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Research Article

Measurement and analysis of agricultural Productivity in Colombia

Estimación y análisis de la Productividad Agrícola en Colombia

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Abstract

Tremendous agricultural potential in Colombia has gone untapped for decades due to: i) civil strife and the criminal drug trade; ii) uncertain property rights; iii) inadequate infrastructure; iv) lack of innovation and technological development; v) lack of funding, vi) lack of investment; and vii) misallocation of resources within the sector. Proof of this is the relatively lower growth of the value of Colombia's agriculture versus other countries in the region during the agricultural prices booms (FAO, 2015). This paper analyzes whether Colombia's weak agricultural performance was due to low productivity growth rather than input accumulation. Using econometric specifications, this paper finds that Colombia's agricultural productivity grew on average between 0.8% and 1.3% annually from 1975 and 2013. This growth was mainly driven by livestock and poultry productivity, which grew between 1.6% and 2.2%, while crop productivity grew between 0% and 0.8%. Likewise, this paper finds biased technical and scale effects whenever the models are able to test their presence. In addition, it finds evidence that Colombia's agricultural productivity growth was affected by changing economic circumstances. These results are significant for post-conflict rural investment because they provide information about the returns on future government investment options in the rural sector of Colombia.

Resumen

Colombia dejó de explotar su gran potencial agrícola por décadas debido a: i) el intenso conflicto armado y el narcotráfico; ii) la gran incertidumbre alrededor de los derechos de propiedad de la tierra; iii) la falta de infraestructura; iv) la falta de innovación y desarrollo tecnológico en el sector; v) la falta de financiamiento; vi) la baja inversión; y vii) la mala distribución de los recursos productivos. Muestra de ello es el bajo crecimiento del valor de su producción agropecuaria frente a otros países de la región durante los recientes auges de precios agrícolas (FAO, 2015). Este artículo analiza si el pobre desempeño de la agricultura colombiana se debe al bajo crecimiento de su productividad o al bajo ritmo de acumulación de sus inventarios. Así, usando métodos econométricos, se encuentra que la productividad agropecuaria de Colombia creció en promedio entre un 0.8% y un 1.3% anual durante 1975 y 2013. Mas específicamente, se encuentra que este crecimiento fue impulsado, principalmente, por la productividad ganadera y avícola que creció entre un 1.6% y un 2.2% en este período, pues la productividad agrícola tan sólo creció entre un 0% y un 0.8%. Igualmente, se encuentra evidencia de crecimiento tecnológico sesgado y efectos a la escala de producción, en todos los casos en los que los modelos econométricos permitieron evaluar esto. Además, se encuentra evidencia de que el crecimiento de la productividad agropecuaria de Colombia fue afectado por las cambiantes condiciones económicas en el país. Todos estos resultados, sin duda, son clave para la inversión rural en esta nueva etapa del posconflicto, al proveer información sobre los posible retornos que obtendría Colombia de dicha inversión pública en el sector rural.

1. Introduction

Tremendous agricultural potential in Colombia has gone untapped for decades due to a myriad of factors, including: i) civil strife and the criminal drug trade; ii) uncertainty regarding property rights; iii) inadequate infrastructure; iv) lack of innovation and technological development; v) lack of access to funding, vi) lack of investment; and vii) misallocation of resources within the sector (COMPITE, 2008; Clavijo, Vera & Fandiño, 2013; Junguito, Perfetti, & Becerra, 2014; and Reina, Zuluaga, Bermúdez & Oviedo, 2011). Government policies have allocated economic and development efforts to urban and industrial areas (e.g. financial, mining and utilities) rather than rural agricultural areas, where insurgent forces have often taken refuge (Junguito et al., 2014).[1] It was generally the case that when agricultural policies were implemented, they were done so with short-term goals in mind (SAC, 2014). With recent advances toward peace between the Colombian government and insurgents as well as less incidences of drug trafficking in the country, Colombia is poised for renewed public and private investment in agriculture and rural communities.[2] This agreement may well improve the environment of agricultural investment, and the return of combatants and others to rural activities means not only a greater labor supply, but also that agriculture must play a key role in future national development. The results presented in this paper have the potential to inform better policies toward rural and agricultural development in Colombia in the post-conflict era.

The value of Colombia's agricultural production grew by only 10% during the agricultural commodity price booms of 2006-2011, relative to its average growth from 2000-2005. In contrast, the value of global agricultural production expanded by 25%, and much greater growth occurred in other Latin American countries: 26.1% in Chile, 28.6% in Argentina, 43.6% in Brazil and 45.6% in Peru (FAO, 2015). We analyze the relatively weak performance of Colombia's agriculture and evaluates whether it was due to a low productivity growth rather than a lack of input accumulation. Our general hypothesis

1 Colombia has been suffering from the following Dutch Disease symptoms: i) a real misalignment of the exchange rate, which oscillated around 15-20% in recent years; ii) an overall economy largely supported by non-tradeable sectors (60% of Colombia's overall GDP); iii) a premature de-industrialization process (i.e. industry GDP reduced its importance in Colombia's overall GDP from 23% in the 1970s to 14% in the 2000s); iv) pronounced export concentration of commodities (close to 70% of total exports); and v) high NAIRU rate of close to 10% (Clavijo et al., 2013).

2 The national government of Colombia recently signed a peace agreement with one of its largest armed groups, Las Fuerzas Armadas Revolucionarias de Colombia (FARC), after more than 50 years of intense conflict.

is that deep structural problems, suggested by low productivity growth rates, prevented Colombia's agriculture from exhibiting the higher growth of the commodity prices booms.

Previous investigations suggest that over recent decades Colombia's agriculture has exhibited stagnant growth of between 1.5% and 2% per year (World Bank, 2016), mainly due to the structural problems mentioned above. Likewise, Colombia's agriculture has been subject to many distortions due to agricultural policy design and administration which limited the country's competitiveness (Anderson and Valdés, 2008). Moreover, public expenditure on Colombia's agriculture has represented just 0.2-0.4% of overall GDP since the late 1990s, while this figure has reached 1% in other emerging markets and 4% in developed countries (Junguito et al., 2014). These deep structural problems leading to slower agricultural sector growth have varied over time due to political and economic circumstances leading to variations in both productivity growth and input accumulation.

In contrast, prices received by Colombian farmers increased by 30% in 2008 and 57% in 2011 relative to average prices from 2000-2005 according to the Producer Price Index (PPI) calculated by the Departamento Administrativo Nacional de Estadística (DANE, 2015). Accordingly, Colombia's farmers surely experienced the effects of high global commodity prices seen in 2008 and 2011. Then, farmers were exposed to incentives to increase both their productivity and input use. However, the aforementioned structural problems seem to have prevented Colombia from reaching a higher standard of agricultural performance.

Colombia's agricultural productivity has rarely been analyzed in the economics literature, and the techniques used to measure its agricultural productivity have been inconsistent (Atkinson, 1970; Avila et al., 2010; Ludena, 2010; Pfeiffer, 2003; USDA, 2015). Most of these studies have relied on accounting methods, employing untested assumptions rather than econometric estimation, and substituting data from neighboring countries for missing Colombian data. Likewise, these studies did not reach a consensus and are essentially incomparable because they address different time periods, employ different data sources, and/or employ contradictory underlying assumptions.

One contribution of this paper is that it econometrically measures Colombia's agricultural productivity growth, both aggregated and disaggregated for crop and livestock production during the period 1975-2013.[3] We employ three commonly used econometric specifications to analyze the robustness of results to alternative specifications and their associated underlying assumptions about technology, etc. One of these is a Translog Cost function model that allows for the investigation of bias in technical change and scale effects, as well as providing confidence intervals for the productivity estimates (Antle and Capalbo 1988). The other two specifications are the Cobb-Douglass and the CES production technologies. A second contribution is that this paper assembles a current and complete Colombia dataset that does not feature data substitution from neighboring countries. Thus, this study assesses how Colombia's agricultural productivity growth has changed over time relative to varying policy regimes and economic circumstances. To this aim, we conduct a historical analysis of Colombia's agriculture from 1975-2013 that models six key structurally different time periods, during which economic conditions and policy regimes strongly influenced agricultural productivity growth (see Table 1).

3 Productivity growth is defined as the increase in output attributable to technical change (Domar, 1961; Jorgenson and Griliches, 1967; Solow, 1957).

This paper proceeds as follows. Section 2 describes the overall context for Colombia's agriculture from 1975-2013. Section 3 presents a review of the relevant literature on Colombia and the most common methodologies used to measure agricultural productivity. Section 4 explains the methodology used in this study. Section 5 describes the data used. Section 6 analyzes the various agricultural productivity growth estimates for Colombia obtained by the current study. Section 7 provides our concluding remarks.

2. Colombia's agriculture from 1975-2013

Agriculture is one of the most important economic activities of Colombia. About 40% of Colombia's land is used for agricultural purposes. Agricultural GDP has averaged 6-8% of Colombia's total GDP and agricultural exports account for 18% of total national exports in recent decades (DANE, 2015). Moreover, agriculture employs 20% of the national labor force and 66% of the rural labor force (COMPITE, 2008; SAC, 2011; DANE, 2015). Colombia increased the value of its production by 50% in the last two decades, ensured its self-sufficiency in agricultural products, and consolidated a diverse portfolio of products (e.g., beef, milk, chicken, sugar cane, coffee and flowers) for domestic consumption and exportation (FAO, 2015).

However, Colombia's agriculture has been seriously affected by a significant lack of investment in recent decades (Junguito et al., 2014). Likewise, the transformation of Colombia's economy into an oil-dependent economy after the discovery of Caño Limon in 1983 and Cusiana-Cupiagua in 1991 (two great oil deposits) damaged the competitiveness of tradable sectors, among them agriculture. Moreover, Colombia's agriculture has tackled all the aforementioned structural problems, which undoubtedly has limited performance. Consequently, Colombia's agricultural GDP has exhibited a significant slowdown, from an annual average growth of 4.5% in the 1970s, 2.7% in the 1980s, 1.5% in the 1990s, and 1.9% in the 2000s (World Bank, 2016).

Looking forward, agriculture in Colombia is a sector with promising prospects in the coming decades. Along with Brazil, the Congo, Angola, Sudan, and Bolivia, Colombia is one of the few countries with the opportunity to expand its agricultural frontier (FAO, 2013). The Orinoco region, similar to the Cerrado in Brazil, would allow Colombia to expand its farmland by 80% (between 3-5 million hectares) if Colombia improves its infrastructure and prioritizes the development of new agricultural technologies in the region (Clavijo & Jimenez, 2011c). Accordingly, Colombia has the potential to become a global exporter of agricultural products, given that: i) the United Nations predicts the world population will grow by 30% to 9,100 million people (2% per year) by 2050 (UN, 2015); ii) the Food and Agriculture Organization (FAO) estimates that global food production must increase by 70% (5% per year) to feed the growing population (FAO, 2009); iii) Colombia's agricultural GDP per capita will grow on average by 2-4% in the coming decades; and iv) Colombia's agricultural GDP is projected to grow 4-5% annually and its population is projected to grow by only 1-1.5% annually, according to official predictions (DANE, 2015; MADR, 2014).

3. Measurement of Agricultural Productivity

3.1 Theoretical Framework

Agricultural productivity has been widely measured worldwide, beginning with the pioneering work of Solow (1957) and Griliches (1963 a-b, 1964). Productivity has been recognized as an essential source of growth that encompasses the output gains attributable to technical change (Pfeiffer, 2003). Development economists have also stated that agricultural productivity is particularly critical to developing countries' improved economic growth and social conditions (Johnson and Mellor, 1961). In addition, studies have also shown that agricultural productivity is a key factor explaining the dynamics of worldwide trade, by determining changes in the comparative advantages among countries (Ball et al., 2010). Accordingly, agricultural productivity has been the focus of a significant number of studies (Ball, 1985; Fernandez-Cornejo and Shumway, 1997; Avila et al., 2010; Evenson & Fuglie, 2010; Fuglie & Rada, 2013 to name a few).

Three different methodology types are often used to measure agricultural productivity. The first is growth accounting. This technique measures agricultural productivity by following a simple accounting exercise (Solow, 1957): aggregate output growth is estimated as the growth of the value of all outputs; aggregate input growth is measured as a cost share weighted average of the growth in inputs used in production of the various outputs; and productivity growth is identified as the residual difference between these two measures.[4]

The simple exercise makes the growth accounting technique very attractive. However, the technique relies on very strong assumptions: i) competitive markets for both outputs and inputs; ii) constant returns to scale; iii) technical change is Hicks neutral; iv) input-output separability; and v) a Cobb-Douglas production function (Antle and Capalbo, 1988; Diewert, 1992).[5 6 7] Many studies have used these techniques and the USDA relies on this methodology for measuring International Agricultural Total Factor Productivity (TFP) Growth (Evenson and Fuglie, 2010; Fuglie, 2010; Fuglie and Rada, 2013; Rada, 2013).

Superlative index methods have been used to relax these assumptions. The most commonly used are the Tornqvist- Theil Index (Ball, 1985; Evenson et al., 1999; Fan and Zhang, 2002; Garcia et al., 2012; Thirtle et al., 2008) and the Fisher Index (Cahill and Rich, 2012; Zhao et al., 2012). These procedures measure the agricultural productivity without estimating a functional structure for the production function for long periods of time. However, these methods are data demanding, and their economic interpretation is not always intuitive (Saikia, 2009). In addition, productivity estimates largely depend on the index number formula (Diewert and Nakamura, 2002).

Another methodology is the frontier technique (Farrell, 1957). These techniques rely on the fact that economic activities may not always be located in their best practice frontiers (i.e. on the Production Possibility Frontier, or PPF) (Coelli, Rao and Battesse, 1998).[8] Accordingly, agricultural productivity corresponds to the estimation and posterior product of two components: technical

4 The main difference in measuring agricultural productivity using a growth accounting technique versus an econometric technique is that growth accounting techniques calculate cost shares using observed accounting data and use those shares as production function parameters, while econometrics techniques estimate the production function parameters (or their dual counterparts) using statistical methods.

5 Hicks (1963) defines neutral and biased technological change by whether their effects increase, remain unchanged, or diminish the ratio of the marginal products among inputs; that is, whether or not the technical change preserves the expansion path.

6 A production function is input-output separable on inputs i and j, when it can be written as $F(X) = g(X_A, X_n)$; where $X_A = f(X_i, X_j)$ (Antle and Capalbo, 1988).

7 These assumptions can be somewhat relaxed during computation, but to do so requires knowledge of information like scale elasticities, which is rarely available.

8 The best practice frontier is defined as the maximum output a firm can produce given a set of inputs and the state of technology at the time (Sena, 2003).

change, which captures shifts in the production possibility frontier, and efficiency change, which considers movements exhibited by a firm or economic activity within its production possibility set toward a position closer to that frontier (Sena, 2013). Hence, agricultural productivity measurement largely depends on a robust estimation of the production possibility frontier and the corresponding estimation of these two components using the frontier as an efficiency benchmark.

Two frontier types are primarily utilized for the measurement of agricultural productivity: i) parametric methods, such as Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA) (Coelli, Rao and Battesse, 1998), and ii) non-parametric methods, such as the Malmquist Index (Caves et al., 1982). These techniques are very attractive when data is a constraint, because they do not require any price data (Coelli and Rao, 2005; Sena 2003). However, they are susceptible to data quality issues and unusual shadow prices (Coelli and Rao, 2005; Thirtle et al., 2003; Tong et al. 2012).

Econometric techniques are another common approach used to measure agricultural productivity (Berndt and Christensen, 1973). These techniques assume that productivity can be directly measured when assuming a functional approximation of the true production relationship (so-called primal techniques) or indirectly measured from its Dual Cost function (so-called dual techniques), which requires the functional approximation of the cost or profit function. The main advantages are that econometric models allow: i) relaxing certain assumptions required by accounting approaches, such as Hicks neutral technical change or constant returns to scale; ii) estimating rather than assuming certain parameters related to technical changes, such as the elasticity of factor substitution; and iii) estimating confidence intervals around the estimates and testing hypotheses on the estimated parameters. However, these primal econometric models require a production function with input-output separability, as do growth accounting approaches. Primal econometric models also require a large enough data set to ensure sufficient degrees of freedom, address multi-collinearity problems and estimate a large number of parameters with good precision. Nevertheless, these techniques estimate productivity growth with fewer constraining assumptions than required by other approaches. Econometric models have been successfully used by several studies devoted to analyzing agricultural productivity. For example: Cungu and Swinnen, 2003; Fan, 1991; Sun et al., 2009.

3.2 Agricultural Productivity in Colombia

Colombia's agricultural productivity has been the focus of just a few studies at the national level (Atkinson, 1970; Avila et al., 2010; Ludena, 2010; Pfeiffer, 2003; USDA, 2015). It has usually been analyzed in the context of multi-national studies (Bravo-Ortega and Lederman, 2004; Coelli and Rao, 2005; Fuglie, 2015; Fulginiti and Perrin, 1998; Trueblood and Coggins, 2003). Relatively little is known about its dynamics over the last several decades.

Atkinson (1970) is the pioneering scholar of Colombia's agricultural productivity. Using partial productivity indices for the period of 1950-1967, he found that Colombia's agricultural productivity was uneven across crops and largely dependent on farms' ability to mechanize their production practices. Also, large farms usually exhibited higher agricultural productivity than small farms, because large farms could afford to pay for better seeds, pesticides and fertilizers.

In more recent studies, growth accounting techniques have been the most common methodology used to measure Colombia's agricultural productivity. For instance, the USDA (2015) used the technique for 173 countries from 1961-2012. The study estimated that Colombia's agricultural productivity grew 1.4% on average per year during this period. Avila et al. (2010) used a Tornqvist-Theil Index to examine Colombia's agricultural productivity between 1961 and 2001 and estimated that it grew an annual average of 0.7%. However, these studies reached different conclusions and none used budget data from Colombian farmers.[9]

Ludena (2010) used a frontier approach and found that Colombia's agricultural productivity grew an average of 2.4% during the 1980s, 2.5% during the 1990s, and 0.2% from 2000-2007. Likewise, Pfeiffer (2003) estimated that Colombia's agricultural productivity grew on average between 0.6-1.9% during the period 1972-2000.[10]

Clearly, these studies obtained varying results from various techniques that provided non-robust estimates for Colombia's agricultural productivity. As the time frames changed, so did productivity and agricultural performance estimates. These studies indicate that Colombia's agricultural productivity grew slowly and unevenly over the last several decades. We suspect that this is probably because most studies implicitly assume that changes in economic conditions and policy regimes did not impact Colombia's agricultural productivity. This paper considers this to be a crucial assumption that accounts for these differences. Therefore, we incorporate important changes in the political economy over time into our analyses of Colombia's agricultural productivity.

4. Methodology to Measure Agricultural Productivity in Colombia

In order to measure Colombia's agricultural productivity, Colombia's agricultural output is assumed to mainly depend on four inputs (capital, labor, fertilizer and animal feed), following the USDA (2015) and given the data availability for the period analyzed in this study (1975-2013). Three functional approximations are estimated for the production technology in an effort to examine the robustness of the results: Cobb-Douglas production function, CES production function and Translog Cost function.

4.1 Cobb-Douglas Production Function

The choice of functional form is a primary issue in the econometric estimation of productivity growth and technical change. The Cobb-Douglas functional form is one of the simplest choices available and has been widely used in applied economics research. The Cobb-Douglas is supported by the same theoretical underpinnings as the growth accounting technique. Rather than use observed farmers' budget data to estimate all parameters, this approach estimates them econometrically by controlling for other factors and substitution possibilities implied by the data. Assuming that agricultural productivity grows on average at a constant rate g, so $A_t = A_0 e^{gt}$, the Cobb-Douglas representation of aggregate production is:

$$Q_t = A_t K_t^{\alpha} L_t^{\beta} F_t^{\gamma} S_t^{\theta} u_t = A_0 e^{gt} K_t^{\alpha} L_t^{\beta} F_t^{\gamma} S_t^{\theta} u_t, \qquad \text{for } t = 1975 \text{ to } 2013 \tag{1}$$

where Q_t is total agricultural output in period t, A_0 is agricultural productivity in the initial period, e is the exponential function, K_t is the stock of capital in agriculture in period t, L_t is labor hired by agriculture in period t, F_t is fertilizer used by agriculture in period t, S_t is animal feed employed by agriculture in period t and u_t is the error in measuring output in period t.

9 For example, the USDA (2015) measured Colombia's agricultural productivity by applying Brazil's input cost shares (i.e. assuming these are representative) since those shares for Colombia were unavailable.

10 Pfeiffer (2003) used a fixed effect parametric production function, a stochastic frontier production function and the Malmquist index.

Colombia's agricultural productivity growth over time is measured as the sum of the average growth g and the residuals of the econometric estimation $\widehat{u_t}$, (which have a mean of zero).[11] Crop and livestock productivity growth are also separately estimated in this paper following a similar approach. One of the advantages of a specification such as the Cobb-Douglas function is that it can be estimated using Ordinary Least Squares (OLS) after transforming to the linear version of equation (1) with variables expressed in natural logarithms. Serial autocorrelation across the time dimensional residuals was tested using the Durbin-Watson statistic. When this problem was detected, one-period lagged output was added to the regression as a concomitant variable to incorporate inertia into the aggregate cropping patterns, which likely led to the serially-correlated error.

The Cobb-Douglas parameters α, β, γ and θ can only be interpreted as input cost shares when the following conditions are satisfied: i) perfect competition; ii) firms maximize their profits; iii) perfect information; and iv) constant returns to scale in period t. Constant returns to scale requires the restriction that $\alpha + \beta + \gamma + \theta = 1$ and that all parameters are non-negative. Otherwise, these parameters represent only the marginal effect of each input on agricultural output. In addition, the Cobb-Douglas function is only capable of representing Hicks-neutral technical change.

The rigid structure and underlying assumptions of the Cobb-Douglas specification may not be supported by the Colombian data. Two alternative econometric approaches were also examined, each of which relaxes some of the assumptions discussed above to varying degrees. The Constant Elasticity of Substitution (CES) production function allows the estimation of a constant elasticity of substitution different from one. The CES also allows for the measurement of biased technical change. Dual approaches that specify a cost function allow for further relaxation of the Cobb-Douglas and growth-accounting assumptions. Dual approaches with higher order polynomial forms are the key aspect of this increased flexibility. In this regard, it is not the dual that is important, but the order of the functional form must be polynomial. However, the dual approach facilitates the use of these functional forms because in many of the more interesting cases, such as the translog functional form, it is not self-dual. This implies that it is not possible to solve the profit maximization problem analytically to obtain a closed form system for the direct estimation of the production function (Antle and Capalbo 1988). The dual approach allows the recovery of potentially unknown but well-behaved production technology information by estimating the input demand and output supply functions derived from the Dual Cost function (Christensen and Greene, 1976). Also, this approach enables the measurement of both biased technical change and the potential impact of aggregate scale effects on productivity growth.

4.2 CES Production Function

The CES production functional form was initially designed to analyze the production of economic activity using only two inputs (Arrow et al., 1961). Sato (1967) generalized this production function for n inputs, explaining that it can be estimated assuming two-input nests. In recent decades, debate has focused on how to determine this nested pair of inputs.

This paper followed the approach developed by Klump et al. (2007) and Leon-Ledesma et al. (2011) to measure Colombia's agricultural productivity assuming a CES production function. We rely on the following normalized structure of a nested CES production function with four inputs and technical change. The primary inputs (i.e. capital and labor) are allocated to the first nest and the intermediate inputs (i.e. fertilizer and animal feed) to the second nest. Also, to circumvent problems related to the

11 Complete derivations for all methods employed in this paper are available upon request.

Diamond McFadden Impossibility Theorem (Diamond et al., 1978), the efficiency growth exhibited by each input E_{it} is restricted to a constant rate γ_i (Klump et al., 2011).

$$Q_t = Q_0 \left\{ a \left[(1-\beta) \left(e^{\gamma_K (t-t_0)} \frac{K_t}{K_0} \right)^{\frac{\eta-1}{n}} + \beta \left(e^{\gamma_L (t-t_0)} \frac{L_t}{L_0} \right)^{\frac{\eta-1}{n}} \right]^{\frac{\eta}{n-1} \frac{\sigma-1}{\sigma}} + (1-a) \left[(1-\pi) \left(e^{\gamma_F (t-t_0)} \frac{F_t}{F_0} \right)^{\frac{\psi-1}{\psi}} + \beta \left(e^{\gamma_S (t-t_0)} \frac{S_t}{S_0} \right)^{\frac{\psi-1}{\psi}} \right]^{\frac{\psi}{\psi-1} \frac{\sigma-1}{\sigma}} \right\}^{\frac{\sigma}{\sigma-1}} + u_t, \quad \text{for } t = 1975 \text{ to } 2013 \tag{2}$$

where the elasticity of substitution between capital and labor (i.e. first nest inputs) is η, between fertilizer and feed (i.e. second nest inputs) is ψ, and between nests is σ. Also, α is the distribution parameter between nests, β within the first nest, π within the second, and u_t is the error in measuring this CES production function.

