RESEARCH ARTICLE

A Real Option Analysis applied to the production of Arabica and Robusta Coffee in Ecuador

Andrés R. Jácome[1] and Alberto Garrido[2]

[1]Universidad Politécnica de Madrid. Avda. Puerta de Hierro 2, 28040 Madrid, Spain. [2]Universidad Politécnica de Madrid, CEIGRAM. C/ Senda del Rey 13, 28040 Madrid, Spain.

Abstract

The coffee market is distinguished for being volatile and uncertain in terms of domestic and international prices. Arabica and Robusta coffee are produced in 23 provinces of Ecuador. A decade-long decline of coffee production prompted the Ecuadorian government to launch a public program for replanting coffee trees towards the end of 2011. A grower's decision to enter, remain in or exit the coffee sector is based on fluctuating profits from each year's harvest sale. We analyzed the hypothesis whereby the coffee grower's decision to leave the sector is explained by volatile and uncertain prices. This paper aimed to evaluate the coffee sector with an application of Real Option Analysis for the period 2002-2012. We also defined entry (H) and exit (L) prices for Arabica and Robusta coffee for the analyzed period. Our findings revealed high H and L prices encourage growers to leave the sector for the most part of the analyzed period. High H and L prices resulted from high variable cost due to increasing wages for farm workers. The Ecuadorian government is developing a policy to help growers make production more efficient, encouraging them to remain in the sector in the long run.

Additional key words: uncertainty; volatility; coffee prices.

Abbreviations used: BCE (Central Bank of Ecuador); COFENAC (National Council of Coffee); FAO (Food and Agriculture Organization of the United Nations); H (Entry price); ICO (International Coffee Organization); INEC (National Institute of Statistic and Census); L (Exit Price); MAGAP (Ecuadorian Ministry of Agriculture).

Authors' contributions: Conception and design: ARJG and AG. Acquisition and interpretation of the data: ARJG. Administrative, technical and material support: ARJG and AG. Writing of the paper: ARJG and AG. Supervising the work: AG.

Citation: Jácome, A. R.; Garrido A. (2017). A Real Option Analysis applied to the production of Arabica and Robusta Coffee in Ecuador. Spanish Journal of Agricultural Research, Volume 15, Issue 1, e0104. https://doi.org/10.5424/sjar/2017151-10098

Supplementary material (Figs. S1, S2, S3) accompanies the paper on SJAR's website.

Received: 14 Jun 2016. **Accepted:** 17 Feb 2017.

Copyright © 2017 INIA. This is an open access article distributed under the terms of the Creative Commons Attribution (CC-by) Spain 3.0 License.

Funding: Government of Ecuador; CEIGRAM (Research Center for the Management of Agricultural and Environment Risks).

Competing interests: The authors have declared that no competing interests exist.

Correspondence should be addressed to Andrés R. Jácome: andresrenato.jacome.gagnay@alumnos.upm.es

Introduction

The coffee sector has been one of the most important export sectors in Ecuador. Exports reached 413 million USD (125,070 t) in 1994 but dropped to 261 million USD (51,526 t) in 2012[1]. The country produces Arabica and Robusta coffee for domestic and foreign markets. Ecuador's share in the world coffee market dropped from 1.18% (1961) to 0.09% (2013) according to calculations using FAO data (FAO, 2015). Planted area and production show a declining trend. The cause of this decrease has not been analyzed in detail. The growing age of bearing trees, outbreaks of pests and diseases, lack of

modernization and poor development of new coffee varieties are signs and reasons for the decline of the sector in Ecuador.

Volatile coffee prices create an uncertain environment for growers' in Ecuador and elsewhere. This uncertainty translates into unstable harvest prices and farm profits. Low-price periods affect growers' household income in coffee-producing countries, and encourage them to abandon the crop (ICO, 2002). Even with volatile and uncertain prices, the growers' motivation and decision to remain in the coffee sector are explained through cultural values, inherited coffee (*Coffea* sp) plantations, tradition and government incentives (Bacon, 2005;

---

[1] Values expressed in current United States Dollars.

Tucker *et al.*, 2010; Borkhataria *et al.*, 2012; Bravo *et al.*, 2016).

To mitigate low prices, alternative strategies such as converting conventional plantations into organic and shading coffee plantations have been evaluated in the literature. Positive benefits include increasing home income (Delgado & Pérez, 2013) and conservation of natural resources (Borkhataria *et al.*, 2012). However, the economic benefit only improved household incomes very slightly due to the increasing cost of labor (Ruben & Fort, 2012). It was attractive only when mainstream market prices were low (Valkila, 2009). Thus, organic and shading coffee systems are not necessarily the best solution in the long run, as coffee prices are formed in the international market, and these prices are volatile.

The Ecuadorian Government was concerned by low coffee production in the last years, and launched a public program to replant coffee trees towards the end of 2011. The program includes technical assistance to improve crop management and credit for growers who established new plantations. Ultimately, it is the farmer's choice to use this support and invest in renewed plantations and entering a sector characterized by uncertain profitability.

The volatile and uncertain environment, previously described, offers an angle for analysis on the coffee sector in Ecuador before the implementation of the public program. In this paper, we address the following questions: Have coffee growers been inclined to exit the sector due to volatile and uncertain prices for the 2002-2012 period? Which coffee prices triggered the exit decision in the Ecuadorian market? To answer these questions, we used the Real Option Analysis, developed by Dixit (1989). This approach incorporates uncertainty and irreversibility in the investment decision. Coffee production is an activity characterized by a large investment in the plantation and production lasting over 20 years. Therefore, it is important to consider volatility and uncertainty in the evaluation of the decision to invest in coffee. Also, we can estimate entry and exit coffee prices in Ecuadorian market for the period 2002-2012. With these results, we aim to understand the Ecuadorian coffee growers' decision in the market for the analyzed period.

The contribution of this work to the literature is two-fold. First, the validation of the hypothesis that volatile and uncertain coffee prices in the Ecuadorian market might explain the growers' decisions to exit the sector. If we fail to reject it, the conclusion would be that volatile coffee prices might have pushed growers to leave the sector during of the analyzed period. Second, we estimate entry and exit coffee prices for the period 2002-2012 for Arabica and Robusta.

Material and methods

Coffee in Ecuador

Coffee is produced in 23 Ecuadorian provinces. Geography and climate are apt for the production of Arabica and Robusta coffee (Arabica in highlands and Robusta in lowlands). Manabí is the main producing province with 43.86% of the total bearing area (49,578 planted hectares in 2012 (INEC, 2012)). According to the data from the (COFENAC) National Council of Coffee, Arabica coffee is mainly produced in the provinces of Manabí, Loja and El Oro. They represented 80.01% of the total production in 2012. The provinces of Orellana, Sucumbíos, Los Ríos and Esmeraldas produced 80.02% of the national production of Robusta in 2012.

