different from zero and possess the expected signs. Results from Cobb-Douglas models for the production function are reported in Table 2.

Table 2. Estimation Results for Production Function Approach

Type	Variables	**Coefficient**
Intercept		0,04
Inputs	f: Fertilizers (kg / ha)	0,07
	x: Pesticides (kg / ha)	0,04

Fixed Cost	s: Planting Seedling /ha)	0,04
	t: Labor days used on the farm (Days/ha)	0,26
Pollination factor	p: Pollination factor	0,31
Proximity to forest	b: Dummy, 1 if is near to 500 mts, 0 if it more than 500mts.	0,30
Type of coffee planting	m: Dummy 1, monocultures full sun, 0 shaded.	0,34
r squared		0,72
n		300
Log-likelihood		-2345

Source: Author

All the parameter estimates in the model are positive and significantly different from zero at 95% confidence level. In the model, the elasticity of yield with respect to labor is 0.26. This means that a 1% increase in the day of work force by hectare is correlated with a 26% increase in yield. In addition, the contribution of pesticide to yield is 0.04 saying that a 1% increase in the amount of pesticide is associated with a 4% increase in yield. Furthermore, the contribution of chemical fertilizer to yield is 0.07 saying that a 1% increase in the amount of chemical fertilizer is correlated with a 7% increase in yield. These input elasticity shows that yield is sensitive to changes in input levels.

According to results, the dummy variable monoculture appears to be the most influential input in yield production. Full-Sun or Un-shaded Monoculture represents a “modern” system with absolutely no canopy. If the farm adopts the monoculture planting instead of shaded type planting, the increase of yield will be in 34%.   However, Coffee bushes that are exposed to direct sunlight require high inputs of chemical fertilizers and pesticides as well as an intensive yearly work force, in other words it is more cost demanding and quality of coffee is less than if compared with shaded type of planting.

As expected, the contribution of pollination factor is extremely important to the production of coffee. 1% increase in the fruit – set by hectare is correlated with a 31% increase in yield. This system yields the highest output of coffee production. This is particularly important in countries like Colombia, where there is not market for pollination, and the evidence shows that these services indeed increase the production and really grow the profits of landowner as well.

Contrary to the expectation, fertilizer and pesticides have almost no impact on coffee yield. On the other hand, pollination, a neglected service, would improve the production greatly.

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4. Conclusions/outlook

The study estimates the marginal implicit prices for input variables that affected the production of coffee during 2013 in Risaralda – Colombia. The Cobb-Douglas equation was specified and parameters were estimated to determine implicit prices for pollination services and other inputs.

The results show the increase of yield production by hectare that corresponds to each input. This study provides the basis for continued improvement in economic incentives for pollination services.

Age of plantation must be considered in next studies. The difference in the flower production among the areas is directly related to coffee plantation's age and to an inter-annual variation characteristic of the culture. Younger coffee plantations, under favorable planting conditions, produce greater numbers of flowers than the older ones, which justifies the pruning use for older coffee plantations to increase their production.

Habitat destruction and degradation as a result of agricultural intensification is believed to threaten the future of different species of bees. In the other hand preserved native forest provides pollinators to local agro-ecosystems and increase the yield production of coffee plantations and logically the yield of other crops around the area of Risaralda – Colombia.

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Revista ESPACIOS. ISSN 0798 1015
Vol. 38 (Nº 23) Año 2017