The measurement of Colombia's agricultural productivity involves a typical profit maximization problem to determine the input demands. Each equation derived from this optimization is normalized and linearized. The profit optimization was solved by assuming that Colombia's agriculture faces a demand function $Y_{it} = \left(\frac{P_{it}}{P_t}\right)^{-\varepsilon}$, its income is $Q_t = (1+\mu)(R_tK_t + W_tL_t + fP_tF_t + sP_tS_t)$ and it exhibits a rent factor $1+\mu = \frac{\varepsilon}{1-\varepsilon}$, where real returns to capital are denoted by R_t, wage paid for labor by W_t, fertilizer price by fP_t, and animal feed price by sP_t.[12] This system of equations was estimated using Iterative Feasible Generalized Non-Linear Least Squares (IFGNLS), as recommended by Kreuser et al. (2015). This technique prevents the estimation of inconsistent parameters and an elasticity of substitution biased towards unity, as is often exhibited when this system of equations is estimated as a Seemingly Unrelated Regression model (SUR) (Luoma and Luoto, 2011).

This model estimated the parameters for technical change γ_i and input elasticities of substitution (σ,η, and ψ) simultaneously and under two scenarios: i) Hicks-Neutral technical change ($\gamma_K = \gamma_L = \gamma_F = \gamma_S$) and ii) biased technical change ($\gamma_K \neq \gamma_L \neq \gamma_F \neq \gamma_S$). Colombia's agricultural productivity growth was also measured over time as the actual output growth in period t unexplained by the input growth in period t.

For the measurement of crop and livestock productivity, a similar nested CES production function was used. Crop production was modeled to depend on capital, labor and fertilizer, and livestock production was modeled to depend on capital, labor and animal feed. Accordingly, a nested CES production function with only one nest and an extra input was defined for each case. Also, two possible forms for their respective, nested CES production functions were examined: i) when primary inputs are in the nest or ii) when capital-related inputs are in the nest.[13]

4.3 TransLog Cost Model

This approach is simpler than using primal methods when price data is available and (as discussed earlier) functional forms of the production function lack a closed form solution to the profit maximization or cost minimization problems. Dual functions, such as a cost or profit function, are valid alternatives to represent the multi-product function and to define the technical change (Antle and Capalbo, 1988).

12 This methodology allows the model to capture possible rents in Colombia's agricultural due market power and scale economies (e.g., as is the case in the coffee sector).

13 The measurement of crop and livestock productivity involved a slightly different profit maximization problem. There were only three derived first order condition equations, one for each input. Also, the first order condition equation for the input out of the nest exhibits a somewhat different functional form.

The effects of technical change can be quantified through a reduction in cost or an increase in profits, given an output level and a set of input prices.

The following translog functional form was specified for the aggregate cost function for Colombia's agriculture:

$$\ln C_t = \alpha_0 + \alpha_Q \ln Q_t + \sum_i \alpha_i \ln w_{it} + \frac{1}{2}\sum_i \beta_{ii} (\ln w_{it})^2 + \sum_i \sum_j \beta_{ij} \ln w_{it} \ln w_{jt}$$
$$+ \sum_i \beta_{iQ} \ln w_{it} \ln Q_t + \frac{1}{2}\alpha_{QQ} (\ln Q_t)^2 + \alpha_t T + \frac{1}{2}\alpha_{tt} T^2 + \sum_i \beta_{it} \ln w_{it} T + \beta_{Qt} \ln Q_t T + u_t, \quad (3)$$
$$\text{for } t = 1975 \text{ to } 2013 \quad \text{and} \quad i,j = \{\text{capital, labor, fetilizer and animal feed}\}$$

where C_t are the production costs of Colombia's agriculture in period t, w_{it} is the price of input i in period t, Q_t is output in time t, T is a time trend variable that captures technological change and u_t is the error in measuring the logarithm of the total cost.

This functional form is a second-order approximation of an arbitrary, twice-continuously differentiable cost function. It exhibits three main strengths: i) flexibility of functional form; ii) does not restrict input substitution possibilities, and iii) scale economies can vary based on output levels (Kant and Nautiyal, 1997; Varian, 1978). The form has been used successfully by other studies in which the production generating dynamic structure was unknown (Binswanger, 1974b; Christensen and Greene, 1976; Clark and Youngblood, 1992; Kant and Nautiyal, 1997; Sun et al., 2009).

Estimation involves each input i cost share equation, which can be derived by applying Shepard's Lemma to equation (3).[14] Christensen and Greene (1976) explained these equations add additional degrees of freedom to the estimation and do not constrain the coefficients, because it constitutes a multivariate system of equations of i+1 equations where across-equation parameter restrictions create more rapid growth in system degrees of freedom than in parameters as equations that are added to the system. The derived cost share equations take the following form, where S_{it} is the cost share in period t for input i and ε_{it} is the error in measurement of cost share i in period t:

$$S_{it} = \frac{\partial \ln C_t}{\partial \ln w_{it}} = \alpha_i + \beta_{ii} \ln w_{it} + \sum_{ij} \beta_{ij} \ln w_{jt} + \beta_{iQ} \ln Q_t + \beta_{it} T + \varepsilon_{it} \quad (4)$$

The measurement of Colombia's agricultural productivity proceeds by estimating this system of equations as a seemingly unrelated regressions (SUR) because a common approximation error is passed to each cost share equation though their residuals (Christensen and Greene, 1976) and the specification of a second order polynomial when the true cost function may be of even higher order. The estimation of the system involves n-1 of the cost share equations due to the adding up restriction of cost shares and associated singularity of the system error variance-covariance matrix.[15] Estimated parameters are invariant to which equation is omitted so long as the estimation involves maximum likelihood and the parameters of the omitted equation can be retrieved via the homogeneity and adding up restrictions imposed on the model for regularity purposes. Iterative Feasible Generalized

14 Shepard's Lemma establishes that input demand x_i can be derived as $\frac{\partial c}{\partial w_i} = x_i$. Thereby, the cost share functions are derived for the assumed trans-log cost function by differentiating the cost function of natural logarithms by the natural logarithm of input prices (i.e. $\frac{\partial \ln c}{\partial \ln w_i} = \frac{\partial c/c}{\partial w_i/w_i} = \frac{\partial c}{\partial w_i}\frac{w_i}{c} = x_i \frac{w_i}{c} = S_i$).

15 Prices and quantities were normalized to 1 in 1995, the mid-point year of the sample, following Capalbo (1988).

Non-Linear Least Squares (IFGNLS) was used to estimate this system of equations because this estimator is equivalent to a Maximum Likelihood estimator (Greene, 2012).

The following restrictions were imposed to ensure that the corresponding production function is well behaved (Capalbo, 1988; Kant and Nautiyal, 1997): i) coefficients are the same in the cost function and cost share equations; ii) certain coefficients are symmetric among equations; iii) $\sum_i a_i = 1$; $\sum_i \beta_{iQ} = 0$; and iv) $\sum_i \beta_{ij} = \sum_j \beta_{ji} = \sum_i \sum_j \beta_{ij} = \sum_i \beta_{it} = 0$ to ensure that this cost function is homogeneous of degree 1 in input prices. Also, curvature restrictions were imposed at the point of the approximation of this cost function (Diewert and Wales, 1987; Ryan and Wales, 2000) and price elasticities for all inputs were computed from estimated parameters using the following expression:

$$\epsilon_{WX} = S_{it} - 1 + \frac{\beta_{ii}}{S_{it}} \tag{5}$$

where this expression is equivalent to calculating these elasticities using the Allen partial elasticities of substitution (AES) (Binswanger, 1974a). The dual rate of technical change $-\dot{B}_t$ was computed as follows:

$$-\dot{B}_t = -\frac{\partial lnC_t}{\partial T} = -(a_t + a_{tt}T + \sum_i \beta_{it} lnw_{it} + \beta_{Qt} lnQ_t) \tag{6}$$

where the basic assumption is that costs decrease due to technology improvements. a_t is the constant rate of technical change, $a_{tt}T$ captures variations in the rate of technical change over time, $\sum_i \beta_{it} \ln w_{it}$ is the input bias and $\beta_{Qt}\ln Q_t$ is the scale bias. Therefore, pure technical change is equal to $-(a_t + a_{tt}T)$, which corresponds to the rate of reduction in overall costs due to a technical innovation, holding constant the scale effect. Also, scale augmenting technical change is measured by $-\beta_{Qt}\ln Q_t$, which is the rate of reduction in costs due to a technical innovation exhibited along with changes in output. Similarly, biased technical change (IBTC) was computed using the following expression when the production function behind a translog cost function is non-homothetic (Antle and Capalbo, 1988):

$$IBTC = \frac{\partial lnS_i}{\partial T} - \left(\frac{\partial LnS_i}{\partial LnQ}\right)\left(\frac{\partial LnC}{\partial LnQ}\right)^{-1}\left(\frac{LnC}{\partial T}\right) \tag{7}$$

where $\frac{\partial lnS_i}{\partial T}$ captures the potential biased technical change exhibited by the input i and $\left(\frac{\partial LnS_i}{\partial LnQ}\right)\left(\frac{\partial LnC}{\partial LnQ}\right)^{-1}\left(\frac{LnC}{\partial T}\right)$ denotes the scale effect of technical change. These results can be used to test the presence of biased technical change, which can be described in terms of input-saving or using, which indicates the rate of change in cost shares due to technical change, $\frac{\partial lnS_i}{\partial T} = \frac{\beta_{ii}}{S_{it}}$ and is a relative concept. That is, input saving means that the ratio of the input relative to others is declining rather than the absolute quantity of use of the input declining, although it is possible for both to occur simultaneously.

Finally, agricultural productivity growth ($T\dot{F}P$) in this model is measured using equation (8):

$$T\dot{F}P_t = -\widehat{\dot{B}}_t + (1 - \widehat{\epsilon_{CQ,t}})\,\dot{Q}_t \tag{8}$$

where $-\widehat{\dot{B}}_t$ is the shift estimated for the cost function due to technical change and $\widehat{\epsilon_{CQ,t}}$ is equal to $\frac{\partial LnC}{\partial LnQ} = a_Q + \sum_i \beta_{iQ} lnw_{it} + a_{QQ} lnQ_t + \beta_{Qt} T$ (Capalbo, 1988). This approach was also used to individually estimate crop and livestock productivity.

4.4 Structural Change Periods

Historical evidence suggests that Colombia's agriculture faced substantial and distinct structural changes over time (see Table 1). Accordingly, six periods of changing economic conditions and policy regimes were analyzed in an effort to determine whether or not Colombia's agricultural productivity and technical change were affected. These periods were identified by conducting a historical analysis of Colombia's agriculture from 1975-2013. Each period was defined based on: i) macroeconomic issues; ii) political changes; iii) economic policy changes (e.g. trade policy); and iv) socioeconomic issues, such as violence.[16] These impacts on agricultural productivity were estimated by including six period specific time trend variables in the Cobb-Douglas regressions. Also, a comparison of the predicted output with and without technical progress was made for the CES and Translog Cost functions.

Table 1. Main Events Determining Colombia's Agriculture from 1975-2013 [17]

Period	Main Event
1975-1983	Coffee boom
1984-1989	Macroeconomic crisis
1990-1997	Agricultural profitability crisis
1998-2002	Armed conflict intensification
2003-2009	Agricultural commodities price boom
2010-2013	Agricultural profitability crisis

5. Data

The underlying data used in this study primarily come from FAOSTAT, the World Bank and the USDA (FAO, 2015; USDA, 2015; World Bank, 2016). In order to expand the data available for Colombia, recent data from the National Department of Statistics of Colombia (DANE), the Central Bank of Colombia (BANREP) and the International Fertilizer Industry Association (IFA) were used (BANREP, 2015; DANE, 2015; IFA, 2016). A historical database for Colombia's' agriculture from 1975-2013 was built based on these data sources. This database includes the value of Colombia's agricultural output (aggregated and disaggregated by crops and livestock) and quantities as well as the prices of inputs (labor, capital, fertilizer and animal feed). An estimation of some of these data series was necessary to focus the analysis on these four inputs, given the problems of data availability for all available sources and the time period analyzed in this paper. The construction of each variable is explained in detail below.

5.1 Output

The value of agricultural production corresponds to the total gross production value released annually by FAOSTAT (FAO, 2015).[18] In the case of Colombia, this figure encompasses the value of production for 85 crops and livestock commodities.[19] These data were used as they were released annually (per calendar year) and in 2005 international dollars. FAOSTAT releases these data in this currency unit

16 Because our observation interval is annual, it is straightforward to identify the breakpoints using economic, policy, and social indicators. In addition, with relatively few observations it would be impossible to effectively identify so many regime changes econometrically. Doing so would rely on Chow Tests that have low power tests when the structural changes are not near the center of the data period. More sophisticated econometric techniques (e.g., Smooth Transition AutoRegressive (STAR) models) would be even more difficult to identify econometrically given our data. Accordingly, our approach yields a set of results that appear to be quite robust regardless of alternative econometric specification. Likewise, we believe that the results from the time periods as we have identified them provide compelling and useful information for the agricultural sector and policy makers in Colombia.

17 Complete table including detailed historical events per period is available in Appendix -A.

18 The FAO dataset was used for output, because there is no comparable data available from a Colombia institution for the entire period analyzed in this study.

19 FAO data do not include the gross production value of coca (to make cocaine), which distorts Colombia's economy and may have provided another problem for Colombia's agricultural productivity. Farmers may have substituted regular crops with illicit ones. Note that coca production may have used inputs attributed here as agricultural, while its production value is not included in agricultural performance.

in order to facilitate comparisons across countries. The aim is to avoid the need to use exchange rates by assigning a single global price to each commodity.

For crops, the data correspond to the crop category as reported by FAOSTAT. This includes data for 74 crops produced in Colombia, sold in the market, and consumed by consumers. These figures were multiplied by producer prices and converted to 2005 international dollars (FAO, 2015). For livestock, the data source is FAOSTAT as well and corresponds to its livestock category, including the production of eleven animal products (cattle meat, poultry meat, pork meat, milk, etc.) multiplied by producer prices.

5.2 Inputs

5.2.1 Capital Stock

The capital stock data corresponds to Colombia's gross capital stock used in agriculture and released annually by FAOSTAT (FAO, 2015). This is calculated as the sum of valued individual physical assets held by Colombian farmers (FAO, 2015). This dataset includes separate data for land development (i.e. arable land, crop land, and irrigated land), plantation crop land, livestock (i.e. fixed assets and inventory), machinery and livestock structures.

Crop capital stock compiles the value of gross capital in plantation crops and land development (FAO, 2015).[20] Livestock capital stock encompasses the value of livestock fixed assets, livestock inventory and livestock structures. FAO also releases figures for capital stock in machinery and equipment (FAO, 2015). However, these figures include assets that can be owned by either activity, such as tractors. Accordingly, this stock was divided for crops and livestock using their respective overall shares in the total value of agricultural production.

Capital stock data in FAOSTAT is only available from 1961-2007. Consequently, this data series was updated for more recent years based on the gross investment flows to Colombia's agriculture from DANE (2015).[21] The data was used as it is released annually (per calendar year) and in 2005 dollars.

The cost (input price) of capital was also estimated by relying on the definition of cost benefit analysis. This considers the cost of capital as the opportunity cost of investing in a particular asset (Campbell and Brown, 2003). Therefore, its measurement corresponds to the sum of the real interest rate plus the depreciation rate of agricultural assets. The real interest rate is calculated as the difference between the nominal interest rate and current inflation rate. This nominal interest rate corresponds to a traditional passive interest rate in Colombia, also known as DTF (i.e. the Fixed Term Deposit Rate in Colombia) because there is not an official interest rate for agricultural credit in Colombia and loans for agriculture are often indexed to this interest rate. In addition, agricultural credits are often subject to a subsidy according to the type of farmer (i.e. small, medium or large), which (for this paper and other research) corresponds to a deduction of 5 percentage points from this interest rate (Illera, 2009;

20 Plantation crops are trees yielding consistent products, such as fruits or nuts (FAO, 2015).

21 For this update, two approaches were explored. One involved the calculation of the annual investment flow from FAO data, as the difference between capital stock in period t+1 and capital stock in period t, followed by a regression on the DANE investment series. However, this estimation yielded a very weak fit. Consequently, an alternative approach was utilized, which consisted of taking the DANE investment series in the same monetary units as the FAO's and calculating its annual growth. Then, to predict the FAO's investment flows for missing years, we used the rates of growth from the DANE investment. Finally, to estimate the missing capital figures, we used the formula $K_{t+1} = K_t + I_{t+1}$, where Kt corresponds to the capital stock from FAO and I_{t+1} to the investment flows.

Jaramillo and Jiménez, 2008).[22] Finally, the depreciation rate for agriculture was taken from Pombo (1999), who calculated the average depreciation rates exhibited by capital for all economic activity in Colombia. The current inflation rate was taken from the World Bank (2016).

5.2.2 Labor and Wages

The farm labor data used in this paper corresponds to the total number of people who were economically active in Colombia's agriculture, as released by the USDA from 1961-2012 (USDA, 2015). An update was conducted for the last decade (2001-2013) using available data from national sources (DANE, 2015). Annual data were used as they were released (per calendar year).

Crops and livestock data were estimated based on Barrientos and Castrillón (2007), whose study analyzes the employment generation path of Colombia's agriculture and shows disaggregated labor data for Colombia from 1993-2005. These data were used as a starting point to estimate the missing labor data for the sample period. It was necessary to estimate labor data for crops and livestock from 1975-1992 and 2006-2013. For this purpose, the average trend of the labor data over time within the sample was used in each case, for which crops exhibited an R^2 of 0.98 and livestock an R^2 of 0.72.[23] These estimates were then adjusted using the aggregate labor data collected from the USDA (USDA, 2015). This involved the estimation of weights for crop and livestock labor in the total predicted data, followed by the multiplication of these weights by the USDA's aggregate agricultural labor data. The process ensured that these predicted labor data for crops and livestock were consistent with the USDA data.

Farm labor wages were implicitly derived from annual national accounts (DANE, 2015). That data revealed the total payroll of each Colombian sector to generate sectoral GDP. Thus, the value paid to labor by agriculture was taken in current pesos, and an estimated average wage paid per employee was calculated by dividing this figure by total farm labor. The amount was then converted into 2005 dollars by: i) dividing this value by the annual average Colombian exchange rate of peso to US American dollars (BANREP, 2015); and ii) dividing the result by the GDP deflator for US prices with the base year of 2005 (FAO, 2015).[24]

5.2.3 Fertilizer

Fertilizer quantities correspond to the total amount of major nutrients ($N+P_2O_5+K_2O$) demanded and applied by farmers in Colombia, released yearly by the IFA (2016). These data include all compound products derived from nitrogen (N), phosphate (P) and potash (K), such as Urea, Ammonium Sulphate, Ammonium Nitrate, Ammonium Phosphate and Potassium Sulphate, among others. Annual data were used as released per calendar year and in metric tons.

Fertilizer prices in Colombia were estimated based on FAOSTAT, DANE and BANREP data (BANREP, 2015; FAO, 2015; DANE, 2015). There is no available historical database that compiles these prices for

22 This corresponds to a weighted average of percentage points commonly deducted for small farmers credits (-8pp) and medium and large farmers' credits (-4pp), taking into account that credits for small farmers historically represent 25% of agricultural credits, while credits for medium and large farmers account for the remaining 75%. Colombian banks have usually deducted these percentage points from farm credits by farmer type (Illera, 2009; Jaramillo and Jiménez, 2008).

23 The high R^2 ensures that these estimates of labor for crops and livestock are good predictions of the actual data, given the lack of available data for Colombia over the entire period covered in this study.

24 This procedure implies imposing exactly the same volatility of aggregated agricultural labor on crops and livestock labor. However, this is a minor cost compared to the gains of estimating labor data for crops and livestock in Colombia via series that are coherent with the actual data, given the current lack of disaggregated data for Colombia.

Colombia for the entire period covered by this study (1975-2013). The available data is only for more recent years (AGRONET, 2014). An estimation of earlier fertilizer prices was completed using the urea price paid in Colombia by farmers as a leader-indicator or benchmark price.[25] This price was reported annually (per calendar year) by FAOSTAT in current Colombian pesos per metric ton for the period 1961-2002. However, the data exhibits some missing values for the 1990s, which this paper approximated using the annual change in the Producer Price Index (PPI), released by BANREP since the early 1990s and by DANE in recent years (BANREP, 2015; DANE, 2015).

5.2.4 Animal Feed

Animal feed quantities used in this paper come from FAOSTAT (FAO, 2015) and correspond to the total crop and animal products used for feeding animals following the USDA (2015). FAOSTAT reports these quantities in its Commodities Balance Sheet. These annual data were used as they were released per calendar year and in metric tons.

The animal feed price was derived from FAOSTAT (FAO, 2015). Basically, this price was implicitly estimated as a weighted average. The producer prices of crop and animal products used for feeding animals reported by FAOSTAT were taken, and the value of each feed was calculated using their quantities. Then, the total annual value was calculated for these products. Finally, this total value was divided by the total product quantity to calculate an average price per metric ton of animal feed for each year. Because this figure was in current Colombian pesos, it was then converted to 2005 dollars.

25 Urea represents about one third of all fertilizer used by Colombian farmers (IFA, 2016).

6. Results

Using the three techniques discussed in Section 4, we obtained the necessary parameters to measure Colombia's agricultural productivity growth from 1975-2013. Table 2 presents the results using a Cobb-Douglas production function. Table 3 presents the results of the CES function.[26] [27] Tables 4 and 5 present results from the Translog Cost function approach and the own price elasticities for all inputs to evaluate the estimated cost function.[28] [29] Overall, the Cobb-Douglas results clearly show statistically significant evidence that Colombia's technical change exhibited different trends during each period defined *a priori* (see Table 2). This varied between 0.5-0.9% per year across periods. These structural changes were not incorporated when estimating the CES production function and Translog Cost approach due to insufficient degrees of freedom. Thus, the results represent an average over the different regimes. However, a comparison of the agricultural productivity growth trajectories predicted by these approaches using a Cobb-Douglas production indicates that all follow almost the same pattern (see Figure 1). Moreover, the CES results show the presence of biased technical change in Colombia's agriculture, and the Translog Cost approach results highlight an important contribution of scale effects into Colombian agricultural productivity.[30]

In the next section, all estimates found using each technique are analyzed with emphasis on three modes of inquiry: i) What was Colombia's agricultural productivity growth—aggregated and also disaggregated for crops and livestock—during this entire period? ii) Did Colombia's agricultural productivity vary during sub-periods when particular economic conditions or policy regime changes were identified?; and iii) Did Colombia's agriculture exhibit biased technical change during the period 1975-2013?

26 For crops and livestock, these results report when capital-related inputs are included in the unique nest and labor outside of this nest. This specification exhibited the best fit in both cases.

27 All CES models present serial autocorrelation across the residuals. We tried to fix this problem by including each dependent variable lagged one period as another regressor in their respective equations, as in the Cobb-Douglas case, but this procedure was ineffective. Then, we attempted to solve this problem by estimating a specification for which technical change might have varied over time. This had been effective to sweep out serial autocorrelation in the Cobb-Douglas case. However, this procedure was also ineffective. Then, we employed the Cochrane-Orcutt procedure, which fixed the problem for livestock, but severely impacted the model's estimation results for the aggregate and crop results. STATA software failed to estimate all elasticities of substitution, probably due to collinearity across variables. Therefore, we report the model without fixing this serial autocorrelation, since the technical change coefficient, which is the most important result from this model, is robust, changing only marginally when the serial autocorrelation is corrected.

28 The Translog Cost models initially predicted positive own price elasticities for certain inputs. This was corrected by imposing curvature restrictions at the point of approximation of this cost function (Diewert & Wales, 1987; Ryan & Wales, 2000).

29 At the request of the editor, we examined stability of the model residuals (see Appendix - B). After adjusting for structural change, the residuals of various models were generally stable using the Augmented Dickey-Fuller (ADF) test as a guide. That is, the unit root null hypothesis was generally rejected. This highlights the well-known ambiguity between nonstationarity and structural change (see Perron, 1989) when using such low power tests on small data sets with an annual observation frequency. CES livestock models were those where the null hypothesis could not be rejected even after accounting for structural change. If one believes that nonstationarity can be identified with this data set then those models where the null hypothesis is rejected would be superconsistent in the Engle and Granger (1987) sense meaning that the distributions of parameter estimates converge more rapidly than they would if nonstationarity were not present (see Hamilton, 1994 for proofs). Logic and the consistency of our results across the specifications suggest that the CES livestock result is spurious and related to the low power of the ADF test and our relatively small (in a time series context) sample. Thus, we do not endeavor to beat the data with unnecessary advanced econometric techniques that rely on nonstandard distributional assumptions.

30 In the cases of system estimation (CES and Translog Cost models), the reported R-squared values are squared correlations between the actual and predicted values because the individual equation R-squared values computed in the normal way are not bounded by 0 and 1; therefore, the values lack useful interpretation.