Fig. S1 [suppl.] shows Ecuadorian coffee production and average yield per hectare. Ecuador reached its highest coffee production in 1996 with 190,696 t; since that year, it dropped to 35,000 t in 2012. The highest average coffee yield was 0.56 t/ha in 2001. Comparing coffee average yields for 2012 between Ecuador (0.23 t/ha) and the main coffee-producing countries, such as Vietnam (2.25 t/ha), Brazil (1.43 t/ha), Colombia (0.60 t/ha) and Indonesia (0.53 t/ha) (FAO, 2015), reveals that Ecuador has a low average yield, which has been decreasing since 2001.

Low prices affected the coffee growers' incentives to maintain or increase the production in following years. Limited use of technology, aging of coffee trees, poor crop management (especially in pruning and insect control activities) and climate anomalies (delayed rainy season) explain the reduction of production and yields (COFENAC, 2013). INEC statistics for 2012 reported a lack of use of improved seeds (only the 8.71% of all coffee growers use improved seeds). Pests and diseases are the main causes of lost coffee hectares (15,829 has.) as well as low use of fertilizers (13.33%) and pesticides (15.45%) (INEC, 2012).

Fig. S2 [suppl.] shows the Ecuadorian coffee value in current USD and exported amounts in t, which reached their maximum in 1994 (USD 413.8 million and 125,070 t). Ecuadorian coffee exports plummeted in 1994-2002, as a result of a reduction on domestic supplies and low price trends in the world market. The main export problem of the manufacture industry is the lack of coffee production in the country. This causes Ecuadorian companies to import coffee beans from Vietnam, Brazil and other countries (COFENAC, 2013). Since 2006, Ecuadorian coffee exports have been revived, reaching USD 261.05 million in 2012 (BCE, 2016). This is caused by the global trend of high coffee prices and increasing export of processed coffee (COFENAC, 2013).

Coffee prices have been volatile due to variations in world supply (new plantations, frost and coffee bean

diseases), established export quotas in the International Coffee Agreement and de-regulation of the market (ICO, 2002, 2014). Fig. S3 [suppl.] shows World Coffee Prices (Other Milds[2] and Robusta) and Ecuadorian prices paid to growers. Ecuadorian prices have similarities with international coffee prices: high prices of 2.27 USD/lb for Arabica (2011) and 1.43 USD/lb for Robusta (1995), and lowest prices of 0.27 USD/lb for Arabica (2001-2002) and 0.11 USD/lb for Robusta (2001-2002). The so-called Coffee crisis in 2001-2002) was caused by both the Vietnamese expansion and new Brazilian plantations (ICO, 2002). This forced a low price tendency in the market that affected growers' income in coffee-producing countries. From 2004 to 2011, coffee prices saw an upward trend, caused by reduced harvests of the main coffee-producing countries (ICO, 2009). In that period of increase, Ecuadorian coffee production did not recover the values from the early 90s.

Real Options

Real Options theory is used to evaluate the implementation of projects as an alternative to the traditional method (Net Present Value) which does not consider volatility and uncertainty in the market. In addition, Real Options analysis is used to understand growers´ decisions concerning agricultural systems and products. Tozer (2009) evaluates the investment in Australian farms between precision agriculture and the conventional system. Delgado & Pérez (2013) analyze the change in coffee systems (conventional to organic) for Mexican growers worried about the fluctuation of coffee prices and the low incomes received each year. Andoseh et al. (2014) examine the implementation of public investment funds in a Biotechnology Research and Conventional Breeding project in Uganda. Wolbert & Musshoff (2014) study growers' decision to maintain a conventional system instead of converting to a Short Rotation Coppice (SRC) system.

Entry and exit price for agriculture products

Entry and exit (price or revenues) resulting from the Real Options Analysis helps understand growers' entry and exit decisions. Price & Wetzstein (1999) investigated peach production with price and yield uncertainty for the Georgian market in the USA. Isik et al. (2003) analyzed the decision of agribusiness firms investing in Remote Sensing Technologies (RST) in farms with uncertain demand. Tauer (2006) defined entry and exit daily prices for five farm sizes in the milk market in the USA. Luong & Tauer (2006) studied Vietnamese coffee

growers from 1990 to 2002 and classified high, average and lower costs. The entry (0.47 USD/lb) and exit (0.17 USD/lb) prices supported the conclusion that a large number of Vietnamese farmers were efficient and survived the global crisis during the period investigated. Schmit et al. (2009) studied investment decisions in ethanol factories considering volatility in gross margins for the period 1998-2007 in USA.

Coffee prices volatility

Several studies analyze the effect of volatile and uncertain coffee prices on growers. Eakin et al. (2006) estimated through household surveys the effect of coffee prices in Mexican, Guatemalan and Honduran communities. Mohan (2007) estimated the profits and costs of a risk-management mechanisms based on the purchase of "put" type options to mitigate the fluctuation in coffee prices and to guarantee a minimum price for growers. With ARCH and GARCH models, Worako et al. (2011) found that Ethiopian coffee prices are more volatile than Brazilian coffee prices. Malan (2013) studied cocoa and coffee price volatility in Côte d'Ivoire with a partial stabilization model to reduce volatility risk with the intervention of storage agencies that stock coffee in low price periods. Rueda & Lambin (2013) analyzed the effect of volatility in Colombian coffee growers' decision with a global chain value (converting from conventional to ecological and sustainable coffee systems). Lukanima & Swaray (2014) used a GARCH model to evaluate the volatility of coffee prices in five different East African Countries after domestic market reforms (loosening government control and market liberalization). Mohan et al. (2014) used a GARCH model to evaluate volatility in coffee prices in India since the market liberalization, and estimated welfare gains if the Indian coffee growers' exposure to volatility was reduced. In conclusion, it is very important to consider volatility in the evaluation of coffee investment decisions.

Methodology

The model used for coffee Real Options valuation in Ecuador was developed by Dixit (1989). The model is based on two assumptions: first, it assumes reinvestment, so that the project will have an infinite life; the second assumption is that land does not depreciate. If a firm wants to enter an economic activity, it will require a certain amount of funds to invest (K), the resources required for maintenance and operation cost (C) and resources to leave the activity (L) at any time.

---

[2] Arabica classification of International Coffee Organization (ICO)

Table 1. Variables of the model

Variable	Item	Unit
V_0	Value of idle project	USD/lb
V_1	Value of active project	USD/lb
P	Coffee market price (paid to grower)	USD/lb
μ	Expected rate of market growth	%
σ^2	Variance rate of price market	%
C	Variable cost per unit	USD/lb
K	Investment cost per unit	USD/lb
X	Abandonment cost per unit	USD/lb
ρ	Capital cost (discount rate), with ρ > μ	%
H	Market price to enter the activity	USD/lb
L	Market price to exit the activity	USD/lb

The application of the model is based on three steps described by Luong & Tauer (2006):

1) Definition of an idle project's value. An idle project is the project awaiting initiation, whose value is equal to the option to invest. An idle project requires an amount of money to reinitiate the economic activity.

2) Definition of an active project's value. An active project's value is the present value of the net revenues (if the firm operates in the market) added to the value of the abandonment option.

3) Definition of the entry and exit prices of option model. These prices are the same for idle and active projects. This results in two conditions: first, the value of an idle project is equal to that of an active project. Second, the rate change of an idle project's value is equal to the rate change of an active project. With these conditions, the model will be resolved to determine the entry and exit prices for the coffee activity.

Table 1 shows the notation of model.

The world market defines the coffee price exogenously. Therefore, it is assumed that it follows a random walk behavior and a geometric Brownian process.

$$dP = \mu P\, dt + \sigma P \varepsilon \sqrt{dt},$$

where ε is a random value that follows a standardized normal distribution, and dP has a normal distribution, which means dP = μP dt and variance dP = σ²P² dt.

The investment value V (P,t) is a function of variables price (P) and time (t). By a second-order Taylor Series, dV can be approximated as:

$$dV = \frac{\partial V}{\partial P}dP + \frac{\partial V}{\partial t}dt + \frac{1}{2}\frac{\partial^2 V}{\partial P^2}(dP)^2 +$$
$$+ \frac{\partial^2 V}{\partial P \partial t}\,dP\,dt + \frac{1}{2}\frac{\partial^2 V}{\partial t^2}(dt)^2 \qquad (1)$$

Terms dP and dt in the limit would tend to zero. Thus, the terms $\frac{\partial^2 V}{\partial P \partial t}$ dP and $\frac{1}{2}\frac{\partial^2 V}{\partial t^2}(dt)^2$ are equal to 0, and replacing the term $(dP)^2 = \sigma^2 p^2$ dt in Eq. (1), it can be rewritten as:

$$dV = \frac{\partial V}{\partial P}dP + \frac{\partial V}{\partial t}dt + \frac{1}{2}\frac{\partial^2 V}{\partial P^2}\sigma^2 P^2\, dt \qquad (2)$$

Replacing $\mu P\, dt + \sigma P \varepsilon \sqrt{dt}$ in Eq. (2), we have Ito's lemma:

$$dV = \left(\frac{\partial V}{\partial P}\mu P + \frac{\partial V}{\partial t} + \frac{1}{2}\frac{\partial^2 V}{\partial P^2}\sigma^2 P^2\right)dt + \frac{\partial V}{\partial P}\sigma P \varepsilon \sqrt{dt} \qquad (3)$$

The term $\frac{\partial V}{\partial t}dt$ is equal to zero in Eq. (3) (the time (t) is not an important variable decision due the infinite life of a project), and so, it can be expressed as:

$$dV = \left(V'(P)\mu P + \frac{1}{2}V''(P)\,\sigma^2 P^2\right)dt + V'(P)\sigma P \varepsilon \sqrt{dt} \qquad (4)$$

where the terms $V'(P) = \frac{\partial V}{\partial P}$ and $V''(P) = \frac{\partial^2 V}{\partial P^2}$.

Next, we can take the expected value of both sides of Eq. (4), we obtain:

$$E(dV) = \left(V'(P)\mu P + \frac{1}{2}V''(P)\,\sigma^2 P^2\right)dt \qquad (5)$$

Definition of an idle project's value

In equilibrium, an expected capital gain of an idle project would be equal to the return of the investment (ρV₀ (P) dt). With V₀ (p) being the idle project to be initiated, therefore, we obtain:

$$\left(V_0'(P)\mu P + \frac{1}{2}V_0''(P)\,\sigma^2 P^2\right)dt = \rho V_0\,(P)\,dt \qquad (6)$$

Dividing by dt, we have:

$$\left(V_0'(P)\mu P + \frac{1}{2}V_0''(P)\,\sigma^2 P^2\right) = \rho V_0\,(P) \qquad (7)$$

The solution of the differential equation is the following: V₀ (P) = AP⁻ᵅ + BPᵝ, A and B constants are estimated in a later section, and where the α and β are equal as:

$$-\alpha = \frac{\sigma^2 - 2\,\mu - \left(\left(\sigma^2 - 2u\right)^2 + 8\rho\sigma^2\right)^{1/2}}{2\sigma^2} < 0 \quad \text{and}$$

$$\beta = \frac{\sigma^2 - 2\,\mu + \left(\left(\sigma^2 - 2u\right)^2 + 8\rho\sigma^2\right)^{1/2}}{2\sigma^2} > 1 \qquad (8)$$

The value of an idle project V_0 (P) is defined as $AP^{-\alpha}$ + BP^β. If the market price is close to zero, it means that there are no incentives to initiate the project (the option is worthless), and so V_0 (P) = 0, to have this fact, the constant A must be equal zero[3] due the value of $\alpha > 0$ and $\beta > 1$. Thus, the value of an idle project can be expressed as:

$$V_0 (P) = BP^\beta \qquad (9)$$

Definition of the value of an active project

In equilibrium, for an active project, the normal return is equal to the addition of expected capital gain and net revenue flow:

$$\rho V_1 (P) \, dt = E[dV_1] + (P - C)dt \qquad (10)$$

Replacing the term $E[dV] = \left(V'(P)\mu P + \frac{1}{2}V''(P)\,\sigma^2 P^2\right) dt$ of Eq. (5) in Eq. (9), and dividing the equation for the term dt, we obtain:

$$\rho V_1(P) = \left(V_1'(P)\mu P + \frac{1}{2}V_1''(P)\,\sigma^2 P^2\right) + (P - C) \qquad (11)$$

Reordering all the terms of equation above and equal to 0, we obtain:

$$V_1'(P)\mu P + \frac{1}{2}V_1''(P)\,\sigma^2 P^2 + (P - C) - \rho V_1(P) = 0 \qquad (12)$$

The solution of Eq. (12) is equal to: $V_1(P) = AP^{-\alpha} + BP^\beta + \frac{P}{(\rho-\mu)} - \frac{C}{\rho}$. The solution shows the net revenue flow expressed as $\left(\frac{P}{(\rho-\mu)} - \frac{C}{\rho}\right)$ and abandonment option expressed as $(AP^{-\alpha} + BP^\beta)$. If the market price tends to infinity ($P \to \infty$), the option abandonment would tend to be zero. Considering the value of $\alpha > 0$ and $\beta > 1$, the abandonment option would be zero ($AP^{-\alpha} + BP^\beta = 0$), only if B constant takes a value of zero[4]. Thus, the value of an active project can be expressed as:

$$V_1(P) = AP^{-\alpha} + \frac{P}{(\rho-\mu)} - \frac{C}{\rho} \qquad (13)$$

Definition of the entry (H) and exit (L) prices

H is the entry price that defines the firm's entry decision. The value of the option of invest V_0(H) must be equal to the expected value of the executed project (V_1(H)) minus the investment cost (K), and so, the value-match condition is:

$$V_0(H) = V_1(H) - K \qquad (14)$$

Also, the smooth-pasting condition requires that the two value functions meet tangentially:

$$V_0'(H) = V_1'(H) \qquad (15)$$

The firm's exit decision is defined by the price L, so the abandonment option V_0(L) must be equal to the expected value of the project (V_1(L)) added to the abandonment cost X. Therefore, the value-match condition is:

$$V_0(L) = V_1(L) + X \qquad (16)$$

And the smooth-pasting condition requires that the two values functions meet tangentially:

$$V_0'(L) = V_1'(L) \qquad (17)$$

We obtain four equations that solve the entry (H) and exit (L) prices. Substituting V_0(H), V_1(H), V_0(L) and V_1(L) in the Eqs. (14), (15), (16) and (17), and reordering the equations, we get the following system:

$$AH^{-\alpha} - BH^\beta + \frac{H}{(\rho-\mu)} - \frac{C}{\rho} = K \qquad (18)$$

$$-\alpha AH^{-\alpha-1} - \beta BH^{\beta-1} + \frac{1}{(\rho-\mu)} = 0 \qquad (19)$$

$$AL^{-\alpha} - BL^\beta + \frac{L}{(\rho-\mu)} - \frac{C}{\rho} = -X \qquad (20)$$

$$-\alpha AL^{-\alpha-1} - \beta BL^{\beta-1} + \frac{1}{(\rho-\mu)} = 0 \qquad (21)$$

First, we must estimate (μ, σ^2 and ρ) with the coffee price and banking rate series. Then, the estimated variables are replaced in Eq. (8) to get α and β. Next, all variables are substituted in Eqs. (18), (19), (20) and (21). Therefore, we can obtain A, B, H and L for numerical solution.

Dixit (1989) estimates H and L prices in the following formulas:

$$H = W_H \frac{(\rho-\mu)}{\rho}\frac{\beta}{(\beta-1)} \text{ and } L = W_L \frac{(\rho-\mu)}{\rho}\frac{\alpha}{(1+\alpha)} \qquad (22)$$

where $W_H \equiv C + \rho K$ and $W_L \equiv C - \rho L$. With these variables and equations, we define the H and L prices

---

[3] If A ≠ 0 and P → 0 in V_0(P), there would be a value of the option to enter, that situation is not logical, because firms do not have incentive to enter with P → 0. So, the constant A must be equal to 0.
[4] If B ≠ 0 and P → ∞ in V_1(P), there would be a value of the abandonment option, that situation is not logical, because with a p → ∞ a firm never has incentive to take exit decision. So, the constant B must equal be to 0.

Table 2. Establishment and maintenance cost (in USD/ha) for Arabica and Robusta coffee

Activities	Robusta coffee			Arabica coffee		
	First year	Second year	From the third year	First year	Second year	From the third year
Land preparation	348	0	0	672	0	0
Sowing	760	0	0	1,390	0	0
Fertilization	455	377	412	640	335	304
Cultural labor	357	441	407	357	465	410
Insect control	26	38	53	26	38	53
Disease control	26	38	53	26	38	53
Harvest	72	96	766	72	96	846
Annual cost	2,044	990	1,691	3,183	972	1,666

Source: MAGAP (2014)

for Arabica and Robusta coffee for the period 2002-2012, and therefore growers' entry or exit decision in this volatile and uncertain sector.

Data

Ecuadorian coffee prices

The Ecuadorian Arabica and Robusta coffee annual prices (USD/lb) for the period 1990-2012 were obtained from the (ICO) International Coffee Organization, denominated in nominal terms. Future coffee prices are negotiated in the New York and London markets. Thus, world coffee prices are exogenous variables that affect the Ecuadorian prices directly.

We supposed that the coffee price follows a random walk behavior as:

$$P_t = \lambda P_{t-1} + u_t \qquad (23)$$

where P_{t-1} is the price of the previous year, and u_t is the error term that follows a random walk with value 0 and constant variance. To determinate if Ecuadorian coffee prices follow a random walk behavior, it is necessary to perform the Unit Root Test ($\lambda=1$). We used the Augmented Dickey-Fuller test to validate the unit root with three possible models for each series: without constant, with constant as well as with constant and trend, where $\Delta P_t = P_t - P_{t-1}$ and $\delta = \lambda-1$.

$$\Delta P_t = \delta P_{t-1} + \alpha \Delta P_{t-1} + u_t$$

$$\Delta P_t = \beta_1 + \delta P_{t-1} + \alpha \Delta P_{t-1} + u_t$$

$$\Delta P_t = \beta_1 + \beta_2 t + \delta P_{t-1} + \alpha \Delta P_{t-1} + u_t$$

This test was performed for Arabica and Robusta price series. In each model, we incorporated lagged terms to analyze, with most accurately, the existence of the unit root. For Arabica series results, none of the models rejects the null hypothesis at a confidence level of 95%. However, for Robusta series results, two of three models cannot reject the null hypothesis at confidence level of 95%[5]. Thus, with these values, we supposed that Ecuadorian Arabica and Robusta coffee prices follow a random walk behavior.

Now, we get the returns ($\theta = \ln(P_t/P_{t-1})$) for Arabica and Robusta price series for the period (2002–2012), and so, we get μ and for each year, whereby, these values are used to estimate H and L prices.

Cost of capital

This information is obtained from the (BCE) Central Bank of Ecuador (2002-2012). In Ecuador, the financial system is divided into segments. The banking interest rate varies according to the segments. However, agricultural growers do not have access to the conventional Ecuadorian banking system because many of them do not have any collateral. For this reason, it is the public bank that provides loans to agricultural growers. For banking data, we select the interest rate that banks used for the period January 2002-June 2007. Since mid-2007, a new regulation of the financial system created segments according to the amount of credit money that the clients applied for. Therefore, we select the PYMES (small and medium firms) segment, which is for clients requiring a loan equal to or less than USD 200,000 for the period August 2007-December 2012. This segment corresponds to the amount of money that growers required for the investment in the coffee activity.

---

[5] The results data and test execution are available from the author upon request

Coffee costs

Coffee is a perennial tree that is productive for up to 20 years. According to the information published by the Ecuadorian Ministry of Agriculture (MAGAP), and shown in the Table 2, Robusta coffee costs 3,034 USD/ha (first and second years) in 2013. This cost does not consider depreciation and assumes that the grower owns the land; additionally, the irrigation system is not considered in this cost. Rainfall, rivers or tanks near the farms provide water for the coffee hectares. In 2012, Ecuador had 108,064 ha of coffee trees that did not have irrigation systems (INEC, 2012); this represents 95.51% of coffee hectares in the country.

Now, we can estimate Arabica and Robusta costs (USD/lb). Table 2 shows establishment and maintenance costs per hectare for Robusta and Arabica coffee (all the cost items are expressed in 2013 prices). The Ecuadorian Ministry of Agriculture (MAGAP) only made public the cost structure for Robusta variety[6]. This cost structure shows the quantity of labor and agrochemical products required to cultivate one hectare of Robusta coffee in Ecuador. For Arabica coffee, we performed an adjustment of the quantity of inputs (labor and agrochemicals) and costs in Table 2 to obtain the most accurate estimated cost for this variety.