Table 2. Cobb-Douglas Production Function Estimates for Colombia's Agriculture from 1975-2013

Variables	Aggregate		Crops		Livestock	
	(1)	(2)	(3)	(4)	(5)	(6)
β	0.070	-0,081	0.436***	0,092	0.192*	-0,031
	(0.109)	(0.144)	(0.141)	(0.176)	(0.106)	(0.117)
a	0.215*	0.752***	0.473***	0.722***	0.637***	0.927***
	(0.117)	(0.193)	(0.144)	(0.160)	(0.163)	(0.168)
γ	0.302***	0.199***	0,092	0.186***		
	(0.047)	(0.040)	(0.089)	(0.044)		
θ	0.413***	0.130			0,171	0,104
	(0.052)	(0.083)			(0.113)	(0.153)
g	-0.002		-0.008*		0.011*	
	(0.002)		(0.004)		(0.006)	
g1975-1983		0.007*		0,001		0.012**
		(0.004)		(0.007)		(0.006)
g1984-1989		0.005*		-0,006		0.017***
		(0.002)		(0.005)		(0.004)
g1990-1997		0.007***		-0,003		0.020***
		(0.002)		(0.003)		(0.006)
g1998-2002		0.007***		-0,001		0.020***
		(0.002)		(0.003)		(0.005)
g2003-2009		0.009***		0,004		0.020***
		(0.003)		(0.003)		(0.006)
g2010-2013		0.005**		0.000		0.016**
		(0.002)		(0.003)		(0.006)
Constant	6.316***	0,484	-6,759	1,819	-9.726*	-2,639
	(1.243)	(2.006)	(5.819)	(1.474)	(5.502)	(1.747)
Observations	39	39	38	39	38	39
Root-MSE	0,034	0,025	0,066	0,039	0,052	0,036
R-squared	0,984	0,992	0,897	0,969	0,977	0,991

Robust standard errors in parentheses
* $p<0.10$, ** $p<0.05$, *** $p<0.01$
Models assuming constant technical change are: (1), (3) and (5)
Models assuming technical change by structural change period (see Table 1) are: (2), (4) and (6)
β is the coefficient of lnLt (Labor)
a is the coefficient of lnKt (Capital)
γ is the coefficient of lnFt (Fertilizer)
θ is the coefficient of lnSt (Animal Feed)
g is the rate of technical change

Table 3. CES Production Function Estimates for Colombia's Agriculture from 1975-2013

Variables	Aggregate		Crops		Livestock	
	(1)	(2)	(3)	(4)	(5)	(6)
σ	1.259***	0.942***	1.718***	0.792***	3.906***	2.253***
	(0.080)	(0.077)	(0.319)	(0.064)	(0.729)	(0.344)
η	2,834	0.882***	1.126***	0.847***	3.860***	2.128***
	(2.661)	(0.241)	(0.101)	(0.059)	(0.820)	(0.327)
ψ	1.916***	0.969***				
	(0.609)	(0.093)				
γ	0.013***		0.008***		0.022***	
	(0.001)		(0.003)		(0.001)	
γ_K		0.041*		0.039***		0.018***
		(0.025)		(0.015)		(0.002)
γ_L		-0,026		-0.042***		0.033***
		(0.143)		(0.010)		(0.010)
γ_F		0.170		0,068		
		(1.147)		(0.050)		
γ_S		-0,252				0.059***
		(0.241)				(0.013)
Observations	38	38	38	38	36	36
R^2 eq. Q	0,954	0,963	0,923	0,875	0,976	0,979
R^2 eq. K	0,978	0,976	0,598	0,787	0,972	0,971
R^2 eq. L	0,022	0,027	0,008	0,011	0,625	0,558
R^2 eq. F	0,091	0,169	0,045	0,324		
R^2 eq. S	0,061	0,018			0,186	0,043

Robust standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01
Models assuming Hicks-Neutral technical change are: (1), (3) and (5)
Models assuming bias technical change are: (2), (4) and (6)
σ is the overall elasticity of substitution between nests
η and ψ are the elasticities of substitution of inputs within each nest
γ is the overall rate of technical change
γ_i is the rate of technical change exhibited by a particular input

Table 4. Trans-Log Cost Function Estimates for Colombia's Agriculture from 1975-2013

Aggregate				Crops				Livestock			
α_0	23.880***	β_{KQ}	-0,049	α_0	22.360***	β_{KQ}	0.030	α_0	23.640***	β_{KQ}	-0,111
	(0.011)		(0.063)		(0.020)		(0.038)		(0.014)		(0.086)
α_K	0.798***	β_{LQ}	-0,029	α_K	0.573***	β_{LQ}	0,033	α_K	0.854***	β_{LQ}	0,067
	(0.007)		(0.032)		(0.006)		(0.066)		(0.010)		(0.055)
α_L	0.128***	β_{FQ}	0,012	α_L	0.376***	β_{FQ}	-0,063	α_L	0.069***	β_{FQ}	
	(0.003)		(0.014)		(0.008)		(0.059)		(0.005)		
α_F	0.016***	β_{SQ}	0.066*	α_F	0.051***	β_{SQ}		α_F		β_{SQ}	0,045
	(0.001)		(0.034)		(0.006)						(0.038)
α_S	0.059***	α_Q	-0.210	α_S		α_Q	-0,044	α_S	0.078***	α_Q	0,118
	(0.004)		(0.184)				(0.225)		(0.005)		(0.148)
β_{KK}	0.161***	α_{QQ}	-1,962	β_{KK}	0.236***	α_{QQ}	0,355	β_{KK}	0.127***	α_{QQ}	0,973
	(0.007)		(2.385)		(0.004)		4.320		(0.010)		(1.939)
β_{KL}	-0.102***	α_t	0.011***	β_{KL}	-0.169***	α_t	0.015***	β_{KL}	-0.059***	α_t	0,002
	(0.003)		(0.004)		(0.008)		(0.004)		(0.005)		(0.004)
β_{KF}	-0.012***	α_{tt}	0.000	β_{KF}	-0.066***	α_{tt}	0.000	β_{KF}		α_{tt}	0,002
	(0.001)		(0.001)		(0.006)		(0.001)				(0.002)
β_{KS}	-0.047***	β_{Kt}	0.000	β_{KS}		β_{Kt}	-0.005***	β_{KS}	-0.066***	β_{Kt}	0.004*
	(0.003)		(0.001)				(0.001)		(0.001)		(0.002)
β_{LL}	0.112***	β_{Lt}	-0.000	β_{LL}	0.174***	β_{Lt}	0.004***	β_{LL}	0.064***	β_{Lt}	-0.005***
	(0.003)		(0.000)		(0.013)		(0.001)		(0.005)		(0.001)
β_{LF}	-0.002***	β_{Ft}	-0.000	β_{LF}	-0,004	β_{Ft}	0,001	β_{LF}		β_{Ft}	
	(0.000)		(0.000)		(0.008)		(0.001)				
β_{LS}	-0.008***	β_{St}	0.000	β_{LS}		β_{St}		β_{LS}	-0.005***	β_{St}	0,001
	(0.001)		(0.000)						(0.001)		(0.001)
β_{FF}	0.015***	β_{Qt}	0,024	β_{FF}	0.071***	β_{Qt}	-0,022	β_{FF}		β_{Qt}	-0,033
	(0.001)		(0.054)		(0.008)		(0.070)				(0.058)
β_{FS}	-0.001***			β_{FS}				β_{FS}			
	(0.000)										
β_{SS}	0.055***			β_{SS}				β_{SS}	0.072***		
	(0.004)								(0.005)		
Observations			38	Observations			38	Observations			38
R^2 eq. TC			0,997	R^2 eq. TC			0,992	R^2 eq. TC			0,997
R^2 eq. Cost Share - K			0,951	R^2 eq. Cost Share - K			0,994	R^2 eq. Cost Share - K			0,869
R^2 eq. Cost Share - L			0,966	R^2 eq. Cost Share - L			0,987	R^2 eq. Cost Share - L			0,825
R^2 eq. Cost Share - F			0,793	R^2 eq. Cost Share - F			0,925	R^2 eq. Cost Share - F			
R^2 eq. Cost Share - S			0.920	R^2 eq. Cost Share - S				R^2 eq. Cost Share - S			0,923

Robust standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01
α_i are the cost shares at the point of approximation of the cost function
β_{ij} are the elasticities of cost shares with respect to input prices
β_{iQ} are the elasticities of cost shares with respect to output
α_t, α_{tt} and β_{it} are the elasticities of cost function and cost shares relatively with respect to technical change

Table 5. Price Elasticities of Input Demands of the Trans-Log Cost

	Aggregate		Crops		Livestock	
	(1)	(2)	(3)	(4)	(5)	(6)
ε_{KK}	0,012	-0.041***	-0.029***	-0,021	0.033***	-0.026**
	(0.010)	(0.010)	(0.008)	(0.027)	(0.014)	(0.012)
ε_{LL}	-0.144***	-0.143***	-0.166***	-0.082**	-0.090	-0,064
	(0.051)	(0.019)	(0.031)	(0.044)	(0.117)	(0.073)
ε_{FF}	-0.351***	-0.884***	-0,107	-0.727***		
	(0.068)	(0.062)	(0.095)	(0.123)		
ε_{SS}	-0.246***	-0.214***			-0.270***	-0.204***
	(0.101)	(0.050)			(0.070)	(0.047)

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01
Without imposing curvature restriction: (1), (3) and (5)
Imposing curvature restriction: (2), (4) and (5)

6.1 Colombia's Agricultural productivity

These results show that Colombia's agricultural productivity grew on average 0.6-1.4% from 1975 to 2013 (see Table 6). In particular, the CES and Translog Cost techniques predict that it grew on average around 1.3-1.4% per year, respectively, which is similar to the USDA's prediction (1.4%). The Cobb-Douglas technique predicts that Colombia's agricultural productivity only grew by 0.6% per year.

These predictions of Colombia's agricultural productivity were estimated using aggregate data. Although all looked very similar, some key differences were identified. Accordingly, we estimated Colombia's agricultural productivity using disaggregated data for crop and livestock productivity. This approach renders more consistent predictions for Colombia's agricultural productivity and removes any difference across techniques generated by the use of aggregate data. Hence, we estimated Colombia's agricultural productivity as a weighted average of the estimates of crop and livestock productivity, using the shares of crop and livestock production values as weights in total agricultural production value.

This exercise shows that the initial estimates for Colombia's agricultural productivity using aggregate data maybe slightly overestimated or underestimated. Using Cobb-Douglas techniques, the initial prediction was that productivity has grown by 0.6%; however, it grew by 0.8% per year when computed as the weighted sum of crop and livestock productivity. Likewise, using Translog Cost model, the prediction was that the productivity average growth was around 1.4% per year, but it grew by 0.9% per year when estimated as the weighted sum of crop and livestock estimates. Only the CES technique provided similar estimates regardless of approach. This exercise reaffirmed our initial estimates using aggregate data, showing that Colombia's agricultural productivity exhibited very low growth from 1975-2013. Also, it suggests that productivity grew in a narrower range, between 0.8% and 1.3%, once a more nuanced crop and livestock productivity performance was considered. These weighted average estimates for Colombia's agricultural productivity are used in the rest of our analysis.

Table 6. Average Agricultural Productivity Growth in Colombia from 1975-2013

	Cobb-Douglas	CES	Translog Cost
Aggregate	0.6%	1.3%	1.4%
Weighted Average	0.8%	1.3%	0.9%
Crops	0.0%	0.8%	0.1%
Livestock	1.6%	2.2%	2.0%

These estimates show that livestock productivity was the driver of Colombia's agricultural productivity from 1975 to 2013. All techniques predict that livestock productivity grew at an average rate between 1.6% and 2.2%, probably due to: i) more efficient production practices in the pork and poultry sectors; ii) higher investments in new herds and technology (mainly dual-purpose cattle) in the late 1990s; and iii) innovations for the feeding and management of livestock, genetic improvements and the purchase of highly productive species in the milk sector (Kalmanovitz and López, 2003; MADR, 2005; Mojica and Paredes, 2005). It is not inconsequential that the poultry and pork sectors of Colombia were dominated by completely vertically-integrated, large-scale producers. These entities have brought modern production systems, improved feeding strategies and advanced the breeding and veterinarian expertise of the animal sector.

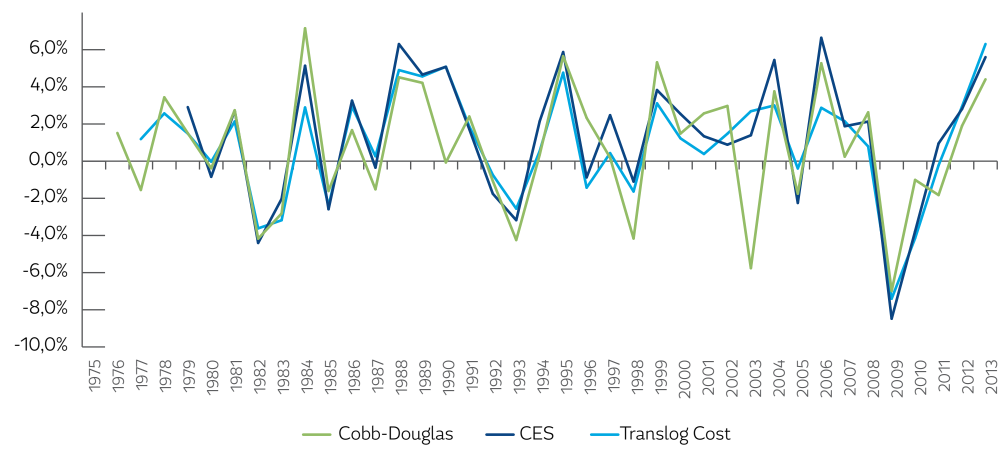
Colombia's crop sectors, with the exception of sugar cane and rice, were dominated by small-scale production, a lack of access to improved technology and potential market power by multinational buyers. The latter is especially true for Colombia's most famous crop, coffee, for which the benefits of advances in world demand have mostly accrued for multinational processors and retailers, and thus have not led to productivity gains in agricultural production. Also, investments made to replace rust-susceptible coffee trees with rust-resistant trees have required agricultural inputs such as labor and nursery stock, which will not yield significant or immediate productivity gains. These latter investments began to generate productivity enhancements in 2016-2017 (USDA, 2017).

Predictably, the estimates of crop productivity are unclear for this period. Assuming a Cobb-Douglas production function and using the Translog Cost approach, the prediction is that Colombia's crop productivity's average growth was zero. However, when assuming a CES production function, crop productivity grew on average by 0.8% per year, which is still low.

Historical evidence suggests that crop productivity would have been low during the period 1975-2013. Colombian farmers experienced difficult conditions during this period due to: i) agricultural budget cuts during the 1980s Latin American debt crisis; ii) profitability crisis after Colombia executed the second wave of Structural Adjustment reforms in the early 1990s; iii) extreme weather conditions (i.e. severe droughts and severe floods); iv) misallocation of resources for agricultural promotion; v) decreased investment due to armed conflict; vi) lack of public resources for promoting Colombia's agricultural competitiveness and vii) segmented and restricted funding of Colombian farmers (Cuevas et al., 2003; Jaramillo, 1998; Junguito, 1994; Junguito et al., 2014; Kalmanovitz and López, 2003; Reina et al., 2011). Also, this evidence suggests that only a few crops exhibited higher levels of productivity during this period (e.g., sugar cane, flower, banana, cereals and vegetables) (Arbeláez, 1993; Becerra, 2009; COMPITE, 2008; Jaramillo, 1998; Montero and Casas, 2012; Ramirez and Garcia, 2006).

In order to reaffirm these findings, we tested the consistency of these annual estimates of Colombia's agricultural productivity growth across techniques. First, we conducted a graphical analysis of Colombia's estimated agricultural productivity trends. This figure clearly shows that all techniques predict similar patterns of Colombia's agricultural productivity during the period 1975-2013 (see Figure 1). Furthermore, this analysis indicates that these estimates exhibit practically the same turning points; the only difference is the magnitude of certain periods of growth or depletion (see Figure 1).

Figure 1. Colombian Agricultural Productivity Growth Predicted by Technique.



Second, we calculated a correlation matrix using the annual predictions of Colombia's agricultural productivity for each technique from 1975-2013. Overall, this correlation varied between 70% to 95%. The highest correlation is between the agricultural productivity predicted by assuming a CES production function and the Translog Cost approach (+94%), whereas the lowest correlation is between the agricultural productivity predicted by assuming a Cobb-Douglas production function and the Translog Cost approach (73%) (see Table 7). These results reaffirm that there is a high consistency across all estimates and techniques used in this study. Also, all techniques broadly predicted similar results for Colombia's agricultural productivity over time.

Table 7. Correlation Matrix of Agricultural Productivity Estimates by Technique

	Cobb-Douglas	CES
CES	0.818	
Translog Cost	0.734	0.943

6.2 Components of Colombia's Agricultural Growth

Given the high consistency of these estimates for Colombia's agricultural productivity, our subsequent analysis focused on examining the possible drivers of Colombia's agricultural growth during the period 1979-2013: agricultural productivity growth or input accumulation growth. To this end, we considered the six periods previously defined, during which: i) Colombia's agriculture exhibited similar economic conditions and ii) agricultural policy regimes did not drastically change (see Table 1).

Using the predictions of Colombia's agricultural productivity by technique, we found that Colombia's agricultural production growth exceeded 2% per year whenever agricultural productivity growth increased (e.g. in the late 1980s and in recent years; see Figures 2, 3 and 4). These estimates suggest that Colombia's agriculture only grew by 1.8% per year from 1979 to 1983 due to an agricultural productivity growth close to 0%, largely explained by the negative impact of the Latin American Debt crisis on Colombian agriculture (Kalmanovitz & López, 2003). From 1984-1989, the agricultural output value increased its average growth to 3.5% per year, the effect of higher agricultural productivity, which grew around 2.2-2.7% per year due to the following favorable conditions: i) agricultural policy focused on promoting private investment, adjusting the price system, raising farmer's margins, limiting agricultural imports, etc.; ii) higher commodity prices; and iii) productivity innovations carried out by farmers to overcome the early 1980s crisis (Guterman, 2007; IMF, 2015; Kalmanovitz & López, 2003; Reina et al., 2011). During the period 1990-1997, Colombia's agriculture exhibited a slowdown and grew on average by 2.1% per year. Annual productivity grew on average only by 0.7-1.4%, seemingly due to the severe profitability crisis exhibited by Colombia's agriculture during this period. From 1998-2002, Colombia's agricultural output slightly reduced its growth to 1.9% per year because: i) agricultural productivity stagnated to 0.9-1.6% growth per year; and ii) farmers diminished their input accumulation, probably due to the macroeconomic crisis and worsening armed conflict during this period. Over 2003 to 2009, Colombia's agriculture continued stagnating, growing at the pace of the 1990s due to a slower agricultural productivity growth (-0.4-1%) caused by: i) lack of political agreement on how resources should be allocated to support agriculture; ii) poor transportation infrastructure; and iii) lack of innovation and technological development to improve agricultural productivity (Reina et al., 2011). Finally, we found that Colombia's agriculture raised its average growth to 2.4% per year from 2010-2013, due to an increased agricultural productivity growth of 0.9-1.4% per year. In other words, Colombia's agricultural growth has been less sensitive to input accumulation and more sensitive to productivity trends, policy regimes and economic circumstances.

Figure 2. Agricultural Growth Components – Assuming a Cobb-Douglas Production Function.

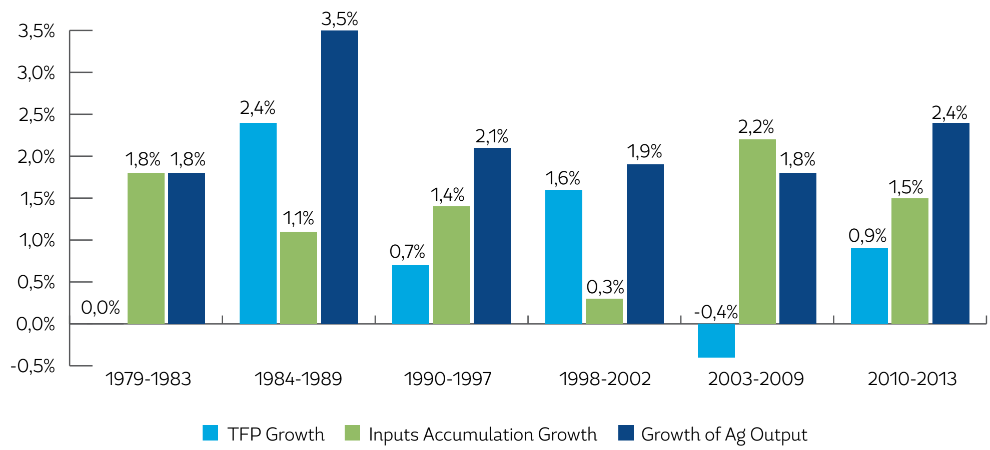


Figure 3. Agricultural Growth Components – Assuming a CES Production Function.

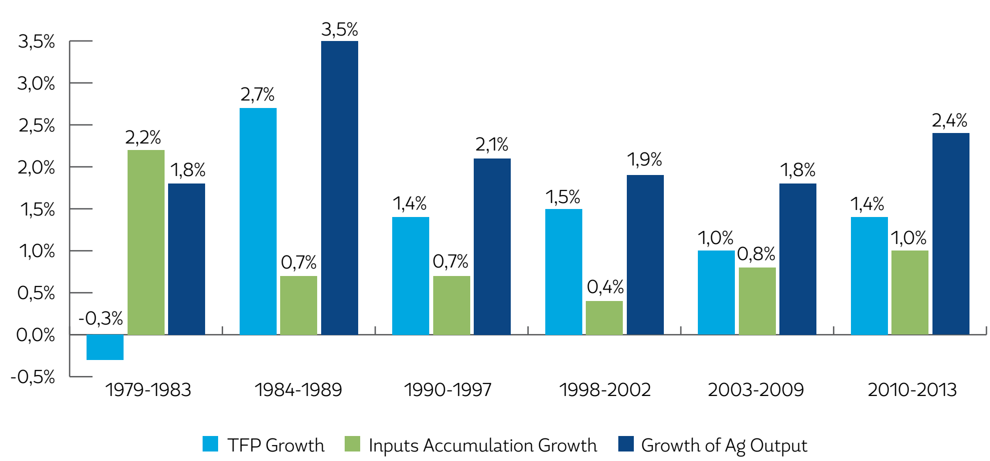
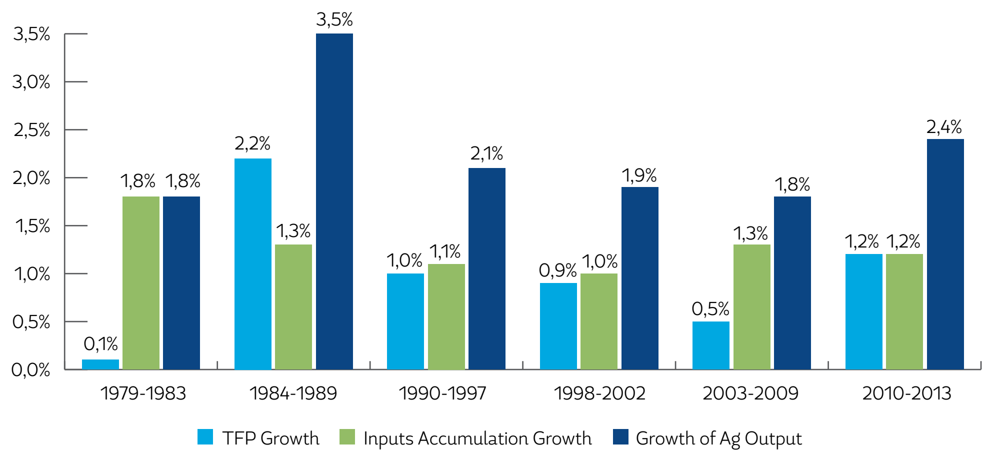


Figure 4. Agricultural Growth Components – Using Translog Cost Techniques.



6.3 Biased Technical Change

All estimates show that Colombia's agriculture exhibited biased technical change during the period 1975-2013 (see Table 10). The CES results show that technical change was capital augmenting using data for the entirety of Colombia's agriculture. The technical change exhibited by capital grew on average by 4.1% per year over this period, whereas the technical change exhibited by other inputs was not statistically significant (see Table 3). We also found that the technical change in crop production was capital augmenting. The difference across the technical change coefficients estimated for each input was tested because some were statistically significant. There is a statistically significant difference between the technical change exhibited by capital and labor as well as the technical change coefficients exhibited by fertilizer and labor (see Table 8). However, there is no statistical difference between the technical change coefficients found for capital and fertilizer. Likewise, we found that livestock production was animal feed augmenting. We also tested these differences across coefficients, and there is a statistically significant difference between the technical change exhibited by animal feed relative to the technical change exhibited by capital and labor (see Table 9). Also, we found that there is no statistically significant difference between the technical changes exhibited by capital and labor in livestock production.