For Robusta coffee, sowing is the largest cost item for the first year (USD 760). Fertilizer and cultural labor represent 82.58% of the total cost for the second year. During our analysis period (2002-2012), the values were adjusted to the inflation rate (agrochemical products, seeds, etc.) and labor wage for each year. During 2012, the cost of establishing a coffee hectare was USD 2,783.15. We could estimate cost K to be 5.49 USD/lb in 2012, this value is calculated by dividing establishment cost per hectare by the average coffee yield (MAGAP data).

To estimate the variable cost per unit (C), we considered as a reference the activities of the third year that the MAGAP has estimated to a value of 1,691 USD/ha for 2013. Harvest was the highest cost in that year (USD 766) due to the wages paid. With the variable cost adjusted to the data and average yield for each year, we could estimate variable C for the whole analyzed period. It is important to note that coffee beans are sold without any transformation process. The model assumes an infinite life project (renewal of the trees and fixed assets). In our case, growers do not have any irrigation system, which means that they do not to require fixed assets. For 2012, we estimated C cost as 3.65 USD/lb; this cost includes variable cost and the cost for growers to renew the trees every 20 years (infinite project assumption).

We tried to estimate the abandonment cost per lb (X), but we did not find any official information (costs of tree-cutting and land-clearing). Therefore, we considered an estimated cost of 16 units of labor per hectare (MAGAP defines that 16 units of labor are required to clear the land before planting Robusta coffee; we will consider that the same amount of labor is necessary to clear the land of coffee trees and switch to another crop). For the 2002-2012 period, we considered MAGAP and the basic Ecuadorian wage to estimate X value for each year. For 2012, the daily wage for land preparation activities in the agricultural sector was USD 10-12.70 depending on the province (MAGAP, 2014). We considered a value of USD 10 for this year. Then, we estimated the X cost as 160 USD/ha and 0.32 USD/lb.

Also, Table 2 shows the cost for an Arabica coffee hectare in 2013. Establishment costs reach USD 4,155 (first and second year) and variable cost USD 1,666. To estimate K, C and X Arabica cost, we adjusted the values to inflation rates, labor wages and tree renewal costs for each year for the analyzed period.

For 2012, we obtained K (7.64 USD/lb), C (3.85 USD/lb) and L (0.32 USD/lb) costs. It was possible to verify that only the K cost had significant difference between both varieties. This results from the investment made in the first year: sowing, land preparation and fertilization activities demand more resources for Arabica coffee, the main reason being that more trees have to be planted per hectare.

Results

We estimated H and L prices for Arabica and Robusta coffee. Fig. 1a shows entry (H) and exit (L) Arabica prices and paid prices to the grower[7] on the left-hand side and the evolution of coffee harvest hectares on the right-hand side for the analyzed period 2002-2012. The price to enter the coffee activity, H, was between 6.40 and 17.57 USD/lb. Since 2004, the H prices followed a downward trend. However, these values would not provide an incentive to enter the coffee activity (H prices were above paid prices to Ecuadorian Growers), nor did they provide incentive for current growers to renew coffee trees.

The L price defines the exit decision for the activity. By comparing L prices with paid prices to Ecuadorian growers, we observed that L prices are above paid prices in most years (except in 2011). Thus, an average coffee grower would be inclined to exit the sector in most of analyzed

---

[6] The MAGAP published the cost farm structure in: http://sinagap.agricultura.gob.ec/insumos-cafe
[7] Paid price data is adjusted to coffee cherry prices according to the COFENAC information.
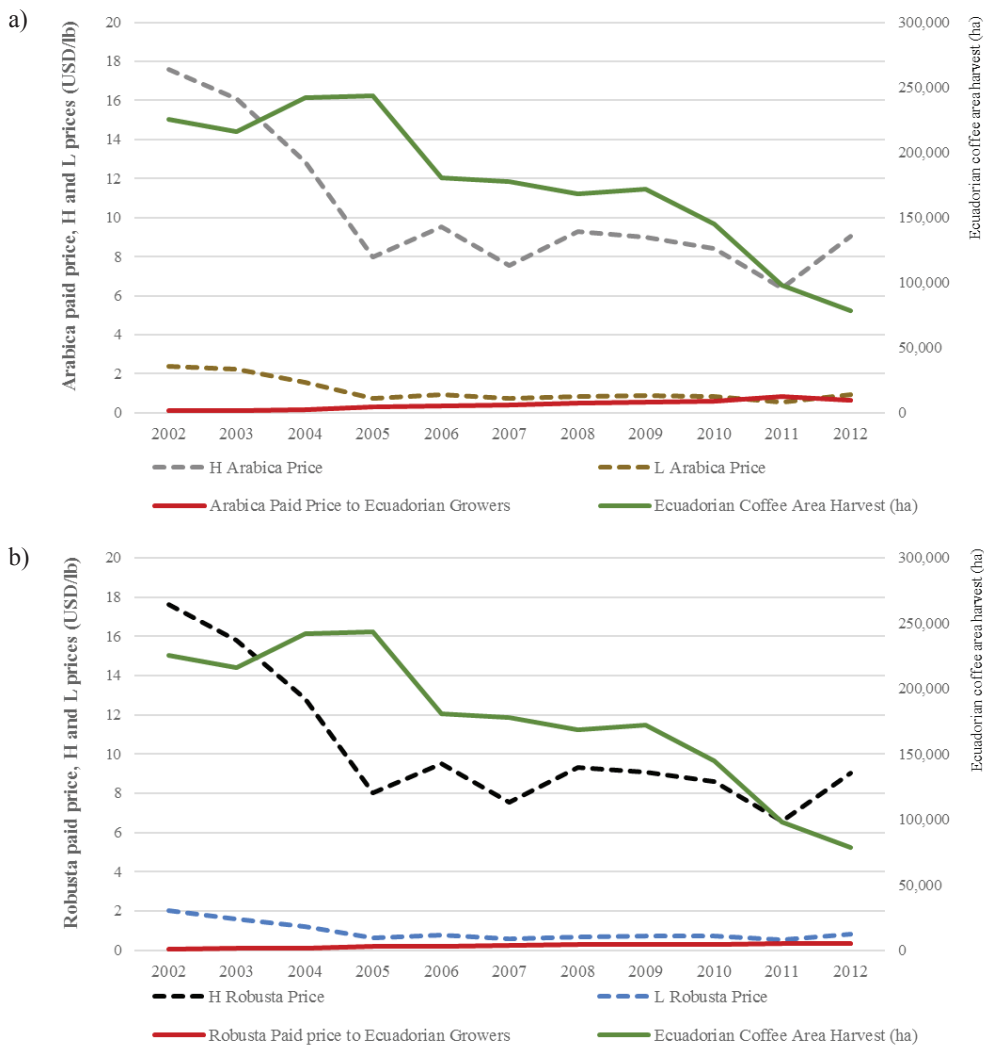
Figure 1. Coffee area harvest, entry (H) and exit (L) Arabica (a) and Robusta (b) prices and paid prices to growers

years. This is consistent with the decreasing number of hectares in the coffee harvest. The decreasing trend started in 2004, despite increasing coffee prices. In Ecuador, the costs agrochemicals products and wages have increased continuously. Variable cost (C) has also experienced an increased tendency, lifting the L price upwards.

Fig. 1b shows the Robusta coffee situation. Entry prices (H) present values between 6.58 and 17.63 USD/lb during the entire analyzed period. With these prices, we can determine that there were insufficient incentives to enter (new growers) or renew coffee hectares (current growers) due to the low prices paid for Robusta coffee in Ecuador during the 2002-2012 period.

The paid prices received by Robusta growers did not cover C costs in any year. Thus, the coffee activity does not generate profits and coffee growers would incur economic losses if they continued in the activity. We

observe that L line was above paid price in all analyzed periods, indicating that coffee prices were too low for current growers. This supports the conclusion that average Ecuadorian coffee growers would take the exit decision every year since 2002.

Our findings indicate that, for both coffee varieties, volatile and uncertain prices as well as increasing costs, forced growers to exit the sector. More specifically, variable   representing the expected rate of market growth exhibited negative values for Robusta in 2002 and for Arabica in 2002-2003. Since 2004, has positive values caused by the high upward trend experienced in the world and Ecuadorian coffee market. This upward movement would be attractive to new (enter) and current (renewal of hectares) growers; nonetheless it did not have the expected effect in the Ecuadorian coffee market. This is explained by the increasing labor costs, which

cause K and C values to increase, in turn triggering high values of H and L prices; the average yield would be measured as an indirect force that pushes K and C costs up. The average coffee yield for Ecuadorian growers is considered low (0.1- 0.3 t/ha) if it is compared with some of the major principal coffee-producing countries. However, even if the average coffee yield improves in the next years, this would not guarantee that K and C would decrease to the necessary extent due to the increasing wage costs in previous years.

Sensitivity analysis

For each coffee variety, we performed a sensitivity analysis to evaluate how changes on the variables influence the entry (H) and exit (L) prices. We used @ Risk software to perform the sensitivity analysis for year 2012[8]. First, we determined the distribution for each variable according to the Akaike Information Criteria (AIC). Next, we defined the entry and exit variables of the model to perform the sensitivity simulations for each coffee variety. With H and L simulation results, we chose the two most important variables for each coffee variety according to the output of the Tornado diagram.

Fig. 2 displays the simulation results of the Arabica. For σ^2 (the variance rate of price market), we simulated values between 5% and 35% and obtain H prices ranging from 6.72 to 13.05 USD/lb. If market volatility

increases, H increases. For variable C, with a value between 0.05 and 5.00 USD/lb we obtained H prices of 2.44 and 12.2 USD/lb. Therefore, if the grower faces a higher cost C each year, the H price would be higher.

For L price, μ (expected rate of the market growth) and (capital cost) were the two most significant variables. We simulated variable μ values ranging from -50% to 10%, raising L between 3.33 USD/lb and 0.70 USD/lb. Our results showed the inverse relation of μ and L, as expected; as high coffee prices would encourage growers to continue producing coffee instead of exiting the sector. With variable ρ values between 7.5% and 30%, L prices varied between 0.09 and 1.82 USD/lb. There was a direct relation between ρ and L: if decreases for coffee growers, L will also decrease. This has an obvious policy conclusion: if access to capital can be obtained at lower interest rates, growers might be stimulated to remain in the coffee sector.

Fig. 3 displays the price results for Robusta coffee. σ^2 and C are the most important variables affecting H prices. In the sensitivity analysis, we modeled values in a range of 5% − 35% to simulate the effect of volatility in H price (6.10 − 10.85 USD/lb). In our simulation, we could find a direct relation between σ^2 and H: if σ^2 increases for coffee activity, a high H price is obtained. Therefore, new coffee growers would not start up a plantation, and current growers would not replant the trees. Variable σ^2 is more important for Robusta than for Arabica growers, based on
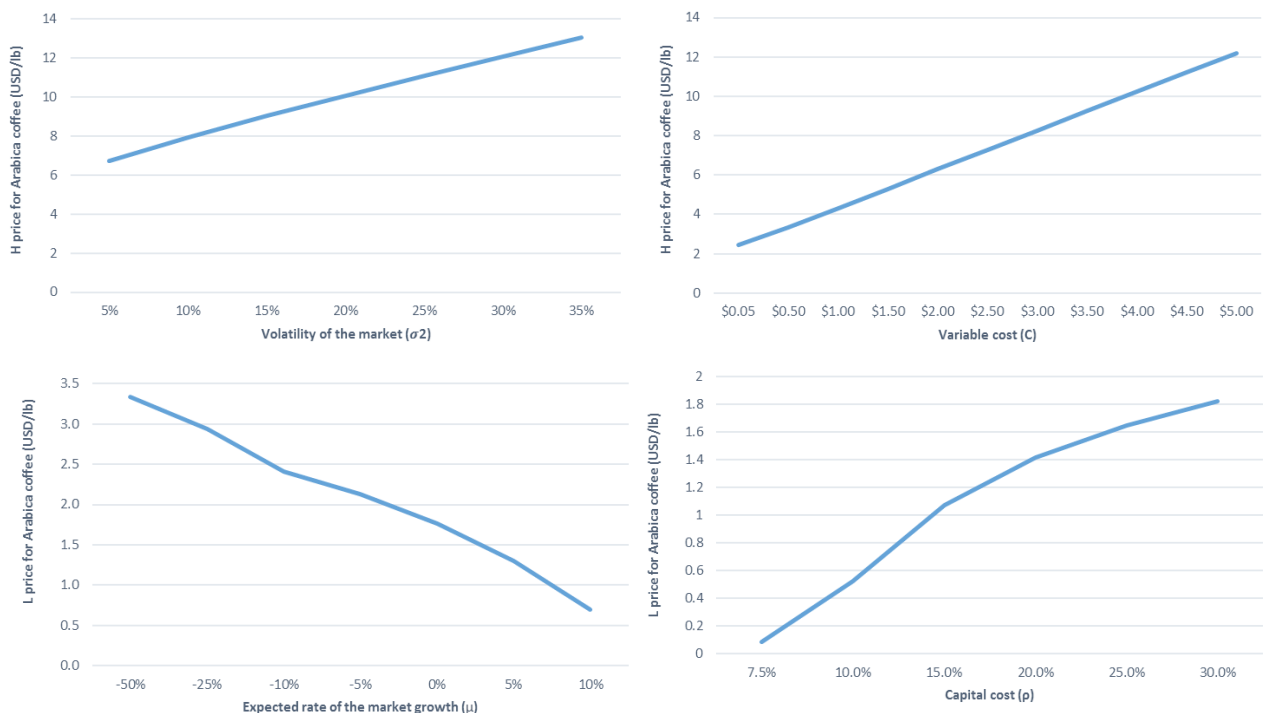