Table 8. Test of Differences among Technical Change Estimates Exhibited by Inputs in Crop Production

	Capital	Labor	Fertilizers
Capital			
Labor	12.23***		
	(0.001)		
Fertilizers	0.29	4.05**	
	(0.590)	(0.044)	

P - values in parentheses
*This is a symmetric matrix.
*** p<0.01, ** p<0.05, * p<0.1

Table 9. Test of Differences among Technical Change Estimates Exhibited by Inputs in Livestock Production

	Capital	Labor	Animal Feed
Capital			
Labor	1.88		
	(0.171)		
Animal Feed	8.25***	4.52**	
	(0.004)	(0.034)	

P - values in parentheses
*This is a symmetric matrix.
*** p<0.01, ** p<0.05, * p<0.1

Translog Cost estimates reaffirm these results for crops, showing that crop production was capital saving. However, the cost model results suggest that livestock production was labor saving.[31] The statistical difference across these technical change indices was not tested, because multicollinearity is a latent problem when a Trans-Log cost function is assumed (Christensen and Greene, 1976). Thus, the standard errors for all parameters may be larger and this test would yield untrustworthy results. Consequently, this analysis only involved a comparison of the magnitudes across these indices.

In any case, the CES and Translog Cost results indicate that changes in the input efficiency of Colombia's agriculture varied across agricultural activities during 1975-2013. Also, technical change tended to improve the marginal productivity of capital in crop production, and marginal productivity of animal feed and labor in livestock production more so than the marginal productivity exhibited by other inputs.

Table 10. Biased Technical Change by Agricultural Activity in Colombia

	Crops	Livestock	Aggregate	Assumed Production Function Behind
CES	Capital Augmenting	Animal Feed Augmenting	Capital Augmenting	
Translog Cost	Capital Saving	Labor Saving	Labor Saving Fertilizer Saving	Homothetic
	Capital Saving	Labor Saving	Capital Saving Labor Saving	Non-Homothetic

31 This result is consistent with the general trend toward vertically coordinated non-ruminant and poultry production systems in Colombia. Not only was more capital invested, but it is likely that the capital was of higher quality. Likewise, highly vertically coordinated organizations likely employed more highly-skilled or trained workers (such as trained herdsmen and veterinarians) which would lead to labor savings per unit of output ceteris paribus.

7. Conclusions

This paper measured Colombia's agricultural productivity from 1975-2013. Using three different econometric specifications, it found evidence that it grew on average between 0.8% and 1.3% per year. All methods used in this study—Cobb-Douglas production function, CES production function and Translog Cost function—estimate that Colombia's agricultural productivity was mainly driven by livestock productivity, which grew on average between 1.6% and 2.2% per year. It is likely this growth was driven by improved technologies and the input quality enhancements of larger vertically-integrated poultry and non-ruminant producers. In contrast, crop productivity expansion is unclear over this period. By assuming a Cobb-Douglas production function and using the Translog Cost approach, it is predicted that crop productivity growth was zero; by assuming a CES production function, it is predicted that crop productivity grew on average by 0.8% per year.

This paper also finds evidence that agricultural productivity was a crucial factor of agricultural production value growth in Colombia in recent decades, especially during periods of sustained growth. Agricultural production growth accelerated to more than 2% per year when agricultural productivity growth increased (e.g. in the late 1980s and in recent years). Moreover, all results suggest that the pace of agricultural productivity was strongly dependent on policy regimes and economic circumstances. Recent peace initiatives should enable improved political and economic circumstances conducive to more rapid economic growth. That being said, better livelihoods for those returning to rural activities require supportive polices that foster long-term productivity rather than the short-term infusion of inputs. Thus, Colombia's agricultural policy must prioritize productivity, a crucial determinant of agricultural growth. Policies that focus on access to improved practices, credit, and efforts to enhance human capital development (i.e. education and healthcare) should be high on the government's list for rural development.

Finally, this study finds evidence that Colombia's agriculture exhibited biased technical change during the period 1975-2013. The results indicate that technical change tended to improve the marginal productivity of capital in crop production and the marginal productivity of animal feed and labor in livestock production relative to other input categories. Scale effects also mattered to productivity growth when the Translog cost function method that permits the identification of such effects was employed. While the more advanced techniques did not exhibit significantly different overall productivity estimates over time, they did enable the examination of these more nuanced aspects of productivity growth.

Future studies might conduct similar analyses on that sectoral level. Colombia is a country that produces a wide variety of agricultural products, and each agricultural sector uses different production structures and key input ratios. Hence, measuring and analyzing productivity on the sector level is key to understanding which microeconomic forces drive the results of this paper. Furthermore, future studies have the potential to improve Colombia's agricultural policy by identifying its most influential sectors. In order to conduct such studies with sufficient accuracy, data collection investments are necessary.

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Appendix - A: Main events about Colombia's Agriculture during 1975-2013

PERIOD	MAIN EVENTS
1975-1983	• Last term of Colombia's agriculture golden age (1950-1980) (Kalmanovitz & López, 2003). • Colombia's agriculture grew on average by 1.8% real per year (World Bank, 2016). • Public finances improved sharply, because government steadily taxed agricultural exports (mainly coffee), which represented 55% of the total, to get funding (J. Cardenas, 1993; GRECO, 2002; Kalmanovitz & López, 2003). • Colombia exhibited a coffee boom due to severe frosts in Brazilian coffee regions (Garay et al., 1998) • Coffee prices increased from an average of US$0.60/lb. in 1970-1974 to US$1.50/lb. in 1975-1983 (FEDECAFE, 2016). • The real exchange rate, Colombian Peso to US American Dollar, remained stable (BANREP, 2015; World Bank, 2016). • Agricultural policy focused on promoting more efficient land use to increase agricultural productivity (Kalmanovitz & López, 2003). • Agricultural policy attempted to improve agricultural productivity by: i) providing technical assistance to farmers; ii) improving education; and iii) promoting research (Kalmanovitz & López, 2003).
1983-1989	• Colombia's economy plunged into a crisis, due to the Latin America Debt crisis (Kalmanovitz & López, 2003). • Colombia's agriculture grew on average by 3.5% real per year (World Bank, 2016). • Colombian Peso depreciated in real terms relative to US dollar on average by 10% per year (BANREP, 2015; World Bank, 2016). • Colombia's Government cut initially its budget for agriculture to restore fiscal balance, due to the Debt crisis (Kalmanovitz & López, 2003). • Commodity prices fell by 30% in real terms, due to the Debt crisis (Dornbusch, 1989). • Agricultural policy focused on promoting private investment, adjusting the price system, raising farmer's margins, and limiting agricultural imports (Guterman, 2007). • Agricultural policy also promoted coordination among agricultural institutions to ensure the availability of seeds, inputs, loans, technical assistance and marketing (Kalmanovitz & López, 2003)

PERIOD	MAIN EVENTS
1990-1997	• Colombia's government accelerated the execution of the second wave of reforms associated with its Structural Adjustment (SA) program (Ocampo, 2000). • Colombia's agriculture fell into a profitability crisis, due to the accelerated and abrupt implementation of these SA reforms (C. F. Jaramillo, 1998; Junguito, 1994; Kalmanovitz & López, 2003; Ocampo, 2000). • Colombia's agriculture grew on average by 2.1% real per year (World Bank, 2016). • Colombia's agriculture experienced a severe drought in 1992 and 1997 (C. F. Jaramillo, 1998). • Colombian Peso appreciated in real terms relative to US dollar on average by 4% per year (BANREP, 2015; World Bank, 2016). • Colombia's agriculture main lender, "La Caja Agraria", fell into a crisis (Villalba, 2002). • Agricultural policy focused on restoring the dynamism of the agricultural sector, by reversal of many of the SA reforms through the "Plan de Reactivation del Sector Agropecuario" (Junguito, 1994) • An unstable agricultural policy, the drug traffic and a worsening armed conflict encouraged very little the creation of attractive environments for productivity and private investment (Kym Anderson & Valenzuela, 2011; Reina et al., 2011).
1998-2002	• Colombia plunged into a macroeconomic crisis, due to a real-estate bubble (Uribe, 2008). • An intensification of armed conflict prompted many people to leave rural areas, and it also discouraged even more private investment (Alban, 2011; DNP, 2002; FAO, 2000; Montero & Casas, 2012). • Colombia's agriculture grew on average by 1.9% real per year (World Bank, 2016). • Agricultural development did not receive much attention from the government, because it gave priority to address the macroeconomic crisis and solve the country's worsening armed conflict (Kalmanovitz & López, 2003). • Colombian Peso depreciated in real terms relative to US dollar on average by 8% per year (BANREP, 2015; World Bank, 2016).

PERIOD	MAIN EVENTS
2003-2009	• Uribe Administration (2002-2010) executed a security policy which restored confidence in investing in Colombia (DNP, 2002, 2006; Kalmanovitz & López, 2003; Montero & Casas, 2012). • Colombia's agriculture grew on average by 1.8% real per year (World Bank, 2016). • Colombia's Government multiplied 4 times the resources for promoting agriculture, but they exhibited a serious misallocation (Reina et al., 2011). • Agricultural commodity prices worldwide exhibited a boom during 2006-2011 (IMF, 2015). • Violence was still a problem in rural areas. • Annual crop farmers started to use better seeds to increase yield per hectare (COMPITE, 2008). • Colombia's agriculture exhibited a lack of innovation and technological development (Reina et al., 2011). • Colombian Peso appreciated in real terms relative to US dollar on average by 5% per year (BANREP, 2015; World Bank, 2016).
2010-2013	• Colombia's agriculture exhibited a new profitability crisis, due to falling agricultural commodity prices worldwide (Clavijo, Vera, & Jimenez, 2014). • Agricultural commodity prices worldwide decrease by almost 5% in 2012 (IMF, 2015) • Fertilizer prices remained high (FAO, 2015) • Colombia's agriculture was seriously affected by climate change effects (Niño/ Niña) (Clavijo, Vera, & Jimenez, 2014). • Colombian Peso appreciated in real terms relative to US dollar on average by 4% per year (BANREP, 2015; World Bank, 2016).

Appendix - B: Stability of the model residuals

ADF test results

	(1)	(2)	(3)	(4)	(5)
Aggregate	-3.363**	-3.727***	-2.019	-2.355	-2.905*
Crops	-2.276	-4.660***	-3.013**	-1.794	-3.657**
Livestock	-1.825	-4.433***	-1.545	-1.653	-2.752*

*** p<0.01, ** p<0.05, * p<0.1
(1) Cobb Douglas assuming constant technical change
(2) Cobb Douglas considering different technical change per Structural Change Periods
(3) CES assuming constant technical change
(4) CES assuming bias technical change
(5) TransLog assuming technical change

Determinantes del uso del crédito de vivienda por parte de los hogares bogotanos

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Research Article

Determinantes del uso del crédito de vivienda por parte de los hogares bogotanos

Determinants of the use of mortgage credit by households in Bogota

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Resumen

El crédito hipotecario es reconocido en Colombia como una de las herramientas más utilizadas para obtener vivienda propia. Esta investigación identifica los principales determinantes del crédito hipotecario, y estima la influencia de factores como la educación, el ingreso y el empleo en la probabilidad de hacer uso efectivo de tal crédito por parte de los hogares bogotanos. Con tal propósito, se realiza una descripción del marco normativo del acceso a la vivienda y las condiciones de financiación establecidas por las principales entidades bancarias. Posteriormente, y con base en los datos recolectados por la encuesta multipropósito, realizada en 2014, para Bogotá, se estima un modelo Logit para establecer la probabilidad de uso del crédito para la compra de vivienda. Los resultados sugieren que la edad, el ingreso y la estabilidad laboral influyen significativamente sobre la decisión de uso de crédito; sin embargo, el factor más importante está dado por el nivel de educación.

Abstract

Mortgage credit is recognized in Colombia as one of the most used tools to obtain homeownership. This research identifies the main determinants of mortgage credit and estimates the influence of factors such as education, income and employment in the probability of making effective use of such credit by households in Bogota. In order to aim that purpose, this paper makes a description of regulatory framework for access to housing and the financial conditions established by major banks. Subsequently, and bases on the data gathered by the multipurpose survey made in 2014 for Bogota, a Logit model was estimated to establish the probability of use of credit for the purchase of housing. The results suggest that age, income and job stability influence the decision to use mortgage credit, however, the most important factor is given by the level of education.

El acceso a la vivienda propia constituye uno de los mayores desafíos que debe enfrentar un hogar en Colombia. La Constitución Política del país establece el derecho de todo colombiano a acceder a una vivienda, y la Ley 546 de 1999 busca estimular su demanda bajo mecanismos de ahorro, subsidios y financiación; sin embargo, estas herramientas parecen ser insuficientes. Según datos del censo general realizado en Colombia en el año 2005, el número de hogares en déficit de vivienda era de 3 828 055, significando el 36 % del total. Además, en las últimas décadas, el crecimiento poblacional y la escasez de la tierra han generado una serie de restricciones desde la oferta que han llevado a crecimientos en los precios de la vivienda superiores al índice general de precios (IPC).

A pesar de existir cierto consenso en que se trata de un problema estructural desde la oferta (Camelo & Ocampo, 2016), el crédito hipotecario se ha convertido en el mecanismo habitual por el cual los hogares optan para financiar su compra de vivienda, el cual es ofrecido por entidades como el Fondo Nacional del Ahorro (FNA) y la banca comercial (entidades autorizadas por el Gobierno Nacional para ofrecer este tipo de financiación). Si bien la estrategia de financiamiento presenta virtudes, el crédito hipotecario cuenta con cierto número de características y requisitos que instigan a las entidades oferentes a racionarlo, restringiendo la posibilidad de las familias de ser propietarias de vivienda. Adicionalmente, como ya se mencionó, los estímulos a la demanda están lejos de resolver los problemas del mercado de vivienda, cuyas características son muy diferentes a las de un bien privado tradicional.

Finalmente, a pesar de la existencia de algunos estudios sobre financiamiento de vivienda, hay ausencia de investigaciones realizadas sobre el acceso a la figura de crédito hipotecario en la ciudad de Bogotá, donde la heterogeneidad de su población y la amplia gama de alternativas financieras permiten obtener evidencias sobre los factores socioeconómicos más importantes. Es así como la presente investigación tuvo como propósito identificar, de manera más precisa, la propensión a utilizar el crédito hipotecario en esta ciudad, según las características socioeconómicas del jefe de hogar. Los resultados son evaluados a la luz de la teoría económica y derivan algunas recomendaciones de política.

Con el anterior propósito, este documento se organiza en cinco secciones, además de la presente introducción: en la primera, se discuten algunos antecedentes de literatura especializada sobre el tema; en la segunda, se realiza una breve revisión de postulados teóricos que pueden relacionarse con la problemática; en la tercera, se realiza una descripción del marco normativo del acceso a la vivienda y las condiciones de financiación establecidas por las principales entidades bancarias; en la cuarta, se estima un modelo Logit para establecer la propensión al uso del crédito para la compra de vivienda en función de las diferentes variables consideradas; y, en la última sección, se plantean algunas conclusiones y recomendaciones.

Antecedentes de literatura

El tema de vivienda es de permanente relevancia en los análisis académicos, pero, sobre todo, en los de política pública. La discusión es de vieja data, alcanzando publicaciones clásicas tales como Friedman (1957), De Leeuw (1971), Poterba (1984), entre otros. El factor común de estos primeros aportes son las imposiciones que implican, para los hogares, las limitaciones presupuestales, es decir, el ingreso.

Aportes posteriores, como el de Fallis y Smith (1984), ponen en relieve algunas particularidades de este mercado, el alto control que implica y el acceso a los recursos vía préstamos bancarios. Esta dinámica, como plantea Connolly (1997), ha complejizado las relaciones entre prestamistas y deudores, quienes no tienen claros incentivos al ofrecer los recursos para este fin, ni al pagar sus deudas, respectivamente. En esta línea de argumentación también están Daphnis (2006) y Young (2007), quienes, en cierta forma, sugieren que las entidades financieras no suelen estar interesadas en disponer recursos para el financiamiento de la compra de vivienda, pues la población objeto de estos créditos no tiende a brindar garantías sobre su retorno.

En cuanto a investigaciones más recientes, la producción científica al respecto ha decaído en los últimos años, siendo el principal enfoque de discusión el aspecto financiero. Así, como se observa en Ferguson y Navarrete (2003), se puede decir que hay cierto consenso sobre la importancia de la vivienda en la calidad de vida de las familias; sin embargo, no se ha avanzado significativamente en propuestas efectivas para su regulación y financiación, pues existen tensiones entre el derecho a la vivienda digna y la autonomía de las entidades financieras privadas (Baena, 2017).

En efecto, en la literatura se encuentra una importante cantidad de trabajos sobre vivienda y, para el caso de Bogotá, en algunos de estos se entiende que la posesión de vivienda determina el bienestar del individuo e, incluso, la no posesión de la misma se asocia con el concepto de pobreza. Para el caso específico de Bogotá, Camargo y Hurtado (2011) destacan factores como la informalidad y los bajos salarios como determinantes del bajo acceso a vivienda propia; sin embargo, mencionan que en los últimos años se ha frenado la tendencia hacia la vivienda informal y la expansión hacia las periferias de la ciudad. Torres, Rincón y Vargas (2009), en un estudio profundo de la pobreza urbana en la ciudad, abordan la problemática de forma semejante, entendiendo que el mejoramiento integral de la vivienda es necesario para superar el déficit cualitativo de la ciudad de Bogotá. Este aspecto tiene que ver con la necesidad que los gobiernos locales han enfrentado por generar planes de ordenamiento territorial.

Otros trabajos se enfocan en los determinantes del financiamiento, el cual, siguiendo a Gonzales (2005), depende de dos características: la rentabilidad para el prestatario y la adecuada capacidad de pago por parte del deudor. Díaz (2011) reconoce al sistema bancario como el principal proveedor de préstamos a los hogares en economías poco desarrolladas; y es en tal punto donde nace la figura del racionamiento de crédito. Dicho racionamiento se da debido a las múltiples condiciones que imponen las entidades financieras para garantizar el retorno de sus recursos, más una utilidad en forma de intereses. Para Villareal (2010), en torno a estas condiciones, existe un "engaño ex ante" generado por la información asimétrica propia de los mercados financieros.

Clavijo, Muñoz y Janna (2004) han realizado modelaciones del crédito de vivienda, donde observan que los factores como ingreso de los hogares y precio de las viviendas afectan las decisiones a la hora de tomar un crédito hipotecario, observando altas elasticidades en sus estimaciones. Por su parte, Murcia (2007) critica el hecho de que, en Colombia, la mayoría de trabajos abordan este tema desde la perspectiva macroeconómica, por lo que destaca que el enfoque microeconómico permite identificar factores como el ingreso, la posición geográfica, el nivel de educación, el acceso a la seguridad social y la edad. Este argumento coincide con Hood (1999), quien considera tan importante la variable educación como la presencia de niños en el hogar, pues hay un efecto sustitución entre vivienda y educación de los niños.

Metodológicamente, cuando se consideran variables microeconómicas, los modelos probabilísticos suelen ser utilizados para evaluar los determinantes del acceso a vivienda de un hogar. Carvajal, García y Cotte (2015) encontraron, mediante un modelo Probit, que los principales determinantes de acceso a vivienda eran el ingreso del hogar, el ahorro programado, el número de miembros del hogar, la edad del jefe de hogar, el valor del arriendo que se pagaba y los años de vivir en arriendo. De otro lado, según Rojas, Bran y Rincón (2013), estas variables pueden diferir dependiendo de la región y el país.

Esta mirada a la literatura requiere destacar algunos trabajos a nivel regional, pues parece evidente que la problemática se extiende a la mayoría de países latinoamericanos. Serageldin y Driscoll (2000) realizaron una serie de estudios de caso en Asia, África y Latinoamérica, encontrando la importancia de los microcréditos como iniciativas para suplir las necesidades de los hogares de escasos recursos. Ferguson y Smets (2010) también destacan este tipo de iniciativas, sugiriendo que la tendencia es a expandir el destino de los recursos hacia el mejoramiento y formalización de las viviendas existentes. Estos esfuerzos son evidentes si se consideran las múltiples propuestas que, desde la academia, el sector público y las organizaciones no gubernamentales, se han desarrollado en cada país para promover el acceso a la vivienda digna (Fruet & Muñoz, 2015; Rodríguez & Sugranyes, 2012; Serrano, 2012; Durán, 2013).

Finalmente, mientras la tendencia hacia el predominio del crédito bancario (hipotecario) como fuente de financiación de vivienda no se revierta —lo cual aún parece ser lejano—, es fundamental establecer en qué medida los hogares son más propensos a hacer uso de él y cuáles son los determinantes de tal uso. El análisis empírico que se desarrolló en esta investigación da algunas luces sobre ello.

Alguna teoría relevante

Esta investigación presenta un enfoque microeconómico, en el sentido que evalúa el comportamiento de los hogares según características del jefe de hogar y las condiciones establecidas por el sistema financiero. De ahí que es posible partir de la teoría del consumidor como referente y, posteriormente, enriquecer el análisis mediante el contraste de las asimetrías de información y la teoría del ciclo vital.

Teoría del consumidor

Esta teoría analiza el comportamiento de los agentes económicos (consumidores) que interactúan en determinados mercados y cuyo problema es alcanzar los niveles máximos de utilidad, sujetos a su restricción presupuestal. Dadas las características del mercado, los consumidores evalúan sus gustos y sus preferencias, y toman decisiones fundamentadas en la racionalidad, de tal manera que son capaces de comparar cestas de consumo adquiriendo aquellas que sean factibles y otorguen una mayor utilidad. Para los marginalistas, esta conducta implica que la utilidad que genera una unidad adicional de un bien debe equipararse con el costo de adquirirlo.

Generalmente, adquirir una vivienda significa enfrentarse a un bien de precio superior con relación a los ingresos potenciales de los hogares, por lo que contraen algún tipo de obligación (crédito hipotecario) para poder acceder a ella. Pero no todos los individuos acceden libremente al mercado de crédito. Gonzales (2005) afirma la existencia de tres obstáculos frente al acceso y financiamiento de vivienda: 1) su insuficiente capacidad adquisitiva no les permite cambiar su demanda potencial por una demanda efectiva; 2) los hogares carecen de garantías aplicables para obtener la financiación necesaria; y 3) en su mayoría, los países con sectores informales presentan la imposibilidad de acreditar ingresos formales y permanentes.

Asimetrías de información

Generalmente, los mercados de crédito influyen en y son influenciados por el resto de la economía. Gurley y Shaw (1955) resaltan la función de los intermediarios financieros a través de la oferta de crédito en la actividad económica, lo que consideran importante para la eficiencia de los mercados; sin embargo, a diferencia de los mercados competitivos donde no hay diferenciación y todos los agentes participan en igualdad de condiciones, la realidad demuestra que los sistemas de mercado son imperfectos o su comportamiento es diferente dada la normatividad, los derechos de propiedad, los costos financieros y de oportunidad, disponibilidad de la información, el volumen de los recursos y el alto número de agentes interactuando en él, entre otros, induciendo a los agentes participantes a tomar decisiones ineficientes, aumentando su incertidumbre.

Asimismo, estas estructuras de mercado traen consigo problemas de asimetrías de información que afectan de manera significativa la interpretación de datos por los agentes del mercado. Este problema implica riesgos tanto para prestamistas como para prestatarios. En efecto, Hoff y Stiglitz (1981) asumen que la información asimétrica influye en la racionalidad de los prestamistas, implicando riesgos, a tal punto que racionan los recursos disponibles entre los prestatarios solicitantes. Este es uno de los motivos más importantes que limitan el financiamiento, ya que, en muchas ocasiones, se oculta información importante para lograr determinar si quien requiere del crédito posee los medios para pagar la obligación con los intereses respectivos. El problema surge cuando uno de los agentes que se encuentra llevando a cabo la transacción posee información relevante desconocida por la otra, de forma que la primera realiza el proceso decisional y la transacción en superioridad de condiciones.

Akerlof (1970) denomina a este problema como una consecuencia de la selección adversa, al presentarse aquellas situaciones de "oportunismo precontractual" en las que, al iniciar o mantener un contrato, una de las partes (la que posee poca información) no tiene la capacidad de distinguir con toda seguridad la calidad de lo ofrecido por la otra parte. En este sentido, Stiglitz y Weiss (1981) establecen que dichos problemas de información afectan negativamente la eficiencia de los mercados de crédito, originando problemas de selección adversa, expresados desde las asimetrías de información y riesgo moral que conducen a los intermediarios financieros al racionamiento de crédito.