Figure 2. Sensitivity analysis for entry (H) and exit (L) Arabica prices (2012)

[8] We selected the last year (2012) for the sensitivity analysis due to its more complete historical information to determine the distribution for each variable of the model.
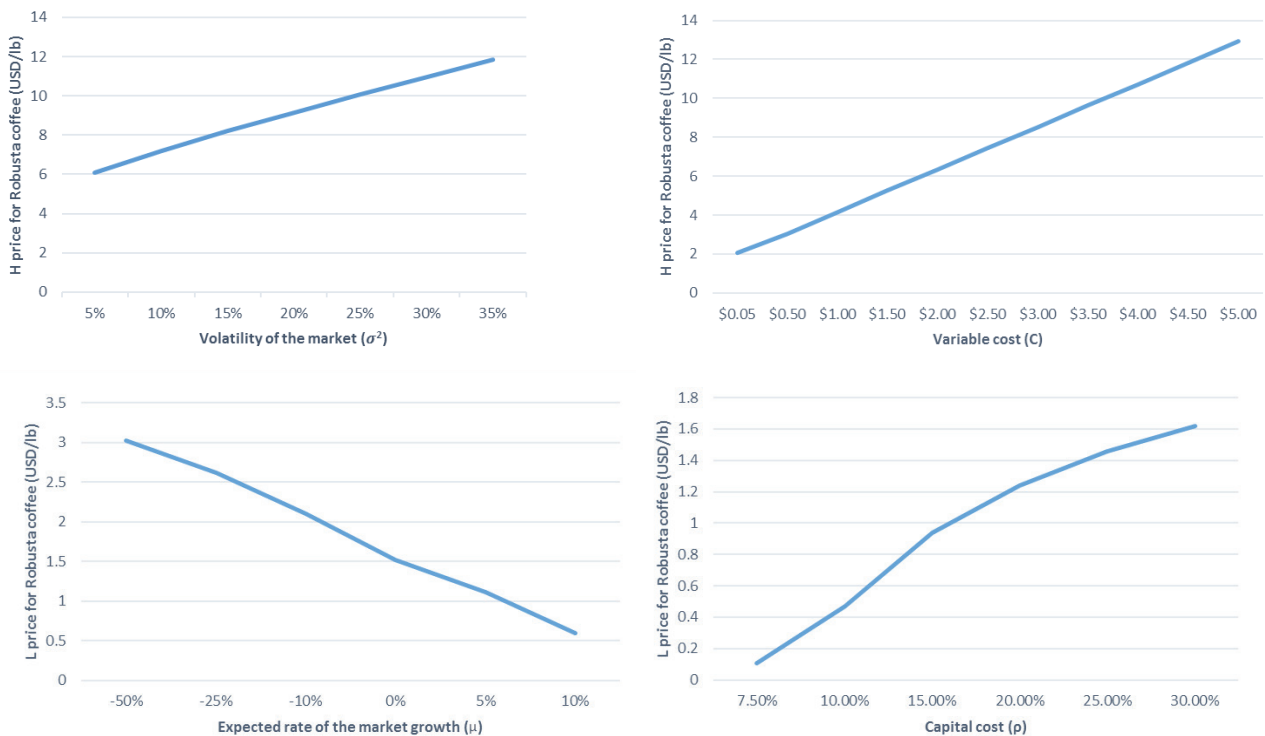
Figure 3. Sensitivity analysis for entry (H) and exit (L) Robusta prices (2012)

the coffee simulation analyses. This suggests that Robusta coffee growers were exposed to more volatility and price uncertainty than Arabica coffee growers. For variable C, we simulated values ranging from 0.05 to 5.00 USD/lb and obtained H prices between 2.07 and 12.92.

We also characterized an inverse relation of μ and L: if μ increases in the coffee market, the L price adopts a low value. This market movement would encourage current coffee growers to remain in business, but increasing costs would compromise the crop profits. When variable ρ was simulated with values ranging from 7.5% to 30%, we obtained L prices between 0.11 and 1.62 USD/lb. The direct relation of μ and L implies that any increase in μ forces L to increase as well.

Additionally, coffee growers were affected by increasing input costs, especially by the cost of labor for sowing, maintenance and harvesting activities. This reduces the profits and inflates L prices, encouraging growers to exit the coffee activity despite periods of high coffee prices.

Discussion

The results show that volatile and uncertain coffee prices may have been the major reason for growers to leave the sector during the period 2002-2012. Our sensitivity analysis highlights the importance of C (variable cost) in the definition of entry and exit coffee prices for both varieties. In year 2012, C had a value

of 3.85 USD/lb for Arabica coffee and 3.65 USD/lb for Robusta coffee. Luong & Tauer (2006) found that cost C of Vietnamese Robusta coffee was from 0.15 to 0.27 USD/lb in the year 2002. In comparison, Ecuadorian Robusta coffee was much more expensive (4.87 USD/lb) during the same year. For Arabica coffee, Bravo *et al*. (2016) found a cost C of 1.51USD/lb in a conventional system for Colombian growers in 2010. For the same year, the difference between Ecuadorian growers and Colombian growers was 1.98 USD/lb. Our conclusion is that Ecuadorian coffee production faced efficiency challenges. One of these challenges was the low yield (0.23 t/ha. for 2012). Since the end of 2011, the Ecuadorian government has offered growers technical assistance and better-quality seed. However, yearly increments in wages for farming activities increased as well harvest costs and reduced the expected profits. The future profits from an improved yield will be reduced in the long run as the wages increase each year.

Simulations carried out on the variable μ (expected rate of the market growth) show that an increase in the value of causes a reduction in L prices for both coffee varieties. This would postpone the exit decision of current growers. At the same time, increasing K and C costs discourage current growers from staying in the activity due to the high production cost. The net effect of and increasing costs (K and C) is a slight reduction of L prices. Thus, the incentives to stay in the activity are low.

Low σ^2 values reduced entry coffee prices, which would be attractive for new growers if C and K costs were not high. The net effect was a slight reduction of H price that did not encourage investment in new hectares or renewal of existing hectares. Price stabilization and risk-management mechanisms have been proposed to reduce the volatile and uncertain nature of the sector, but its successful application depends on transparency, fairness and intermediaries in the process (Mohan, 2007; Malan, 2013).

An option to improve the growers' household income is turning into organic growing and shading the coffee plantations. These coffee production systems would fetch better prices than the conventional system, but costs and premium prices would not guarantee high profits in the long run according to an evaluation in other coffee producing countries (Valkila, 2009; Ruben & Fort, 2012). These possible solutions require more studies in order to find out whether they can succeed in the long run.