Dentro de la teoría neokeynesiana, se plantea que el riesgo moral es la causa ex post que deben enfrentar los intermediarios financieros. Vickrey (1961) hace referencia a los comportamientos "morales" de los agentes; en su obra utiliza el caso de una empresa donde los empleados (agentes) utilizan información privada privilegiada hacia el empresario contratante (principal), induciendo a generar un sistema de conductas veraces y comprometidas con el contrato de trabajo. En ese sentido, los oferentes se enfrentan a problemas de selección adversa para identificar y medir los niveles de riesgo para cada cliente, generando una tendencia al equilibrio del mercado; esto lleva a que la demanda de crédito no sea cubierta, estimulando la oferta con créditos de tasas bajas, atrayendo a los prestatarios de menor riesgo.

La teoría del ciclo vital

Franco Modigliani (1986) es uno de los primeros teóricos que hizo referencia a la teoría de ciclo vital o función del consumo. En su investigación, considera que los individuos otorgan un ciclo natural a sus ingresos. Su planteamiento principal reside en que el consumidor representativo decidirá realizar un consumo razonable y estable, por lo que debe ser lo más cercano a la cantidad media que prevé consumir a lo largo de toda su vida. En ese sentido, el ingreso que perciben las personas tiende a variar sistemáticamente, de forma que, a lo largo de su vida, su comportamiento con respecto al ahorro y el consumo se encuentra determinado por su edad. Ando y Modigliani (1963) afirman que los ingresos percibidos por el trabajo poseen un perfil, y que a lo largo del tiempo es predecible, dadas las retribuciones máximas que se perciben en la edad adulta. Por ejemplo, cuando se nace o se pasa por la etapa de la niñez no se perciben altos ingresos; en la madurez, se perciben los ingresos necesarios para cumplir con la satisfacción de necesidades básicas (como puede ser la adquisición de vivienda y el ahorro); ya posteriormente, con la jubilación, el ingreso puede aumentar o disminuir, dependiendo del ahorro o ingreso generado para la posteridad. En efecto, la teoría del ciclo vital implica que las personas planifican su consumo y ahorro de acuerdo a grandes períodos de tiempo (juventud, adultez).

Por su parte, Friedman (1957) considera que el individuo tiende a suavizar su consumo prefiriendo mantenerlo estable, bajo un perfil uniforme de su renta a lo largo de su vida. Bajo este supuesto, se espera siempre recibir un ingreso permanente sin importar el momento del ciclo vital donde se encuentre; esta teoría es muy controvertida porque a medida que se va envejeciendo el poder adquisitivo disminuye y, al relacionarlo con esta investigación, la edad propicia para adquirir un crédito hipotecario es en las etapas juventud y adultez.

Modigliani (1986) concluye que los jóvenes son los que más dependerán del crédito; los adultos, los que más ahorrarán, y los ancianos, los que gastarán los ahorros que hicieron cuando fueron adultos. Pero, en la actualidad, esta teoría puede pasar a un segundo plano debido a que el ingreso, en muchos casos, no es el principal determinante para adquirir un crédito hipotecario, ya que en la juventud y a medida que se hace más adulto puede ser más riesgoso para una entidad financiera brindar un crédito hipotecario.

Marco normativo del acceso a la vivienda y las condiciones de financiación

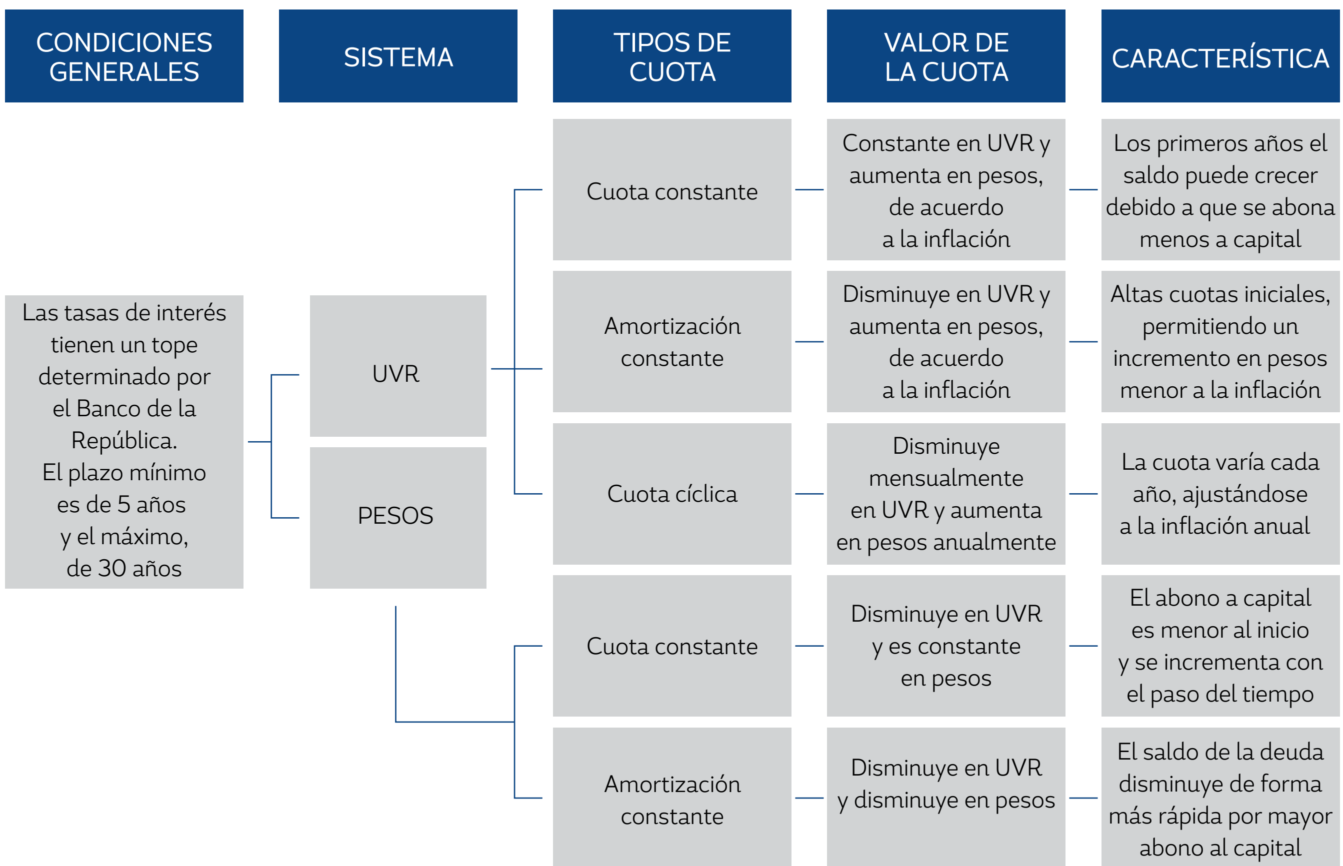
El derecho a la vivienda digna se incorpora en el Artículo 51 de la Constitución de Colombia, de la siguiente manera:

> Todos los colombianos tienen derecho a vivienda digna. El Estado fijará las condiciones necesarias para hacer efectivo este derecho y promoverá planes de vivienda de interés social, sistemas adecuados de financiación a largo plazo y formas asociativas de ejecución de estos programas de vivienda (Asamblea Nacional Constituyente, 1991).

De esta manera, se ha establecido un marco jurídico en el país que propende por el ejercicio y la responsabilidad del Estado como garante del acceso a la vivienda de sus ciudadanos. Sin embargo, dicho mandato posee una limitante, al ser un derecho de carácter asistencial, por lo que el Estado no está en la obligación de proporcionar unidades habitacionales a todos sus ciudadanos, relegando la función pública a la formulación de políticas de carácter financiero. En ese sentido, el crédito hipotecario en Colombia se rige por la Ley 546 de 1999, en la que se dictaron las normas más importantes en materia de financiación de vivienda para créditos de largo plazo y, en general, esta ley confiere las herramientas necesarias al Gobierno Nacional, para la regulación del mercado.

Los créditos hipotecarios son ofrecidos bajo dos modalidades o sistemas de amortización: pesos y UVR[1]. Estos sistemas fueron aprobados bajo la Ley 546 de 1999 y la Circular Externa 068 de 2000 (Superintendencia Financiera de Colombia [SFC], 2000a), en las que se estableció su instauración y, finalmente, su puesta en marcha por las diferentes entidades oferentes de crédito hipotecario. De la misma manera, y por disposición de la Circular Externa 085 de 2000 (SFC, 2000b), se autorizaron otras características aplicables a todo crédito con sistemas de amortización en UVR y pesos, como se muestra en la Figura 1.

Figura 1. Características de los sistemas de amortización en UVR y Pesos.
Fuente: Elaboración propia



Además de las características mencionadas, se destacan las siguientes disposiciones respecto a los créditos hipotecarios:

- Tener un monto máximo sin exceder el porcentaje establecido por el Gobierno Nacional sobre el valor de la vivienda a financiar. Hoy en día, los montos solicitados como recursos iniciales oscilan entre 20 % y 30 % para vivienda VIS y no VIS.

- El crédito debe ser garantizado con hipoteca en primer grado del bien inmueble.

1 Un sistema de amortización es la forma como se estipula realizar el pago del préstamo, en cuotas mensuales que incluyen capital, intereses y seguros, y que se cancelan durante el plazo pactado.

- La primera cuota del crédito no puede representar un porcentaje mayor a los ingresos familiares establecidos por el Gobierno Nacional. El valor fijado no puede superar el 30 % de los ingresos demostrados (Decreto 145 de 2000).

- Los establecimientos de crédito están en la obligación de obtener y analizar la información de los deudores y la respectiva garantía. Además de ello, deben garantizar una metodología eficaz que permita evaluar el precio del inmueble a financiar, los ingresos del deudor, y que el crédito sea puntualmente atendido.

- Seguro de vida para el tomador del crédito que respalde la deuda ante la entidad en caso de deceso o incapacidad total. Además, seguro de incendio o terremoto para la protección del inmueble en caso de siniestro.

Las Tablas 1 y 2 ofrecen luces sobre las principales características y requisitos del crédito hipotecario, tomando como referencia las cinco entidades bancarias que presentaron el mayor índice de desembolsos en el año 2016.

Tabla 1. Características de los créditos hipotecarios en el sector financiero

Banco	Plazos en años		Porcentaje de financiación		Monto mínimo (SMMLV)
	UVR	Pesos	VIS	No VIS	
Bancolombia	5 a 30	5 a 15	80%	70%	20
Banco de Bogotá	5 a 20	5 a 20	80%	70%	20
Banco Davivienda	5 a 30	5 a 20	70%	70%	5
Banco BBVA	5 a 20	5 a 20	70%	70%	6
Banco Caja Social	5 a 20	5 a 15	70%	70%	20

Nota: elaboración propia a partir de las páginas web de las entidades bancarias.

Tabla 2. Requisitos para el estudio de crédito para empleados e independientes

Banco	Rango de edad		Ingresos mínimos (SMMLV)	
	Empleados	Independientes	Empleados	Independientes
Bancolombia	18 a 69	23 a 69	1,5	1,5
Banco de Bogotá	18 a 70	18 a 70	1,5	1,5
Davivienda	18 a 69	18 a 69	1,5	1,5
BBVA	18 a 69	18 a 69	2	1,5
Caja Social	18 a 69	18 a 69	1	1,5

Nota: elaboración propia a partir de las páginas web de las entidades bancarias.

Otra de las entidades encargadas de ofrecer crédito hipotecario, es el Fondo Nacional del Ahorro (FNA), creado mediante el Decreto 3118 de 1968, como un ente del Estado, de ámbito financiero, para la administración de las cesantías de los empleados públicos. Posteriormente, fue transformado, mediante la Ley 432 de 1998, en una entidad comercial y financiera bajo la propiedad del Estado, dándole autonomía administrativa y capital independiente. Este proceso tuvo como objetivo principal cubrir las necesidades básicas para la adquisición de vivienda por los hogares. Lo anterior lo convierte en otra de las principales alternativas de financiación utilizadas por los hogares. De hecho, el FNA cuenta con un portafolio de servicios que brinda diferentes tipos de opciones y beneficios, siendo el principal requisito ser afiliado. En ese orden, para poder aplicar a un crédito hipotecario, el fondo ofrece dos posibilidades de crédito: a través de ahorro voluntario y a través de cesantías.

El crédito hipotecario a través de ahorro voluntario es un mecanismo utilizado por el FNA, incentivando el ahorro voluntario con destinación a la adquisición de vivienda. Este se constituye mediante contrato, en el cual el futuro solicitante de crédito se compromete con un ahorro voluntario mínimo de doce meses, cumpliendo tres reglas principales: periodicidad en los abonos, monto periódico y monto total. La otra alternativa brindada por el fondo es el crédito hipotecario por cesantías, en el cual se requiere que las cesantías sean trasladadas a la cuenta del FNA, libre de pignoración y embargos de los recursos. En esta modalidad de crédito, el solicitante ahorra la cuota inicial dependiendo del valor del inmueble.

Modelo Logit para el acceso a crédito de vivienda

Datos

Con el propósito de evaluar los determinantes de la probabilidad de hacer uso de un crédito hipotecario en Bogotá, se utilizaron los datos de la encuesta multipropósito para esta ciudad (Departamento Administrativo Nacional de Estadística [DANE], 2014). La información utilizó como unidad observacional el hogar, el cual es definido como la persona o el grupo de personas que, independiente de su parentesco, ocupan la totalidad o parte de una unidad de vivienda; además de atender sus necesidades básicas, también comparten un presupuesto en común (DANE, 2007, p. 11). La encuesta contempla 20 518 hogares para la ciudad, donde las variables de interés para efectos de esta investigación son el género, la edad, la educación, el ingreso y la vinculación laboral del jefe de hogar.

Para la elaboración del modelo, fue necesario procesar la encuesta, tomando la pregunta que indagaba sobre la fuente de financiamiento utilizada para la compra de vivienda con el objetivo de construir la variable dependiente[2]. Esta variable es de naturaleza dicotómica, tal que los individuos que optaron por la utilización de un crédito hipotecario para financiar su vivienda toman el valor 1, mientras que las personas que no utilizaron el crédito hipotecario toman el valor 0.

$$y_i = \begin{cases} 1 \text{ si utilizó crédito hipotecario} \\ 0 \text{ si no utilizó crédito hipotecario} \end{cases} \tag{1}$$

Una vez identificada la muestra de la variable dependiente, se filtró la base para identificar a los individuos que respondieron a cada una de las preguntas que fueron tomadas como variables independientes, obteniendo finalmente una muestra de 4611 observaciones. A continuación, se describen las variables que se utilizaron para el modelo:

- **Ingreso:** representa el valor mensual de los ingresos que tienen los jefes de hogar. Se utilizaron los valores por encima del salario mínimo para 2014, dado los problemas de especificación que se encuentran por debajo de este rango.

- **Edad:** variable discreta que identifica la edad del jefe de hogar. No se realiza ninguna modificación.

2 Los usuarios de crédito hipotecario contemplados en este estudio son aquellos que se financiaron a través de establecimientos de la banca comercial y el FNA.

- **Género:** variable dicotómica que representa el sexo del jefe del hogar. El jefe de hogar mujer es representado con 0 y el hombre, con 1. No se tuvieron en cuenta algunas personas que contestaron la condición de intersexual.

- **Educación:** corresponde al número de años de escolaridad del jefe de hogar. Para la elaboración del modelo se transformó en variable dicotómica, donde 1 representa ser profesional y 0 no serlo.

- **Tipo de contrato laboral:** variable cualitativa que representa el tipo de contrato que posee el jefe del hogar (indefinido, fijo, no sabe no responde). Esta variable se transformó en dicotómica para la elaboración del modelo, asignando el valor 1 para contrato a término indefinido, y 0 para contratos de término fijo y otros tipos de contrato (obra labor, prestación de servicios).

Relaciones básicas entre variables

A continuación, se caracteriza la variable dependiente (hogares que usaron crédito hipotecario), según cada una de las variables independientes. Como se observa en las Figuras 2 a 6, existen indicios de que las variables ingreso, educación y tipo de contrato se relacionan con la posibilidad de acceso a crédito hipotecario; en el caso de género no se observa relación; y en el de edad no es evidente.

Figura 2. Porcentaje de hogares que utilizaron o no crédito hipotecario según su nivel de ingreso. Adaptado de DANE (2014).

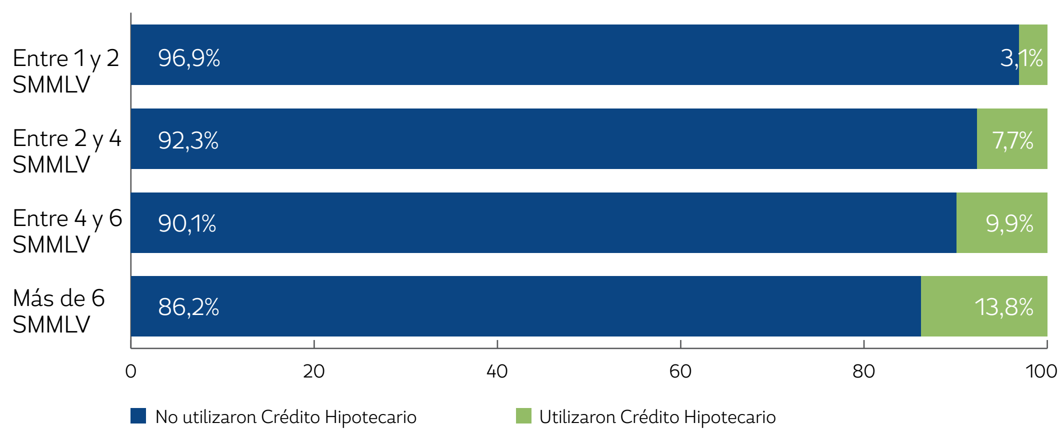


Figura 3. Porcentaje de hogares que utilizaron o no crédito hipotecario según su género. Adaptado de DANE (2014).

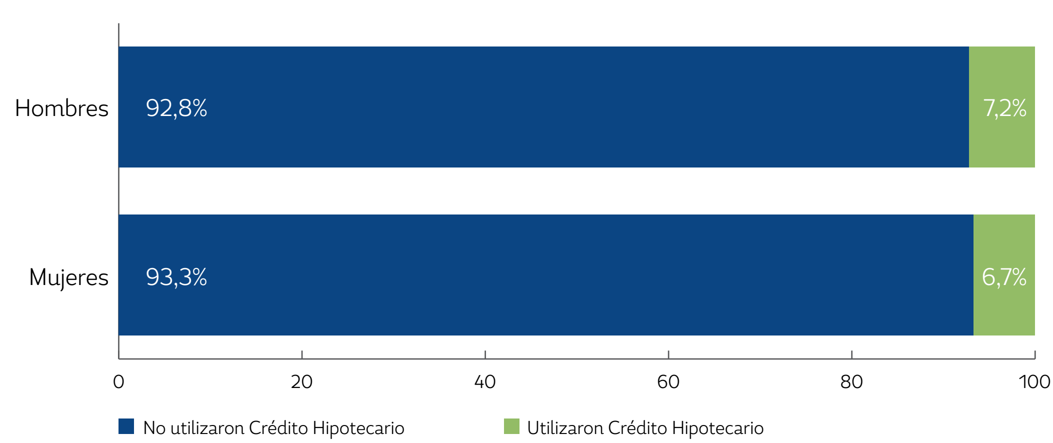


Figura 4. Porcentaje de hogares que utilizaron o no crédito hipotecario según su nivel educativo. Adaptado de DANE (2014).

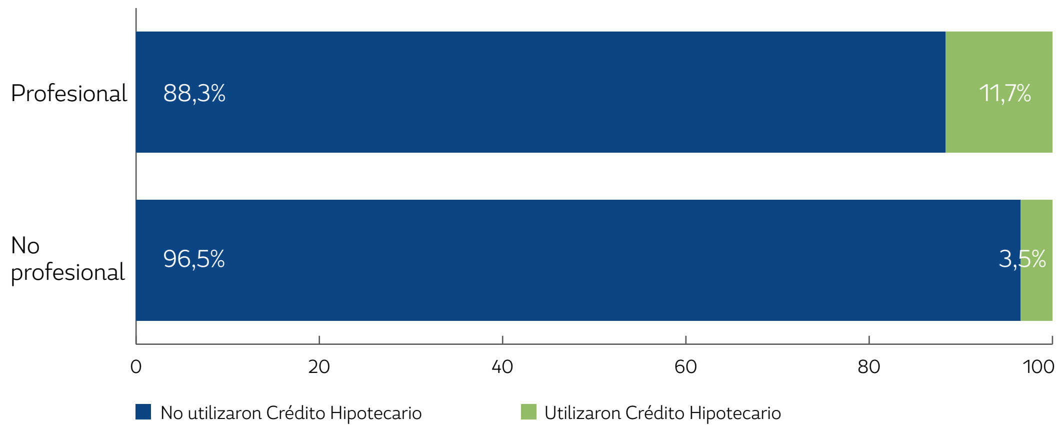


Figura 5. Porcentaje de hogares que utilizaron o no crédito hipotecario según tipo de contrato laboral. Adaptado de DANE (2014).

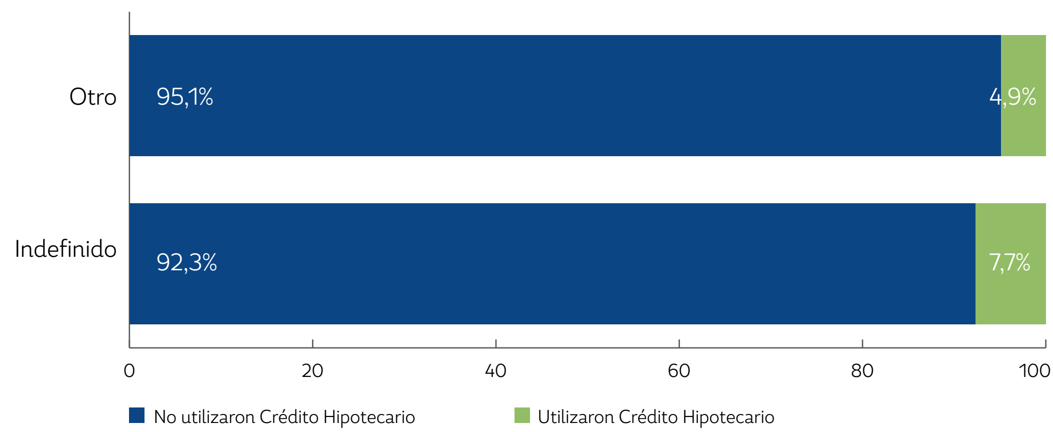
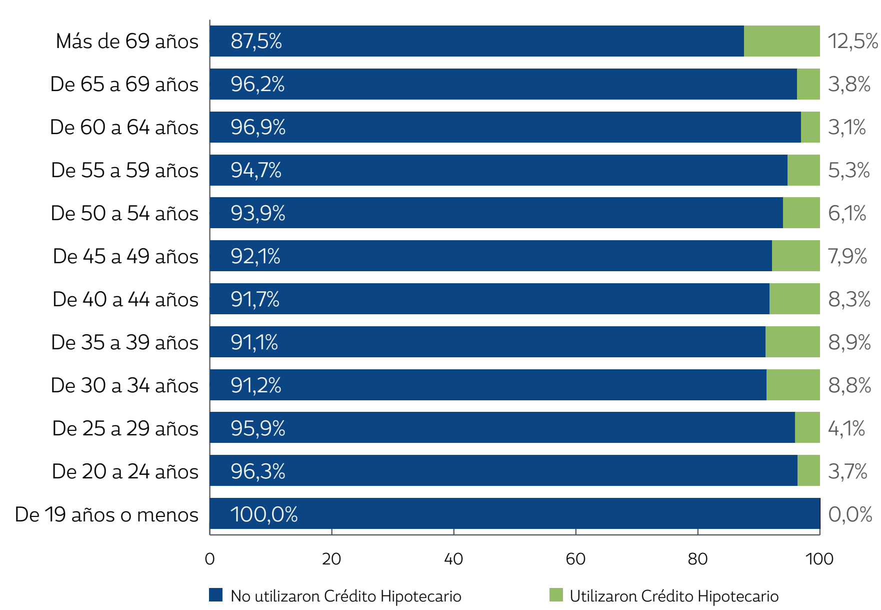


Figura 6. Porcentaje de hogares que utilizaron o no crédito hipotecario según su edad. Adaptado de DANE (2014).



Finalmente, el análisis de correlación entre las variables independientes sugiere poca relación entre ellas, de ahí que no parecen presentar colinealidad (ver Anexo 1).

Forma funcional del modelo

La naturaleza de la variable dependiente lleva a la necesidad de utilizar un modelo de respuesta cualitativa, de ahí que un análisis de regresión lineal tradicional no sea adecuado. En este sentido, los modelos candidatos para la estimación son: Lineal de Probabilidad (MLP), Logit, Probit y Tobit.

Inicialmente, se descartó el modelo Tobit, debido a que se cuenta con información completa sobre las variables dependiente e independientes (Gujarati & Porter, 2010, p. 574). En cuanto al MLP, no es adecuado porque, por construcción, no cumple los supuestos básicos del método de mínimos cuadrados ordinarios (MCO) (Gujarati & Porter, 2010, p. 552), perdiendo así confiabilidad en las estimaciones. Finalmente, aunque el modelo Probit es una alternativa para analizar problemas donde la variable dependiente es de respuesta cualitativa, en este trabajo se utilizó el modelo Logit por tres razones: 1) la función Logit es matemáticamente fácil de aplicar e interpretar; 2) la mayoría de investigaciones utilizan esta forma funcional en el caso de respuesta binomial; y 3) en general, la bondad de ajuste del modelo es similar al Probit y más adecuado que el MLP (Moscote & Rincón, 2012).

En principio, el modelo Logit es no lineal, el cual está representado por la función logística de la forma:

$$\pi_i = \frac{1}{1 + e^{-x'\beta}} \quad (2)$$

Donde denota las variables independientes y π_i la probabilidad de que la variable dependiente tome al valor de 1 ($E(y_i/x) = 1$). No obstante, la función Logit puede transformarse de forma que pueda aplicarse un análisis semejante al de regresión lineal. Despejando $e^{x'\beta}$ de la ecuación (2), se obtiene:

$$\frac{\pi_i}{1 - \pi_i} = e^{-x'\beta} \quad (3)$$

La ecuación (3) es conocida como la transformación Logit de la probabilidad, donde la parte izquierda $\left(\frac{\pi_i}{1 - \pi_i}\right)$ se conoce como el *odds ratio* o razón de probabilidades (Moscote & Rincón, 2012). Obteniendo el logaritmo natural en la ecuación (3), se llega a la ecuación (4), con lo que se establece una relación lineal entre el logaritmo del *odds ratio* y las variables independientes.

$$\ln\left(\frac{\pi_i}{1 - \pi_i}\right) = x'\beta \quad (4)$$

Dado que los datos de la encuesta multipropósito se presentan de manera no agrupada (cada observación es un hogar), el método apropiado de estimación de los parámetros es el de máxima verosimilitud, el cual aplica para muestras grandes. Así, el modelo Logit inicial puede expresarse como:

$$\ln\left(\frac{\pi_i}{1 - \pi_i}\right) = \beta_0 + \beta_1 Edad_i + \beta_2 Genero_i + \beta_3 Educación_i + \beta_4 Ingreso_i + \beta_5 TContrato_i + U_i \quad (5)$$

En la ecuación (5), π_i indica la probabilidad de que un hogar utilice el crédito hipotecario para el financiamiento de vivienda, por lo tanto, el Logit $\ln\left(\frac{\pi_i}{1 - \pi_i}\right)$ es el logaritmo de la razón de probabilidades entre utilizar el crédito hipotecario o no hacerlo. El modelo permite observar cómo los cambios en las respuestas brindadas por los hogares afectan la probabilidad de adquirir crédito hipotecario; también permite demostrar cuáles de las variables utilizadas son consideradas significativas o no para el modelo (Moscote & Rincón, 2012, p. 132). Después de eliminar las variables no significativas, se opta por tomar el sistema *Stepwise* para la elaboración del modelo, el cual plantea realizar interacciones entre las variables significativas para dar resultados más acordes con la investigación.

Bondad de ajuste del modelo Logit con interacciones

Para los modelos Logit, la prueba R cuadrado como medida de bondad de ajuste no es la más indicada, de ahí que se utilizó otro tipo de pruebas como el porcentaje de aciertos y la Hosmer-Lemeshow (Moscote & Rincón, 2012, p. 132).

Para la validación del modelo, existen diferentes pruebas; sin embargo, una de las más indicadas para los modelos Logit con observaciones muy grandes es el porcentaje de aciertos estimados en el modelo, el cual permite determinar la bondad del mismo[3]. Esta prueba consiste en validar la exactitud predictiva a través de comparaciones entre el valor estimado y el observado por grupos; esta no se basa en el valor de la función de verosimilitud, sino en la predicción real de la variable dependiente (Borooah, 2002).

Tabla 3. Porcentaje de aciertos estimados en el modelo

Índice	Valor	Índice	Valor
Tasa de aciertos	92,97 %	Sensibilidad	0,00 %
Tasa de errores	7,03 %	Tasa de falsos 0	7,03 %
Especificidad	100,00 %	Tasa de falsos 1	100 %

Fuente: elaboración propia a partir de los datos obtenidos del modelo econométrico.

El modelo Logit tiene un buen porcentaje de aceptabilidad para el total de las predicciones, la cual se refleja en las altas tasas de acierto en la totalidad del modelo.

De otro lado, se utilizó la prueba de Hosmer-Lemeshow, la cual pretende comprobar si el modelo propuesto puede explicar las observaciones. Su elaboración consiste en dividir las observaciones en *j* grupos o intervalos (generalmente 10 observaciones), del mismo tamaño, dividiendo la probabilidad de ocurrencia de la hipótesis planteada; es decir, se valida intervalo por intervalo (esperado y observado) para todos los resultados de la variable dependiente (Borooah, 2002). En contraste, el valor de probabilidad para el modelo estimado es de 0,0623, lo que indica que presenta un buen ajuste, dados los datos brindados por la encuesta multipropósito.

Resultados

Los resultados arrojaron la siguiente ecuación estimada:

$$\ln\left(\frac{\pi_i}{1-\pi_i}\right) = -3.3926 - 0.0103 Edad + 1.1156 Educacion + 5{,}40^{E-08} Ingreso + 0{,}4248 TContrato + U \qquad (6)$$

En la primera estimación del modelo, la variable género no resultó significativa al 5 % (ver Anexo 2), de ahí que se excluya en la ecuación (6). Por su parte, las demás variables consideradas parecen tener la influencia esperada sobre el uso de crédito hipotecario: cuanto mayor edad del jefe de hogar menor propensión a utilizar crédito hipotecario; un mayor ingreso implica mayor probabilidad de utilizar el crédito; y el hecho de contar con contrato a término indefinido y un nivel de educación superior incrementa las probabilidades de utilizar el crédito para adquirir vivienda.

3 El valor de la prueba "c" generalmente es 0,5. Con esto, se determina que, si el valor de la predicción es igual a 1 o 0, es de 0,5, puesto que parece lógico que la predicción sea 1 cuando el modelo dice que es más probable obtener un 1 que un 0.

Ante la posibilidad de encontrar otro tipo de relaciones no lineales entre las variables independientes y la dependiente, se realizó el proceso *Stepwise*, el cual permitió identificar interacciones entre las variables regresadas. De esta manera, se estimó la siguiente ecuación:

$$\ln\left(\frac{\pi_i}{1-\pi_i}\right) = -4.0387 - 0.0159Edad + 2.1319Educación - 0.0173TContrato + 5.85^{E-08}\ Ingreso - 0.0391Educación * Edad + 0.6993Educación * TContrato + U_1 \quad (7)$$

En la ecuación se puede evidenciar que existen variables con relación positiva, las cuales, al aumentar, otorgaron mayor posibilidad de acceder a crédito; este es el caso de la edad, la educación y el gasto. Ahora, el tipo de contrato no es significativa individualmente, pero sí lo es mediante interacción con la educación; en este sentido, el tipo de contrato indefinido mejora las probabilidades de utilización del crédito de vivienda, siempre y cuando esto esté acompañado de mayor nivel de educación. No obstante, la interacción entre educación y edad también es significativa, cuyo coeficiente negativo sugiere que los jefes de hogar con mayor edad, y que al mismo tiempo presentan mayor nivel educativo, tienden a hacer menos uso del crédito hipotecario.

El modelo estimado presenta una aceptable bondad de ajuste y permite realizar predicciones respecto a la probabilidad de hacer uso del crédito hipotecario por parte de determinado jefe de hogar.

Interpretación a partir de escenarios

Con base en la ecuación (7), la Tabla 4 presenta la estimación de probabilidad de hacer uso de crédito hipotecario ante diferentes escenarios, sobre las características del jefe de hogar.

Tabla 4. Escenarios de probabilidad de utilización de un crédito hipotecario

Escenario	Edad	Educación	Tipo decontrato	Ingreso	Probabilidad
1	30	0	0	1000000	1,15 %
2	40	0	0	1000000	0,98 %
3	30	1	0	1000000	2,94 %
4	30	0	1	1000000	1,13 %
5	30	0	0	2000000	1,21 %
6	40	1	0	1000000	1,72 %
7	30	1	1	1000000	5,64 %

Fuente: elaboración propia a partir de los datos obtenidos del modelo econométrico.

Es posible identificar, mediante tales escenarios, el efecto concreto de cada una de las variables consideradas sobre el uso de crédito hipotecario que hacen los hogares. En particular, partiendo de un caso referencia (escenario 1) donde el jefe de hogar tiene 30 años de edad, no profesional, sin contrato laboral a término indefinido y un ingreso de $1 000 000 mensuales, tiene una probabilidad de uso del crédito hipotecario de 1,15 %. Los escenarios 2, 3, 4 y 5 modifican las variables edad, educación, tipo de contrato e ingreso, evidenciando que la variable educación es aquella que presenta mayor importancia en el modelo. En particular, si el individuo referencia pasa a tener educación profesional, su probabilidad de uso de crédito hipotecario aumenta a 2,94 %, pero si, además, obtiene un contrato a término indefinido, su probabilidad será cercana a 5,64 %.

Se observa que la edad, el tipo de contrato y el ingreso, de manera individual, no son variables muy determinantes en el uso del crédito hipotecario; sin embargo, tienden a ser factores complementarios. En otras palabras, la edad del jefe de hogar es una variable que afecta el uso del crédito de manera inversa, lo cual es consistente con la idea del ciclo vital en el consumo (Modigliani, 1986); no obstante, tal efecto es mayor en las personas con educación profesional. Por su parte, el tipo de contrato a término indefinido puede favorecer el uso de crédito de vivienda, siempre que el jefe de hogar cuente con educación profesional, pero lo afectaría de manera inversa (aunque leve) en hogares sin educación. Este último hallazgo puede explicarse, en parte, por los factores enunciados por Gonzales (2005), según los cuales la insuficiente capacidad adquisitiva de los hogares limita su demanda efectiva de vivienda.

Conclusiones

El alto costo de la vivienda y las condiciones socioeconómicas de muchos hogares colombianos han hecho del crédito hipotecario una herramienta esencial que apalanca el acceso a la vivienda; sin embargo, este análisis sugiere que las actuales políticas no suelen ser efectivas en el mercado de vivienda, cuya prioridad pasa por promover la demanda sin atacar estructuralmente las limitantes de ingreso, educación y empleo de la población. En efecto, el marco normativo del financiamiento de vivienda en el país se ha concentrado en mecanismos de financiación, pero sin promover alternativas eficaces que hagan asequible la vivienda para muchas familias.

Aunque existe una amplia gama de opciones para que un hogar elija un esquema de financiación bancaria, tanto en UVR como en pesos, todas ellas requieren unas garantías mínimas de mediano y largo plazo, tanto de nivel de ingresos como de estabilidad laboral. Para aquellos hogares que no cuentan con un ingreso suficiente, las restricciones impuestas por el mercado financiero siguen siendo muy fuertes, y esto es evidente ante la necesidad de contar con un ahorro que alcance al menos el 30 % del valor del inmueble para hacer uso del crédito hipotecario. De otra parte, en cuanto a la estabilidad laboral, es una condición normativa para otorgar créditos hipotecarios por parte de las entidades bancarias, siendo un elemento que pocas veces es ofrecido por el mercado.

Algunas variables analizadas empíricamente en esta investigación, tales como la edad, el empleo y los ingresos, son tenidas en cuenta en los requisitos que imponen las entidades bancarias en Colombia; No obstante, otras no lo son de manera directa, es el caso de aspectos culturales o idiosincráticos. Como una variable *proxy* de estos elementos, puede sugerirse el nivel de educación, que, como se observó en el ejercicio empírico, es uno de los principales determinantes que llevan a un hogar a hacer uso efectivo del crédito hipotecario para su acceso a vivienda. En este sentido, mediante la estimación del modelo Logit, se valida la importancia del ingreso, la edad, la educación y el empleo en el uso del crédito hipotecario, pero tal importancia se potencializa cuando el jefe de hogar cuenta con un nivel educativo profesional.

Concretamente, en el caso de la edad, son los jóvenes con educación profesional los que presentan mayor probabilidad de uso de crédito, y en el caso del empleo a término indefinido, este es importante en la medida que el jefe de hogar cuente con educación profesional. Así, un hallazgo central es que la educación se ha convertido en un aspecto fundamental, pues no se trata solamente de acceder a un crédito hipotecario, sino de tener las condiciones efectivas para soportar dicho crédito durante un plazo de hasta 30 años.

Desde un enfoque teórico, se evidencia que las asimetrías de información propias del mercado, al no reconocer suficientemente el grado de solvencia y cumplimiento de un hogar, conllevan la incapacidad del sistema financiero de dar oportunidades de acceso, de manera equitativa, a toda la población. De otro lado, la teoría del ciclo vital parece tener relevancia en la medida que los hogares cuyo jefe de hogar tiene mayor edad no suelen hacer uso del crédito hipotecario para obtención de vivienda propia. Se puede entender que muchas personas mayores ya cuentan con vivienda propia obtenida a través de otras alternativas, y en sus prioridades no se encuentra el endeudamiento para obtención de vivienda; aun así, hace parte de una agenda futura el identificar si estos patrones se dan por restricciones del mercado o por elección de los hogares.

En términos prácticos, este estudio es de alta relevancia, tanto para las entidades que ofrecen alternativas de financiamiento de vivienda como para los hacedores de política pública. Es fundamental, para las entidades financieras, considerar factores más allá de lo estrictamente económico, por lo que se deben establecer criterios de identificación de variables como la cultura de pago del individuo y los incentivos. No obstante, es evidente que sigue existiendo una dicotomía entre las garantías requeridas por las entidades y el derecho de vivienda digna que consagra la ley. En este último aspecto, los hacedores de política son los encargados de fijar mecanismos de solidaridad y subsidiariedad que no se limiten a la mera regulación, sino que propendan por la formalidad laboral y la educación, especialmente de la población joven que recién se incorpora en la dinámica del mercado de vivienda.

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Anexo 1

Matriz de correlación entre variables independientes

	Edad	Educación	Género	Ingreso	Tcontrato
Edad	1,00000	0,05804	0,01676	0,10741	0,05653
Educación	0,05804	1,00000	-0,10235	0,47972	0,02252
Género	0,01676	-0,10235	1,00000	0,05959	0,04161
Ingreso	0,10741	0,47972	0,05959	1,00000	0,06201
Tcontrato	0,05653	0,02252	0,04161	0,06201	1,00000

Nota: Adaptado de DANE (2014).

Anexo 2

Estimación de modelos

Resultados de la estimación Logit para el modelo inicial

Variable	Coeficiente	Error Std	Z estadística	Probabilidad
Edad*	-0,010323	0,005532	-1,865914	0,0621
Género	0,130051	0,129198	1,006606	0,3141
Educación***	1,115556	0,138566	8,050723	0,0000
Ingreso***	5,40E-08	1,42E-08	3,793934	0,0001
TContrato**	0,424816	0,158004	2,688643	0,0072
C***	-3,392585	0,284487	-1,192525	0,0000

Nota: Adaptado de DANE (2014). *Nivel de significancia al 0,1. **Nivel de significancia al 0,05. ***Nivel de significancia al 0,01.

Resultados de la estimación Logit con interacciones (*STEPWISE*)

Variable	Coeficiente	Error Std	Z estadística	Probabilidad
Edad*	0,015985	0,009587	1,667279	0,0955
Educación***	2,131948	0,559558	3,810060	0,0001
Ingreso***	5,85E-08	1,42E-08	4,134269	0,0000
TContrato	-0,017276	0.249060	-0,069364	0,9447
Educación x Edad***	-0,039124	0,011808	-3,313387	0,0009
Educación x TContrato**	0,699256	0,322812	2,166138	0,0303
C***	-4,038665	0,454502	-8,885905	0,0000

Nota: Adaptado de DANE (2014). *Nivel de significancia al 0,1. **Nivel de significancia al 0,05. ***Nivel de significancia al 0,01.

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Research Article

Perceptions of affiliates to private pension funds

Percepciones de afiliados a fondos de pensiones privados

Jorge Braulio Guillen*

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Palabras clave: Modelos SEM, Fondos de pensiones privados, Transferencias.

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Abstract

The following paper studies the determinants of choosing a private pension fund institution by processing a questionnaire of 514 affiliates. The questionnaire attempts to measure perceptions of the consumer with respect to their private pension fund institution. Using a structural equation model, we found that socioeconomic variables are irrelevant but some perceptions like the return of portfolio and leadership of the private pension fund were relevant in the choice of a private pension fund institution. We contrast the model in two different periods of time between 2009 and 2016. The periods before and after financial turmoil in the stock market.

Resumen

El siguiente artículo estudia los determinantes de la elección de un fondo de pensiones privado, mediante el procesamiento de un cuestionario de 514 afiliados. El cuestionario intenta medir las percepciones del consumidor con respecto a sus AFPs. Usando un modelo de ecuación estructural, encontramos que las variables socioeconómicas son irrelevantes, pero algunas percepciones como el retorno de la cartera y el liderazgo del fondo de pensiones privado fueron relevantes en la elección de una institución de fondos de pensiones privada. Contrastamos el modelo en dos diferentes períodos de tiempo : 2009 y 2016. Estos son los períodos antes y después de la turbulencia internacional en el mercado de valores.

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Introduction

Private pension funds institutions are very important for economies (Barrientos, 2001; Acuña, Palomino, Villar, Villagómez, and Valero, 2014; Corbo and Schmidt-Hebbel, 2003). Domestic Savings have been influenced positively since the main purpose of these institutions is mainly[1] to collect workers' contributions for retirement purposes. Retirement should reflect workers' efforts during their years of activity, so it is important to manage and get profitable returns in the retirement fund. The private pension fund system is similar to the 401k plan in the US. The best retirement plan will come after a significant amount of funds accumulated during the affiliate's working life.

In Chile (Kay, 2009), there is a discussion about the sustainability of the private pension fund system. There is a perception that the saving effort does not match the retirement pension. The latter perception can be captured with the replacement ratio. The replacement ratio is the percentage of precautionary retirement pension with respect to actual salary. As long as this ratio is close to 100%, then it means that the affiliate is fully covered with his retirement expenses. In Chile, the retirement ratio is 30%, so there is a discomfort and suspicion with respect to the efficiency of private pension funds. This ratio varies across different countries because regulations of private pension institutions are different for every single country.

Given this discomfort with respect to precautionary savings, we attempt to study the perception of the affiliate in selecting their private pension fund institution. We have processed a survey of 520 respondents. The respondents answer different questions regarding preferences with respect to private pension funds. For example, the respondent ranks in a Likert scale prestige, leadership in the market, return of portfolio, fees, service, and attention of a private pension fund institution.

Our study analyses what the main drivers are in selecting a private pension fund institution for two different periods of time: 2009 and 2016, the years before and after the volatility of the stock market and pension funds due to the subprime crisis.

During the second half of 2008, the international financial crisis created some negative effect in the region which produced some exposure in the Latin American private pension funds. Titelman, Pérez-Caldentey y Pineda (2009) verified the latter effects of the financial crisis on the region.[2] Even Latin American economies slow down because of financial turmoil.

Our paper is divided as follows: the next section describes the latest reform of private pension funds, then the structural model of selecting a private pension fund is introduced, Results and conclusions area made afterwards.

1 In some countries like Mexico, we have two institutions managing pension funds: AFORES - Administradora de Fondos para el Retiro (Fundraiser for Retirement) and SIEFORES - Sociedad de Inversión Especializada en Fondos para el Retiro (Investment Company Specialized in Retirement Funds). The former collects the money from workers and the latter invests it.

2 The authors explain that compared to the previous international crisis, the effect of recent financial turmoil can be a credit crunch and fall in exports.

Reforms of private pension funds

In 1980, Chile took the unprecedented step of switching from a pay-as-you-go pension system to a private pension system (fully funded). There are several countries in the region that followed the Chilean path: Peru (1993), Colombia (1993), Argentina (1994), Uruguay (1996), Bolivia and Mexico (1997), El Salvador (1998), and Costa Rica (2001). The private pension funds are mainly regulated and monitored by Superintendencia de Administradoras de Pensiones – SPPF (Superintendence of Pension Administrators) except Uruguay, where Central banks assume this role of assessment and surveillance.[3]

Except for Chile[4], the new system coexists with the old in some countries. Therefore, Fully Funded and Pay as You Go are competing with each other (Barassi, Bertín, Musalem, 2009). In Argentina, the government took the private fund and there is no fully funded system anymore.[5]

The regulation of private pension funds differs across countries. Besides the establishing of the private pension system in Latin America, other countries in other regions joined the system: Australia, Eastern Europe, Hong Kong, Israel and New Zealand (Impavido, Lasagabaster, and Garcia-Huitron, 2010). The model of funding without any government participation was accepted in favor of the establishing of the system in the countries.

There is also a study[6] that claimed positive effects of the private pension system in Chile and the region. However, there are some caveats and revisions that need to be fixed and done in order to improve the efficiency of the system in favor of the affiliate. The plans do not account for most of the popularity.[7]

The problem is that also the Pay as You Go System is not the perfect substitute to the Fully Funded mentioned above. There is a lack of credibility about pension and governance (Besley and Prat, 2005)[8]

In general, Impavido et al., 2010 conclude that there are problems in both systems related to market efficiency, competition regulation and the return of funds; mainly low coverage[9] is still a caveat in both systems which does not allow better pensions (see Figure 1).

3 In Colombia, the Superintendencia Financiera (Financial Superintendence) do the control for the private pension funds.

4 In Chile Fully Funded exist alone with a solidarity pillar in order to cover the exposure of low-income families.

5 The financial crisis of 2001 in Argentina affected negatively the portfolio of the private pension fund institutions and the government took the decision to expropriate the fund and manage those. The private pension funds in Argentina concentrate their portfolio in public stocks that were affected by the 2001 Argentinian crisis (Kay, 2009).

6 Corbo and Schmidt-Hebbel (2003), Gill, Packard, and Yermo (2005), Cerda (2008) and Acuña et al. (2014).

7 See Mesa-Lago (2014) and Kay (2009) how Argentina nationalized its private retirement plan and Bolivia did the same in 2011.

8 The model by the author produces a number of predictions accounting between facts of the media industry, media capture, and political outcomes which are consistent with the countries´ reality.

9 This is associated with labor frictions. The coverage problem is always linked to evasion (Queisser and Whitehouse, 2006) and informality. Higher ratios of evasion and informality bring lower coverage for the private pension funds.

Figure 1. Coverage of private pension funds

*Working labor force refers to people occupying a job. This situation happens in an informal economy, which is the case of Peru.

Source: AIOS

We can see from the figures above that coverage is a common problem in the Latin-American Region. Coverage is measured under several ratios of Affiliates as ratio of labor force, contributors as share of labor and contributor as ratio of affiliates. As long as the ratio increases, then coverage rises.

There should be room for improvement still. In Peru, the coverage is very low, and it does not provide economies of scale may reduce fees. Melguizo, Bosh, and Pages (2015) added a contribution regarding coverage problems claim that despite perspectives of low economic growth and reduced fiscal space, the region is going through intense demographic and socio-economic changes, which increase the demand for better jobs and provide a real opportunity for initiating the bold reforms in pensions, labor, and taxes needed to achieve universal coverage.

Also, Blommestein et al. (2009) evaluated the risk of the private pension (Fully Funded) and collective system (Pay as You Go). The authors conclude that the hybrid plan seems to be more efficient than the independent plan which relies on one of the schemes. The author uses cost-benefit analysis, employing replacement (retirement salary/salary) ratio and funding ratio (asset/liability) to perform the assessment.

For Impavido et al., 2010, the indexation plan is the best in terms of risk exposure, and it is preferred by the affiliates. The ability to commit intergenerational risk sharing is also a key element that permits the preference among pensioners. The main concern for the private pension system is the downside of the stock market and the absence of acceptable protection against insolvency of the plan sponsor that guarantees benefit. Also, for the pay-as-you-go system, the concern is that young workers with a large human to financial capital may end up paying the elderly which is not optimal for this system.

The research of the pension system, either called Pay as You Go or Fully Funded, shed light on different aspects. In the literature, we would like to focus on the discussion of the consumer preferences in order to have a better form of social welfare. Therefore, to find determinants of motives to remain in the private pension system is relevant for this study, we will control for socioeconomic and demographic effects under two different periods of time: 2009 and 2016.

The survey has been conducted in Peru for a large and significant number of respondents. The questionnaire has been provided by a private institution in order to capture the preferences of affiliates with regards to their selection of a private pension institution. Most of the questions open in the discussion above will be answered in our sample study.

The next section will describe the model that allows to perform the assessment. The technique is called the Structural Equation Model (SEM), which is a method that quantifies qualitative scales. Then we can capture social welfare related to preferences of consumers with regard to their utility preference for a private pension institution.