The increasing farming costs forced all inefficient growers to leave the sector, a hypothesis that is proved by the exit prices obtained in the model. H and L coffee prices would be signs of profitable activity despite the volatility and uncertainty of the sector. The Ecuadorian government implemented a program offering technical and financial support. This policy only improves the harvest in the short or medium term. The main problem remains in the volatile and uncertain prices and increasing cost of production in the long term, which coffee growers have to face each year. The government and coffee growers must work together towards efficient production: finding a way to have an attractive and profitable activity despite of volatility and uncertainty.

Acknowledgements

References

Andoseh S, Bahn R, Gu J, 2014. The case for a real options approach to ex-ante cost-benefit analyses of agricultural research projects. Food Policy 44: 218-226. https://doi.org/10.1016/j.foodpol.2013.09.016

Bacon C, 2005. Confronting the coffee crisis: can fair trade, organic, and specialty coffees reduce small-scale farmer vulnerability in Northern Nicaragua? World Develop 33 (3): 497-511. https://doi.org/10.1016/j.worlddev.2004.10.002

BCE, 2016. Boletin Estadístico 1955. Banco Central del Ecuador. http://contenido.bce.fin.ec/home1/estadisticas/bolmensual/IEMensual.jsp [15 February 2016].

Borkhataria R, Collazo J, Groom M, Jordan-Garcia A, 2012. Shade-grown coffee in Puerto Rico: Opportunities to preserve biodiversity while reinvigorating a struggling agricultural commodity. Agr Ecosyst Environ 149: 164-170. https://doi.org/10.1016/j.agee.2010.12.023

Bravo-Monroy L, Potts S, Tzanopoulos J, 2016. Drivers influencing farmer decisions for adopting organic or conventional coffee management practices. Food Policy 58: 49-61. https://doi.org/10.1016/j.foodpol.2015.11.003

COFENAC, 2013. Situación del sector cafetalero ecuatoriano. Consejo Cafetalero Nacional.

Delgado G, Pérez P, 2013. Evaluación de la conversión a café orgánico usando la metodología de opciones reales. Contaduría y Administración 58 (1): 87-115. https://doi.org/10.1016/S0186-1042(13)71199-9

Dixit A, 1989. Entry and exit decisions under uncertainty. J Polit Econ 97 (3): 620-638. https://doi.org/10.1086/261619

Eakin H, Tucker C, Castellanos E, 2006. Responding to the coffee crisis: A pilot study of farmers' adaptations in Mexico, Guatemala and Honduras. The Geographical Journal 172 (2): 156-171. https://doi.org/10.1111/j.1475-4959.2006.00195.x

FAO, 2015. Crops. FAOSTAT, Food and Agriculture Organization of the United Nations. http://faostat3.fao.org/download/Q/QC/E [5 December 2015].

ICO, 2002. The global coffee crisis: A threat to sustainable development. International Coffee Organization, London. http://www.ico.org/documents/globalcrisise.pdf [15 October 2015].

ICO, 2009. Informe sobre el mercado de café. International Coffee Organization, London. http://dev.ico.org/documents/cmr-1209-c.pdf [6 February 2015].

ICO, 2014. Comparative analysis of world coffee prices and manufactured goods. International Coffee Organization. http://www.ico.org/documents/cy2013-14/icc-112-8e-study-manufactured-goods.pdf [22 September 2015].

INEC, 2012. Visualizador de estadísticas agropecuarias del Ecuador (ESPAC). Instituto Nacional de Estadísticas y Censos. http://www.inec.gob.ec/estadisticas/ [20 October 2015].

Isik M, Coble K, Hudson D, House L, 2003. A model of entry-exit decisions and capacity choice under demand uncertainty. Agr Econ 28 (3): 215-224. https://doi.org/10.1111/j.1574-0862.2003.tb00139.x

Lukanima B, Swaray R, 2014. Market reforms and commodity price volatility: The case of East African coffee market. The World Economy 37(8): 1152-1185. https://doi.org/10.1111/twec.12124

Luong Q, Tauer L, 2006. A real options analysis of coffee planting in Vietnam. Agr Econ 35 (1): 49-57. https://doi.org/10.1111/j.1574-0862.2006.00138.x

MAGAP, 2014. Boletin Agrícola Integral. Ministerio de Agricultura, Ganadería, Acuacultura y Pesca, Ecuador. http://sinagap.agricultura.gob.ec/ [12 October 2015].

Malan B, 2013. Volatility and stabilization of the price of coffee and cocoa in Cote d'Ivoire. Agric Econ- Czech 59 (7): 333-340.

Mohan S, 2007. Market-based price-risk management for coffee producers. Dev Policy Rev 25 (3): 333-354.

Mohan S, Gemech F, Reeves A, Struthers J, 2014. The welfare gain from eliminating coffee price volatility: The case of Indian coffee producers. J Devel Areas 48 (4): 57-72. https://doi.org/10.1353/jda.2014.0070

Price T, Wetzstein M, 1999. Irreversible investment decisions in perennial crops with yield and price uncertainty. J Agr Resour Econ 24 (1): 173-185.

Ruben R, Fort R, 2012. The impact of fair trade certification for coffee farmers in Peru. World Develop 40 (3): 570-582. https://doi.org/10.1016/j.worlddev.2011.07.030

Rueda X, Lambin E, 2013. Linking globalization to local land uses: How eco-consumers and gourmands are changing the Colombian coffee landscapes. World Develop 41(1): 286-301. https://doi.org/10.1016/j.worlddev.2012.05.018

Schmit T, Luo J, Tauer L, 2009. Ethanol plant investment using net present value and real options analyses. Biomass Bioenerg 33 (10): 1442-1451. https://doi.org/10.1016/j.biombioe.2009.06.010

Tauer L, 2006. When to get in and out of dairy farming: A Real Option Analysis. Agr Resour Econ Rev 35 (2): 339-347. https://doi.org/10.1017/S1068280500006778

Tozer P, 2009. Uncertainty and investment in precision agriculture - Is it worth the money? Agr Syst 100 (1-3): 80-87. https://doi.org/10.1016/j.agsy.2009.02.001

Tucker C, Eakin H, Castellanos E, 2010. Perceptions of risk and adaptation: Coffee producers, market shocks, and extreme weather in Central America and Mexico. Global Environ Change 20 (1): 23-32. https://doi.org/10.1016/j.gloenvcha.2009.07.006

Valkila J, 2009. Fair trade organic coffee production in Nicaragua — Sustainable development or a poverty trap? Ecol Econ 68 (12): 3018-3025. https://doi.org/10.1016/j.ecolecon.2009.07.002

Wolbert-Haverkamp M, Musshoff O, 2014. Are short rotation coppices an economically interesting form of land use? A Real Options Analysis. Land Use Policy 38: 163-174. https://doi.org/10.1016/j.landusepol.2013.10.006

Worako T, Jordaan H, and Van Schalkwyk H, 2011. Investigating volatility in coffee prices along the Ethiopian coffee value chain. Agrekon 50 (3): 90-108. https://doi.org/10.1080/03031853.2011.617865