The Structural Equation Model (SEM) for affiliate´s perception

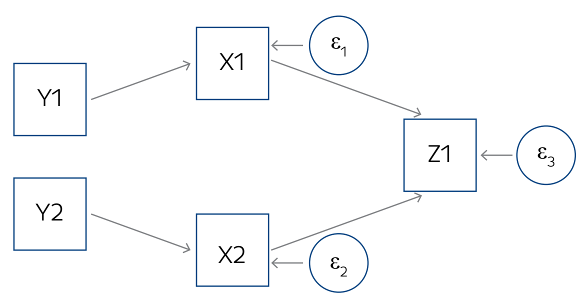
The Structural Equation Model (SEM) is an empirical technique used for business literature (Jöreskog and Sörbom, 1982). The methodology can capture relationships between qualitative variables and quantitative variables as well. SEM allows to exploit the best assessment of a survey of respondents for any decision-making after finding significant relationships that any other technique fails to explore and highlight. Recently, there have been several applications of SEM, for example, in the literature of tourism, Chaitip et al. (2010) run an analysis between tourist travel motivations (travel cost satisfaction and tourist demographics) and tourist destination (tourism product, tourism product attributes, and tourism product management). These latter perceptions are difficult to capture in a regular econometric perspective like Panel or Pool Data Analysis. However, SEM can assess unobservable 'latent' constructs.

The regular procedure of estimation of SEM is to run a measurement model that defines latent variables, using one or more observed variables, and then estimate a structural model that imputes relationships between latent variables. The links and estimations can be estimated under regression equations. Structural equation modeling has been widely used in the sciences, business, education, and other fields (Goldberger, 1972).

However, there are some disadvantages of SEM methods which often addresses pitfalls in a mathematical formulation, linearity or not of the relationship, weak external validity of some accepted models, subject to sampling and philosophical bias inherent in the standard procedures (see for example Westland, 2015, and MacCallum et al., 1996).

There are three models in SEM[10], the first is the Path Model which is the application of structural equation modeling without latent variables. One of the advantages of this type of assessment is the inclusion of relationships among variables that are used as predictors in one single model. Figure 2 explains the latter idea.

Figure 2: Path analysis-Observed variables



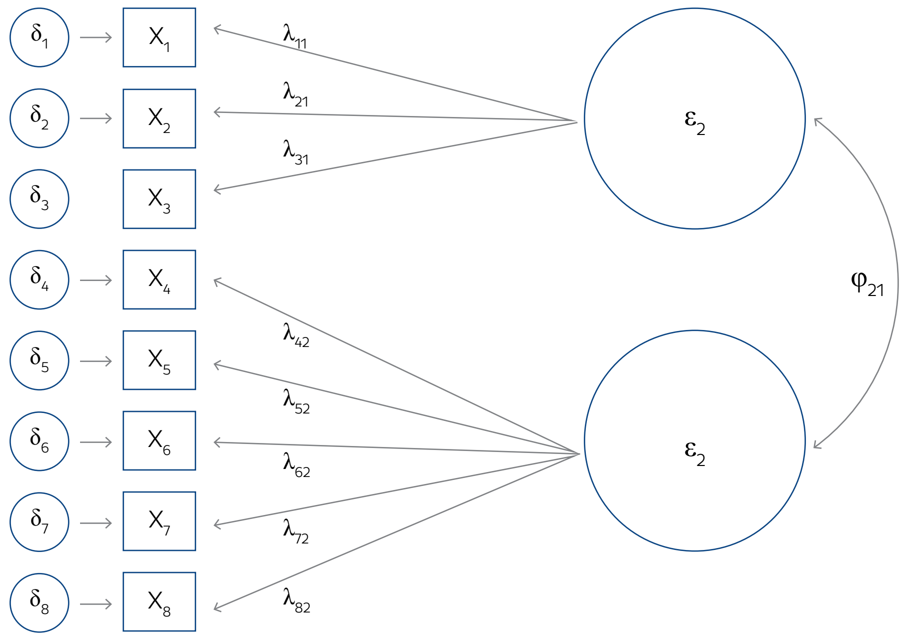
Source : Bagozzi (2012)

X, Y and Z are variables related in the model

The next group of SEM model is the Confirmatory Analysis. This model estimates the paths that link each indicator to their corresponding factor o latent variables. Here we can process surveys and combine qualitative with quantitative variables as well. Confirmatory Analysis is still a bit exploratory, the confirmatory can be run the previous conception of the theoretical model the researcher has discussed previously in the literature. Figure 3 shows a simple path diagram of a two-factor CFA.

10 See for example Bagozzi and Yi (2012), and Bentler (1980).

Figure 3: Latent variable Structural Model

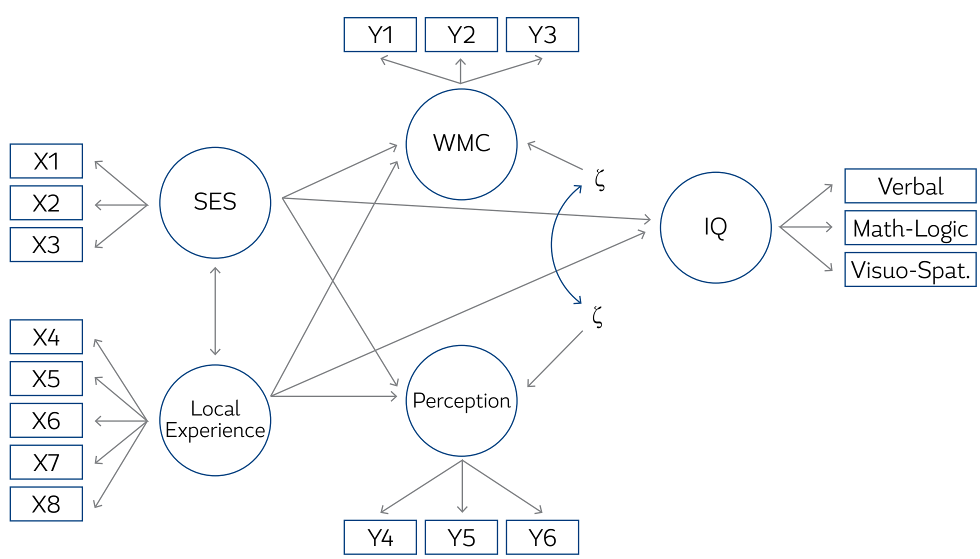


Source : Bagozzi (2012)

X_1 to X_8 are variables related in the model

The model below is the more accurate representation of the SEM model. It combines the measured latent variables within the path analysis framework already explained above. Once you have declared the latent variables, then we can verify the researcher hypothesis and test their relationships with this more complex model. The relationship can be as shown in Figure 4.

Figure 4: Structural Equation Model



Latent Variable Structural Model

Source : Bagozzi (2012)

X_1 to X_8 are variables related in the model, the variables SES. Local Experience, WMC and IQ and Perception are latent variables. For example IQ has its own factor variables verbal, math and Visual Spatial

There are more variations of the Model that may include moderations and double Moderations. We can mix observed and unobserved variables which are captured in a latent relationship. Also, control variables in the form of dummies can be attached for the inferential exploration.

In our paper we will analyze the relationship of the affiliate according to the Latent Variable Structural Model; socioeconomic control variables are addressed for this purpose. There is no empirical framework that has been used before in the literature of provisional studies that have accomplished such inference. Considering the privilege of a survey for the Peruvian case, we can start the exploration of the latter model in the following section.[11]

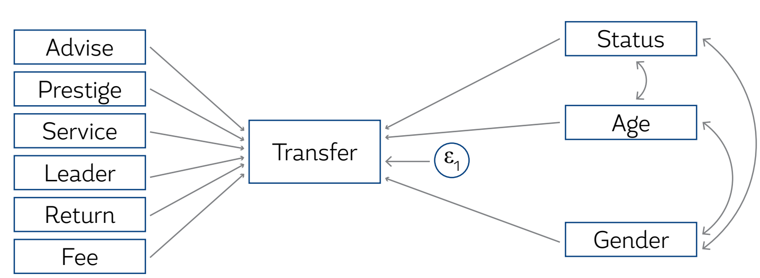
Data analysis and model estimation of affiliate's preferences

We employ a survey of perceptions for 804 respondents which was made in 2009. The same survey was conducted in 2016 with 513 respondents. The survey asks for questions about the perception of the affiliate with respect to their private pension Funds. Socioeconomic variables are also included in the Survey like gender, economic status, and age. We will try to explore if the latter control variables may infer in our assessment.

Perception questions to the respondents were classified in a Likert scale, they were asked to rank the relevance of prestige of their private pension fund, the leadership of the private pension fund in the system, the return of the fund, fees charged by the pension fund and the relevance of customer service. The variables were attempted to be attached in a single latent variable of perceptions, but the confirmatory analysis did not provide a significative agglomeration.[12]

Before estimating the structural model, we have made some estimation of correlation between latent, observed and control variables in a measurement model. We have finally ended up with the following structural model (Figure 5) to be tested in order to verify the determinants of the perception of an affiliate to their private pension fund.

Figure 5: Structural Model of affiliate's perception



Elaboration: Own

11 Only Patrami et al. (2018) used an application of SEM to show that intention of Bogor City to pension funds in the retirement planning is influenced by subjective norms.

12 Munnell and Sundén (2001) and Ring (2005) made some relevant assessments regarding the importance of Trust in selecting a private pension. Also, Van Dalen, H. P. and Henkens, K. (2018). mentioned the importance of freedom of choice for precautionary savings

Figure 5 shows the Theoretical Structural Model to be estimated later. Socioeconomic variables like social status, age and gender are included as control variables in the model. The variable transfer captures the preference of the affiliate to change his private pension fund. The socioeconomic variables may influence the decision to switch to a different precautionary system provider. There should be some correlation between the variables which is captured under SEM methodology.

Finally, we have included several variables of affiliate's perceptions like the importance of receiving advice, the leadership of the system, the return of portfolio, fees[13] and the prestige of the private pension system. We may expect the sign of these perception variables to be negative, if the affiliate considers the perception variables as relevant, then it may reduce the probability of changing the private pension fund.

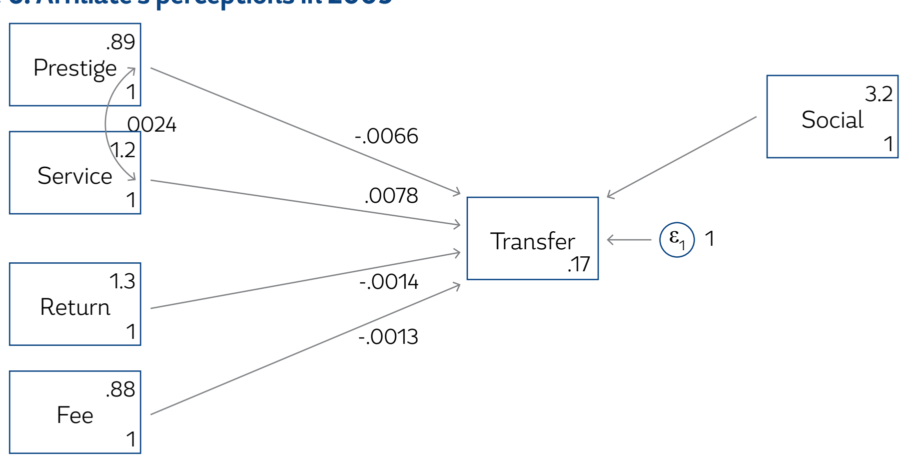
We can infer what the main variables are that affect the affiliate's decision to select a private pension fund. The next section will include the estimation and results to the model specified above.

Model results for two different periods of time

The results are split for two samples, one for 2009 and the other for the most recent event in 2016. The estimation for the two periods of time permits us to see any structural change after the financial turmoil of 2009. The financial crisis may have some impact in willingness to invest and affiliate perceptions (Antolín and Stewart, 2009).[14]

The figure and table below summarize the results for 2009, the period of financial turmoil in the stock markets. The variables here were not significant, there is no single determinant to the affiliate. Socioeconomic variables of control, as well as affiliates' perceptions, are not significant. The financial turmoil may have triggered some unreliability on the precautionary savings system. The result goes along the lines of some previous findings discussed above in Titelman et al. (2009). There is a concern about the sustainability of the system (Mesa-Lago, 2014) which is activated during the period of global stock market volatility. Figures 6 and 7 show the result for 2009 and 2016 periods.

Figure 6: Affiliate's perceptions in 2009

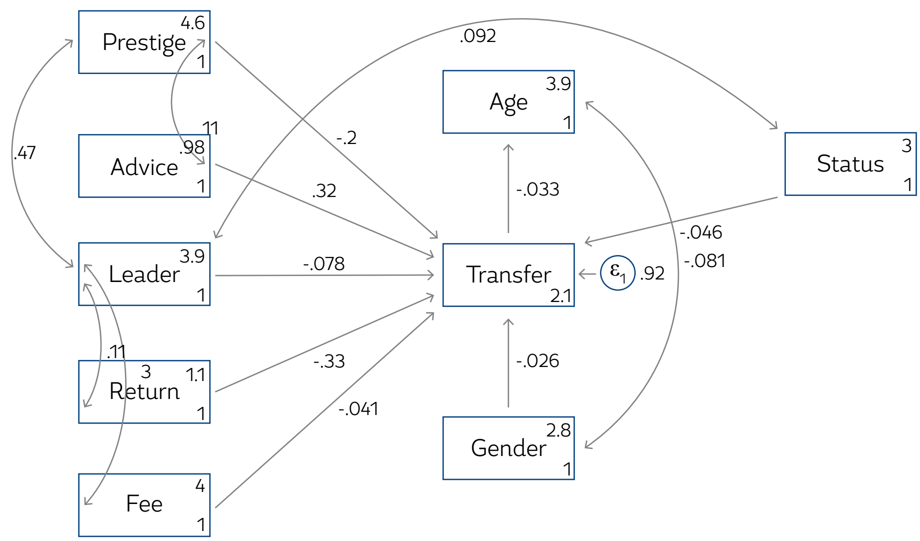


Elaboration: Own

13 Fees are related to the problems faced in the previous section, regarding the coverage and avoidance of drop fees. Our purpose is to find if this variable is relevant to the affiliate's perception.

14 The article is an OECD report about the relevance of private pension funds and they point out the lack of financial education for the affiliate.

Figure 7: Affiliate's perception in 2016



Elaboration: Own

Table 1: Structural Model for affiliate perceptions (2009)

Dependent variable: Transfer							
Variables	Coef	Std. err.	z	P>|z|		[95% Conf]	
Structural transfer							
Service	0.0077781	0.0352675	0.22	0.825		-0.0613450	0.0769012
Return	-0.0014365	0.0493286	-0.03	0.077	*	-0.0981188	0.0952458
Fee	-0.0013346	0.0493094	-0.03	0.978		-0.0979792	0.0953101
Prestige	-0.0065741	0.0352817	-0.19	0.852		-0.0757250	0.0625768
Social status	0.0346319	0.0352769	0.98	0.326		-0.0345096	0.1037733
_Cons	0.1731633	0.1376432	1.26	0.208		-0.0966124	0.4429389
Observations	803						
LR test of model vs. Saturated: chi2(0) = 0.00, Prob> chi2= .							
*** Significant at 1% ** Significant at 5% *Significant at 10%							

Source: Own elaboration.

Table 2:

Statistic	Value
Likelihood ratio	
chi2_bs(5)	1.059
p>chi2	0.958
Baseline comparison	
CFI	1.000
TLI	1.000
Size of residuals	
CD	0.079
SRMR	0.001

Source:

Table 3: Structural Model for affiliate perceptions (2016)

Variables	Coef.	Std. err.	z	P>|z|		[95% Conf]	
Structural transfer							
Age	-0.0327194	0.0429781	-0.76	0.446		-0.1169548	0.051516
Advise	0.3159606	0.2036847	1.55	0.121		-0.0832541	0.7151753
Leader	-0.077877	0.0488471	-1.62	0.100	*	-0.1736155	0.0178615
Return	-0.3267833	0.2036817	1.6	0.109		-0.725992	0.0724255
Fee	-0.0413271	0.0478005	-0.86	0.387		-0.1350144	0.0523602
Prestige	-0.1990706	0.0505995	-3.93	0.000	***	-0.2982438	-0.0998973
Social status	-0.0455993	0.0431336	-1.06	0.290		-0.1301395	0.0389409
Gender	-0.0264457	0.0429762	-0.62	0.538		-0.1106776	0.0577862
_Cons	2.06346	0.3386918	6.09	0.000	***	1.399636	2.727283
Observations	**510**						
LR test of model vs. Saturated: chi2(0) = 0.00, Prob> chi2= .							
*** Significant at 1% ** Significant at 5% * Significant at 10%							

Source: Own elaboration.

Table 4:

Statistic	Value
Likelihood ratio	
chi2_bs(5)	41.904
p>chi2	0.000
Baseline comparison	
CFI	1.000
TLI	1.000
Size of residuals	
CD	0.070
SRMR	0.000

For 2016, the result differs from the period of financial turmoil. The perception variables of leadership and prestige were relevant in the decision of switching a private pension fund. As long as the affiliate considers the leadership of his private pension fund relevant, then his decision to change private pension fund drops. The same results are for the perception variable prestige, if the affiliate considers the private pension fund prestige relevant, then he is very unlikely to switch to another private provider of precautionary savings.

The variable advice had the opposite expected sign, but it was not significant. In addition, the variable fee has the expected sign, but it did not result as significant either. Finally, the socioeconomic variable status did not result as significant.

The fee result was irrelevant. It means that the previous discussion about informality, coverage and consequent drop of fees does not necessarily affect any decision of the affiliate regarding his preference for a private pension fund. Our study attempts to look for an improvement in the welfare of the customer of precautionary savings.

Our purpose is not to predict the decision to change a private pension fund but to find the determinants of the latter decision. Our result in 2016 is consistent and fit statistics were relevant as well (see tables below). Tables 1 and 3 present the result of the SEM model for 2009 and 2016 periods. Tables 2 and 4 show the reliability of the same model for the 2009 and 2016 periods. The assessment is relevant to explore customer´s loyalty in the private pension funds.

Conclusions

We have concluded that there is structural change over time in the perceptions of affiliate to private pension funds. For our two surveys conducted in 2009 and 2016, perceptions vary for the decision to change a private pension fund provider.

In 2009, there is no driver to commit a decision to change a private pension fund, neither socioeconomic variables nor preferences are relevant for the dependent variable: change a private pension fund. Financial turmoil triggered unreliability in the precautionary savings system.

For 2016, the perception variables: leadership and prestige were relevant in the decision of selecting a private pension fund. If the affiliate considers leadership of his private pension fund relevant, then his decision to change a private pension fund drops. The same results are for the perception variable prestige. If the affiliate considers the private pension fund prestige relevant, then he is very unlikely to switch to another private provider of precautionary savings.

Our results are relevant for marketing purposes in the process of capturing new affiliates. Once we know which preference is relevant in the affiliate, then we can assign resources in the internal firm in order to enhance these relevant preferences to get more affiliates for the firm. Market segmentation made by our control variables: gender and social status were not relevant in the preference for a private pension fund provider.

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Dependencia condicional en el bloque TLCAN: un análisis con modelos GARCH y Cópula

Conditional dependence in NAFTA block: GARCH model and Copula approach

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Research Article

Dependencia condicional en el bloque TLCAN: un análisis con modelos GARCH y Cópula

Conditional dependence in NAFTA block: GARCH model and Copula approach

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Palabras clave: Dependencia Condicional, TLCAN, GARCH Cópula, Efecto Contagio

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Resumen

El presente artículo tiene por objetivo analizar la dependencia condicional entre los mercados de valores de Estados Unidos, México y Canadá durante el período 2003-2018. Las Cópulas Arquimedianas y Elípticas, así como los modelos GARCH y TARCH son utilizados para realizar la modelación en tres subperíodos: antes, durante y después de la crisis financiera global. Los resultados evidencian un incremento promedio de 38 % de la dependencia condicional en la crisis financiera, con respecto al período previo; asimismo, existe una leve disminución del parámetro de dependencia al modelar la asimetría en la volatilidad de las series.

Abstract

This article aims to analyze conditional dependence between the Mexican, American and Canadian stock markets during the period 2003-2018. Archimedean and elliptical Copulas and GARCH and TARCH models are employed to estimate conditional dependence in three subperiods: pre-crisis, crisis and pos- global financial crisis. Results reveal a 38% rise in conditional dependence during the crisis period, in relation to the previous period. On the other hand, the conditional dependence parameter diminishes when asymmetry is included.

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Cambios importantes en el contexto financiero global (regulación, evolución tecnológica e innovación financiera) han impactado, crecientemente, la interrelación de los mercados financieros, sobre todo de las bolsas de valores, aumentando la probabilidad de efecto contagio, especialmente, entre aquellos que sostienen diversos nexos económicos y comerciales. Tal es el caso de los mercados pertenecientes al Tratado de Libre Comercio de América del Norte (TLCAN), los cuales se han caracterizado por tener una progresiva relación a partir de la firma de dicho tratado.

La crisis financiera global, cuyo principal antecedente es la crisis *subprime*, ha puesto de manifiesto la cohesión y fragilidad de los mercados de capital ante desequilibrios externos, incrementando la atención sobre la naturaleza de las interrelaciones bursátiles, su evolución y cambios abruptos en la intensidad de estas ante eventos extremos o momentos de calma e incertidumbre.

El contagio y dependencia financieros son temas tratados recurrentemente en la literatura, debido al impacto de dichos fenómenos en la formulación de políticas económicas, la localización eficiente de activos, y el desarrollo de estrategias de diversificación y cobertura del riesgo. Dichos temas atañen tanto a inversionistas como a las autoridades económicas, así como a académicos y profesionales que se encuentran profundamente relacionados con el campo de las finanzas.

La presente investigación se suma a las ya existentes, aportando evidencia empírica sobre cambios en la dependencia condicional entre los mercados de capitales de los países pertenecientes al TLCAN, los cuales apuntan a develar la existencia de efecto contagio, durante el más reciente y profundo desequilibrio bursátil a nivel internacional: la crisis financiera global. Para lograr dicho objetivo, se utiliza una metodología relativamente reciente y complementaria, que integra dos modelos generalizados autorregresivos con heterocedasticidad condicional (GARCH y TARCH), y la estimación vía cópulas.

El estudio abarca de 2003 a 2018, subdividido en tres períodos: antes, durante y después de la crisis financiera global, permitiendo determinar si hubo cambios en la dependencia condicional, si dichos cambios sugieren la presencia de efecto contagio y cuál fue la magnitud de dicho efecto. La estructura del trabajo es la siguiente: después de la presente introducción, se revisa la literatura relacionada; la tercera sección describe los datos y la metodología; la siguiente presenta y analiza los resultados de la estimación; y la quinta sección concluye.

Revisión de la literatura

El contagio y dependencia financieros son temas extensamente tratados en la literatura. En términos empíricos, se han desarrollado diversas aproximaciones para analizar los cambios en las relaciones entre diversos mercados financieros. El término contagio hace referencia, en su acepción más general, al incremento en la relación entre dos mercados, a partir de un desequilibrio o *shock*. Otro concepto ampliamente utilizado es aquel de interdependencia, fenómeno caracterizado por la existencia de altos niveles de relación entre mercados.

Ambos temas han sido probados a lo largo de la literatura. Por ejemplo, Bennet y Kelleher (1988), King y Wadhwani (1990), y Musumeci y Sinkey (1990) encontraron evidencia de efecto contagio en el *crash* de 1987, originado en Estados Unidos. Frankel y Schmukler (1996), al igual que Calvo, Leiderman y Reinhart (1996), analizaron el impacto de la crisis de 1994. Por su parte, Chiang, Jeon y Li (2007), y Baig y Goldfajn (1999) estudiaron la transmisión de la crisis asiática; mientras Baig y Goldfajn (2001), y Haile y Pozo (2008) investigaron los efectos de la crisis rusa; y Aloui, Aïssa y Nguyen (2011), Dimitriou, Kenourgios y Simos (2013), y Bekaert, Ehrmann, Fratzscher y Mehl (2014) analizaron el contagio causado por la más reciente —y aún no resuelta— crisis financiera global (CFG), cuyos efectos tuvieron como principal antecedente la denominada "crisis *subprime*".

Forbes y Rigobon (2002), Loretan y English (2000), y Boyer, Gibson y Loretan (1997) han demostrado que la correlación convencional puede conducir a resultados sesgados e inadecuados en la modelación de relaciones financieras, debido a que no captura hechos estilizados en las series (como heteroscedasticidad, colas pesadas, conjuntos de volatilidad, memoria larga y asimetría). Además, la correlación lineal puede arrojar resultados espurios (Forbes y Rigobon, 2002; Baur, 2003). Para superar dichas limitaciones, se propone una metodología basada en la teoría de cópulas, la cual arroja mejores estimaciones, ajustándose para capturar el comportamiento de las series financieras.

Otros estudios, como aquellos realizados por Cheung, Fung y Tsai (2010), sugirieron que, en la crisis financiera global no solo ocurrió contagio, sino que también hay evidencia de que, en algunos mercados, la interdependencia se hizo más fuerte durante los momentos de crisis. En esta misma dirección, Samarakoon (2011) afirmaba que, durante dicha crisis, se encontraron efectos de ambos fenómenos (interdependencia y contagio) en mercados emergentes. Los resultados apuntaron a que el fenómeno de interdependencia estaba más ligado con los desequilibrios generados en Estados Unidos, mientras que el contagio estaba relacionado con los *shocks* provenientes de economías emergentes.

En dirección contraria a las investigaciones presentadas al inicio de esta sección, existen otras, como aquellas desarrolladas por Forbes y Rigobon (2002), donde se argumentó que, al estimar la correlación condicional, se pudo encontrar que no existió contagio en el *crash* de Estados Unidos en 1987, la crisis mexicana y la asiática, entre algunos países como: Estados Unidos, Canadá, Japón, Reino Unido y Alemania, sino que ha sido un fenómeno de interdependencia, debido a que la correlación entre dichos mercados se ha mantenido en niveles altos, en los períodos previos y posteriores a dichos eventos.

Como se observa en la literatura previamente analizada, los resultados respecto a la relación entre mercados financieros en episodios de incertidumbre son mixtos, debido a que estos dependen del tipo de análisis empírico que se lleve a cabo. En este sentido, se han desarrollado análisis complementarios, cada vez más refinados, con la intensión de obtener evidencia más acertada.

Algunos de los modelos que se han utilizado para configurar los cambios en la dependencia entre mercados financieros son aquellos de tipo Autorregresivo con Heteroscedasticidad Condicional (ARCH, por sus siglas en inglés). Dentro de dichos estudios, se encuentran aquellos que incluyen en el análisis a países en desarrollo, como aquel realizado por Marçal, Valls Pereira, Martin y Nakamura (2011), quienes investigaron el efecto contagio durante la crisis mexicana y asiática; sus resultados apuntaron a que los efectos se esparcieron de Asia a Latinoamérica, pero no en dirección opuesta.

Otro estudio que incluye tanto a países desarrollados como emergentes es aquel elaborado por Celik (2012), quien encontró que, durante la crisis financiera global, existió efecto contagio para la mayoría de los países bajo estudio; sin embargo, aquellos que sufrieron mayor efecto fueron los mercados emergentes. En esta misma dirección, Chittedi (2015) analizó los cambios en las relaciones entre los mercados de valores de India y Estados Unidos, a partir de la CFG; la evidencia señala que hubo un incremento importante en los niveles de correlación, durante las fechas cercanas a los efectos de dicha crisis.

Otra de las aplicaciones de los modelos ARCH, relacionada con los temas de contagio y dependencia, fue aquella implementada por Billio y Caporin (2005), quienes estimaron la correlación incondicional y los parámetros necesarios para analizar procesos de Markov no observables. Los resultados obtenidos son comparados con la evidencia de modelos de correlación condicional dinámica (DCC) y correlación condicional constante (CCC).

Además de los modelos ARCH, los fenómenos de contagio e interdependencia han sido aproximados empíricamente a través de la estimación de relaciones de dependencia entre mercados empleando cópulas. Rodríguez (2007) usó la metodología de cópula con parámetro cambiante, para analizar el efecto de la crisis mexicana y asiática en las relaciones entre los mercados latinoamericanos y del este asiático. Los resultados apuntaron a que hubo efecto contagio en ellos.

Chen, Wei, Lang, Lin y Liu (2014) emplearon cópulas multifractales para analizar la estructura de dependencia entre los mercados de valores de Estados Unidos y China. La evidencia empírica sugirió que el efecto contagio comenzó en Estados Unidos y tuvo una repercusión en el mercado chino. Empleando la misma metodología que Chen et al. (2014), Moreno (2017) investigó sobre el contagio financiero en una muestra de países europeos y latinoamericanos, donde sus resultados indicaron la presencia de contagio entre los países bajo estudio.

Otro estudio que incluyó la metodología de cópulas para analizar la relación de dependencia entre mercados, fue el realizado por Nguyen, Bhatti y Henry (2017), donde se analizó si los mercados de Vietnam y China fueron afectados por los desequilibrios generados en el estadounidense. Los hallazgos revelaron efectos diferenciados para los mercados de Vietnam y China, existiendo gran potencial de diversificación.

Con base en lo anterior, se puede señalar que los modelos de la familia ARCH y las cópulas son aproximaciones empíricas que permiten analizar a detalle los cambios en la relación de dependencia entre los mercados de valores. Dentro de los estudios que han empleado la metodología de Cópula-GARCH, se encuentra el de Su (2017), quien analizó la dependencia de cola y el riesgo de contagio entre los mercados de Taiwan, Corea del Sur, Estados Unidos, China y el índice global europeo MSCI Europe. Los resultados sugirieron efectos diferenciados de la crisis *subprime* y de la crisis de la deuda soberana griega, en términos de los estados de tendencia y salto del riesgo de contagio.

Mokni y Mansouri (2017), por su parte, estudiaron la relación entre los principales mercados de valores a nivel mundial, donde la evidencia indicó que la estructura de dependencia fue afectada en el largo plazo en la volatilidad. Otros estudios, anteriores a los mencionados, que emplearon la metodología Cópula-GARCH para estudiar la dependencia en mercados financieros, fueron los de Wei y Zhang (2004), Jondeau y Rockinger (2006), Huang, Lee, Liang y Lin (2009), y Aloui, Aïssa y Nguyen (2013).

El presente trabajo se une a los esfuerzos académicos antes citados, con el objetivo de analizar la dependencia condicional entre los mercados de valores de los países que componen el bloque TLCAN. El análisis propuesto incluye una metodología, relativamente innovadora y complementaria, denominada Cópula-GARCH, en la cual se estima la volatilidad de las series a partir de modelos de la familia ARCH, uno simétrico (GARCH) y otro asimétrico (TARCH) y, una vez estimada la volatilidad, se aproxima la relación de dependencia entre dichas series por medio de la cópula.

Metodología y descripción de los datos

La estimación del modelo Cópula-GARCH se realizó empleando los datos de los principales índices bursátiles de México (IPC), Canadá (TSX) y Estados Unidos (S&P500), para el período enero/2004-marzo/2018, todos ellos en dólares, para incluir el efecto del tipo de cambio. Igualmente, todas las series fueron homologadas, eliminando los días en los cuales los mercados no operaron. La muestra total incluyó 3425 datos diarios, divididos en tres subperíodos: precrisis (ene/2004-jul/2007), crisis (ago/2007-dic/2012)[1] y poscrisis (ene/2013-mar/2018).

Los modelos GARCH y todas sus posibles variantes se han planteado como instrumentos de análisis idóneos en el estudio de las variables financieras, ya que permiten modelar las características de las series financieras (asimetría, exceso de curtosis, conjuntos de volatilidad, por mencionar algunas). La modelación de la volatilidad se realiza a partir de modelos autorregresivos con varianza condicional GARCH (1,1) y TARCH (1,1). Para la modelación de las series, son utilizados rendimientos diarios de los índices bursátiles, los cuales son estimados a través de la diferencia de los logaritmos naturales del precio de cierre de dos días consecutivos de operación, es decir:

$$R_t = \log (SY\,P500)(t) - \log (SY\,P500)(t\text{-}1) \tag{1}$$

Una condición necesaria para la aplicación del modelo es que las series sean estacionarias, es decir, que no presenten raíz unitaria. Para probar que dicha condición se cumple, es aplicada la prueba propuesta por Dickey y Fuller (1979; 1981), la cual, en honor a ambos, se denomina ADF. Siendo R_t el rendimiento diario de las series, la prueba ADF consiste en una regresión de la primera diferencia de las series contra las series con k rezagos, como se describe a continuación:

$$\Delta\, r_t = a + \delta r_{t\text{-}1} + \sum_{i=1}^{p} \beta_i\, \Delta\, r_{t\text{-i}} + \varepsilon_t \tag{2}$$

$$\Delta r_t = r_t - r_{t\text{-}1}\, ;\, r_t = \ln\,(R_t) \tag{3}$$

La hipótesis nula es $H_0 : \delta = 0$ y $H_1 : \delta < 1$.

Modelo GARCH. En cuanto a la estimación de la varianza σ^2 , en el modelo GARCH, desarrollado por Bollerslev (1986) y Taylor (1986), la varianza condicional depende no solo de los cuadrados de las perturbaciones, sino también de las varianzas condicionales de períodos anteriores (Casas Monsegny y Cepeda Cuervo, 2008). Así, la varianza condicional del modelo GARCH (p, q) es especificada como:

$$h_t = a_0 + \sum_{j=1}^{q} a_j\, \varepsilon_{t\text{-}j}{}^2 + \sum_{i=1}^{p} \beta_i\, h_{t\text{-i}} \tag{4}$$

1 Desde el inicio de agosto de 2007, diversas instituciones financieras mostraron problemas que iban desde el cierre de la operación de algunos fondos –como el caso de Bearn Stearns–, hasta la quiebra de algunas compañías; la American Home Mortgage (décimo banco hipotecario en Estados Unidos) y la compañía Blackstone son un ejemplo de ello (Tatom, 2009). Se puede considerar que la “calma” volvió a los mercados a finales de 2013, una vez que se llevaron programas, y planes fiscales y monetarios, relacionados con políticas de austeridad, y que se realizaron rescates en economías como la italiana y la griega.

Donde es necesario que se cumplan las siguientes condiciones, para asegurar que la varianza condicional sea positiva: $\alpha_0 > 0, \alpha_1, \alpha_2, \ldots \alpha_q \geq 0$ y $\beta_1, \beta_2, \beta_3, \ldots \beta_q \geq 0$.

Este modelo también es conocido como GARCH simétrico, ya que se asume que los cambios negativos impactan en la misma magnitud que las variaciones positivas. A h_t se le denomina varianza condicional, pues es estimada a partir de información pasada relevante. Los coeficientes rezagados del GARCH β_i indican que los efectos de cambios en la varianza condicional toman largo tiempo en desaparecer, a esta propiedad de la serie se le denomina persistencia en la volatilidad. Grandes valores en el coeficiente de error del GARCH α_j indican que la volatilidad reacciona intensamente a los movimientos del mercado. Si el valor de $(\alpha+\beta)$ es cercano y menor a la unidad, significa que un choque recibido en el tiempo t persistirá en períodos futuros. Un alto valor implicará que la serie tiene memoria larga (Joshi, 2012). Posteriormente, el modelo es probado para efecto ARCH, usando la prueba ARCH-LM. Si el resultado de esta prueba resulta no significativo, el modelo será adecuado (Joshi, 2012).

Modelo TARCH. Para detectar el efecto de la asimetría, han sido desarrollados numerosos modelos, entre los que se encuentran: EGARCH de Nelson (1991); GJR-GARCH de Glosten, Jagannathan y Runkle (1993); T-GARCH de Zakoian (1994); APARCH, desarrollado por Ding, Granger y Engle (1993); PNP-GARCH, utilizado por Bae y Karolyi (1994); y T-GARCH, por Hsin (2004). Dichos modelos son mayormente utilizados en la modelización de volatilidades, ya que capturan de forma diferenciada los efectos de los *shocks* positivos y negativos, siendo útiles tanto en períodos de estabilidad como de incertidumbre.

Para el caso del TARCH, que es el modelo en cuestión, la especificación generalizada de la ecuación de varianza condicional está dada por:

$$\sigma^2 = \alpha + \sum_{j=1}^{q} \beta_j \sigma_{t-j}^2 + \sum_{i=1}^{p} \alpha_i \varepsilon_{t-i}^2 + \sum_{h=1}^{r} \gamma_h \varepsilon_{t-h}^2 d_{t-h} \quad (5)$$

Donde $d_t = 1$ si $\varepsilon_t < 0$.

En este modelo, si $\varepsilon_{t-i} > 0$ los valores positivos del residuo se interpretan como buenas noticias $\varepsilon_{t-i} < 0$ y los valores negativos del residuo representan malas noticias. De igual manera, el efecto sobre la varianza condicional genera que las buenas noticias tengan un impacto de α_1; y las malas, un efecto de $\alpha_1 + \gamma_1$. Si $\gamma_1 > 0$. Las malas noticias incrementan la volatilidad, lo cual se conoce como efecto apalancamiento o *leverage*. Si $\gamma_1 \neq 0$ el impacto de las noticias es asimétrico (Joshi, 2012).

Cópula. Una cópula es una función con las siguientes propiedades:

- $\forall$ u $\in$ [0,1],C (1,...,1,u,1,...,1) = u.
- $\forall$ $u_i \in [0,1]$, C $(u_1, \ldots, u_n)$=0 si al menos uno de los u_i's es igual a cero.
- C está definida y es n-creciente, i.e., el C-volumen de cada caja cuyos vértices se encuentran en $[0,1]^n$ es positivo.

Así, se puede definir la cópula como una distribución multivariada dentro del intervalo $[0,1]^n$ con marginales uniformes, teniendo en consideración cómo se deriva una cópula de una distribución multivariada continua. Por tanto, la cópula es la función de distribución multivariada original, con una transformación hacia una marginal univariada (Sosa, Bucio y Cabello, 2015).

Sea una función de distribución n-dimensional F con distribuciones marginales continuas F_1, ..., F_n, existe una única n-cópula C: [0,1]n → [0,1] tal que:

$$F(x_1, \ldots, x_n) = C(F_1(x_1), \ldots, F_n(x_n)) \tag{6}$$

El teorema de Sklar (1973) permite combinar las marginales, para formar una distribución multivariada. Dada una distribución F con marginales multivariantes F_1, ..., F_n, la función:

$$C(u_1, \ldots, u_n) = F(F_1^{-1}(u_1), \ldots, F_n^{-1}(u_n)) \tag{7}$$

es automáticamente una -cópula. Esta cópula es la de la distribución multivariada . Mediante este teorema, Sklar (1973) señaló que, para cada función de distribución multivariada, se puede derivar fácilmente una cópula. Existen diversas familias, siendo las de mayor utilización en temas financieros las elípticas y Arquimedianas, por sus bondades y características.

Cópulas elípticas. Las cópulas elípticas han sido de las más utilizadas en aplicaciones financieras (Hernández y Sánchez, 2009; Hammoudeh, Nguyen, Reboredo y Wen, 2014) y tienen la particularidad de ser de tipo simétrico. Dentro de esta familia de cópulas, destacan la t-Student y la Gaussiana, que derivan de funciones multivariadas que poseen los mismos nombres. La densidad de dichas cópulas se encuentra representada por:

$$c_{\rho,n}(u_1, u_n) = \frac{1}{\sqrt{\det \rho}} \exp\left(-\frac{1}{2} y^t(u)(\rho^{-1} - Id)\, y(u)\right) \tag{8}$$

$$\text{con } y^t(u) = (\Phi^{-1}(u_1), \Phi^{-1}(u_2))$$

De manera particular, la cópula gaussiana está determinada por el conocimiento de la matriz del coeficiente de correlación ρ.

Cópula t-Student. Sea una distribución t-Student -dimensional $T_{n,p,v}$ con ν grados de libertad y una matriz ρ

$$T_{n,p,v} = \frac{1}{\sqrt{\det \rho}} \frac{\Gamma\left(\frac{\nu+n}{2}\right)}{\Gamma\left(\frac{\nu}{2}\right)(\pi\nu)^{n/2}} \int_{-\infty}^{x_1} \int_{-\infty}^{x_2} \frac{dx}{\left(1 + \frac{x^t \rho^{-1} x}{\nu}\right)^{\frac{\nu+n}{2}}} \tag{9}$$

La cópula t-Student es

$$C_{n,\rho,v}(u_1, u_n) = T_{n,p,v}(T_v^{-1}(u_1), T_v^{-1}(u_2)) \tag{10}$$

Donde T_v es la distribución univariada t-Student con ν grados de libertad.

La densidad de la cópula t-Student es

$$C_{n,\rho,v}(u_1, u_n) = \frac{1}{\sqrt{\det \rho}} \frac{\Gamma\left(\frac{\nu+n}{2}\right)\left[\Gamma\left(\frac{\nu}{2}\right)\right]^{n-1}}{\left[\Gamma\left(\frac{\nu+n}{2}\right)\right]^{n}} \frac{\prod_{k=1}^{n}\left(1+\frac{y_k^2}{\nu}\right)^{\frac{\nu+1}{2}}}{\left(1+\frac{y^t \rho^{-1} y}{\nu}\right)^{\frac{\nu+n}{2}}} \tag{11}$$

$$\text{con } y^t = (T_v^{-1}(u_1), T_v^{-1}(u_2))$$

La cópula t-Student, al igual que la Gaussiana, se basa en el parámetro de correlación ρ; así como en los grados de libertad .

Cópula Gaussiana. La n-cópula Gaussiana con matriz de correlación ρ, se describe a través de la siguiente ecuación:

$$C_{\rho,n}(u_1, u_n) = \Phi_{\rho,n}(\Phi^{-1}(u_1), \Phi^{-1}(u_2)) \tag{12}$$

Donde Φ denota la distribución Normal (acumulada) y $\Phi_{\rho,n}$ denota la distribución Gaussiana estándar -dimensional con matriz de correlación ρ.

Cópulas Arquimedianas. Las cópulas bivariadas de tipo arquimediano son representadas de la siguiente forma:

$$C_{\alpha}(u_1, u_2) = \phi_{\alpha}^{-1}[\phi_{\alpha}(u_1) + \phi_{\alpha}(u_2)], \quad 0 \leq u_1, u_2 \leq 1 \tag{13}$$

donde ϕ_{α} es convexa y decreciente tal que $\phi_{\alpha} \geq 0$. A la función ϕ_{α} se le denomina generador de la cópula Ca y la inversa del generador ϕ_{α}^{-1} es la transformada de Laplace de una variable latente denotada γ, la cual induce la dependencia α. Por ello, la selección de un generador da como resultado diferentes cópulas dentro de esta familia. Por la naturaleza de la presente investigación, se hace referencia a las cópulas Clayton, Gumbel y Frank.

Cópula Clayton. La cópula bivariada de este tipo esta especificada como:

$$C_{\alpha}(u_1, u_2) = \{u_1^{1-\alpha} + u_2^{1-\alpha} - 1\}^{1/(1-\alpha)}, \quad \alpha > 1 \tag{14}$$

con generador $\phi_{\alpha}(t)\ t^{1-\alpha}-1$, y transformada de Laplace $\phi_{\alpha}^{-1}(s) = (1+s)^{1/(1-\alpha)}$.

Cópula Gumbel. La cópula bivariada perteneciente a la familia Gumbel es:

$$C_{\alpha}(u_1, u_2) = \exp\{-[(-\ln u_1)^{1/\alpha} + (-\ln u_2)^{1/\alpha}]^{\alpha}\}, \quad 0 < \alpha < 1 \tag{15}$$

con generador $\phi_{\alpha}(t) = (-\ln t)^{1/\alpha}$, y transformada de Laplace $\phi_{\alpha}^{-1}(s) = \exp\{-s^{\alpha}\}$.

Cópula Frank. Esta cópula bivariada se especifica como:

$$C_{\alpha}(u_1, u_2) = \ln[1 + (\alpha^{u_1}-1)(\alpha^{u_2}-1)/(\alpha-1)] / \ln \alpha \tag{16}$$

$$\alpha > 0$$

con generador $\phi_{\alpha}(t) = \ln \frac{\alpha^t - 1}{\alpha - 1}$, y transformada de Laplace $\phi_{\alpha}^{-1}(s) = \ln[1 + (\alpha-1)e^s] / \ln \alpha$

Estimación de los parámetros de la cópula. Existen diversas metodologías para la estimación de los parámetros de la cópula. En el presente, se utiliza el de máxima verosimilitud, ya que este mecanismo permite estimar los parámetros para cualquier tipo de cópula, maximizando su función de log-verosimilitud. De esta manera, dados el conjunto de marginales y una cópula, la función de log-verosimilitud puede ser maximizada obteniendo, de esta forma, el estimador de máxima verosimilitud,

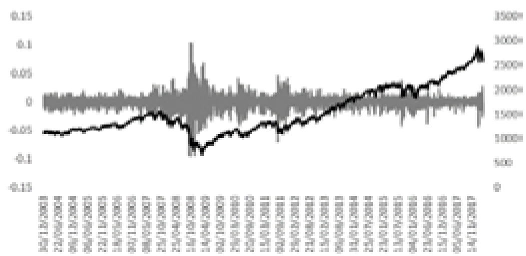
$$\hat{\theta}_{MLE} = \max_{\theta \in \Theta} l(\theta) \tag{17}$$

Evidencia empírica

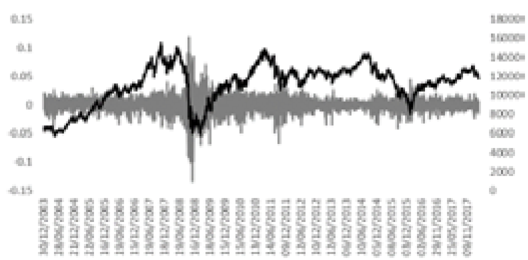
Los datos representados en la Figura 1 revelan el comportamiento de los índices bajo estudio, en niveles y rendimientos logarítmicos, calculados a partir de la ecuación (1). En dicha figura, se puede observar que las series en niveles presentan comportamiento similar, en términos de una caída abrupta en el tercer trimestre del año 2008, período en el cual se globalizó la crisis *subprime*. Igualmente, se presentan caídas conjuntas menores a finales del año 2015 y principios del 2016, lo cual, aparentemente, se debe a la respuesta de los mercados ante las noticias originadas a partir del Brexit y la crisis de la deuda en Grecia. En términos de los rendimientos de los índices, los períodos de las caídas de los bursátiles coinciden con conjuntos de volatilidad.

Figura 1. Índices bursátiles en niveles y rendimientos

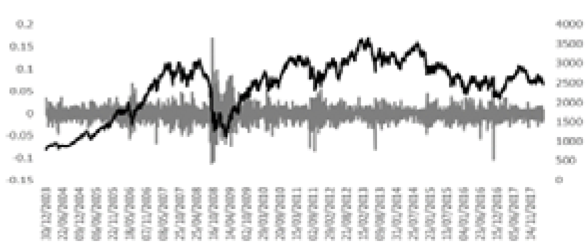
S&P 500



S&P TSX



IPC



Nota: Elaboración propia

La Tabla 1 presenta los estadísticos descriptivos de las series en rendimientos. Como es de esperarse, el mercado de valores mexicano es aquel con la mayor rentabilidad, seguido del estadounidense y el canadiense. El mercado con la mayor variabilidad, medida como la desviación estándar, es el de México, seguido por el de Canadá y EE. UU. Las series presentan sesgo negativo y leptocurtosis; las distribuciones tienen colas pesadas y son puntiagudas. La prueba de Jarque Bera muestra que las series son no normales.

Tabla 1. Estadísticos descriptivos

		IPC	S&P500	TSX
	Media	3,34E-04	2,49E-04	1,81E-04
	Mediana	0,00098	0,000658	0,000868
	Máximo	0,169459	0,104236	0,119323
	Mínimo	-0,112099	-0,094695	-0,132593
	Desviación Estándar	0,016108	0,011878	0,01404
	Sesgo	-0,131788	-0,383699	-0,539404
	Curtosis	11,98813	14,29286	13,83531
	Jarque-Bera	11542,18	18288,79	16925,56
ARCH-LM	Estadístico F	74,97508	2,738252	2,571938
	Probabilidad	0	0,06	0,07

Nota: la prueba estadística ARCH-LM es el multiplicador de Lagrange usado para la detección del efecto ARCH. Bajo la hipótesis nula de no heteroscedasticidad, dicho termino se distribuye como $\lambda^2(k)$. Elaboración propia.

La Tabla 1 muestra los resultados de la prueba ARCH-LM, los cuales indican la presencia de efecto ARCH para todas y cada una de las series bajo estudio, ya que la probabilidad asociada a los mismos es menor a 0,1. Dado que los modelos de la familia GARCH son aptos para la modelación de series leptocúrticas, se emplea uno de dichos modelos de tipo simétrico y uno asimétrico, para la modelación de la volatilidad de las series.

Tabla 2. Resultado de la prueba Dickey Fuller Aumentada

	Intercepto		Intercepto tendencia		Ninguno	
	Niveles	PD	Niveles	PD	Niveles	PD
IPC	-52,938*	-25,35732*	-52,99176*	-25,35574*	-52,88886*	-25,36041*
S&P500	-61,20796*	-21,01554*	-61,2193*	-21,0126*	-61,14662*	-21,0184*
TSX	-58,75659*	-22,90249*	-58,74913*	-22,89944*	-58,74474*	-22,9055*

Nota: la hipótesis nula de la prueba ADF es que las series tienen raíz unitaria. El valor crítico de MacKinnon al nivel de significancia del 1 % es -3,44. * Nivel de significancia del 1%. Elaboración propia.

La condición de estacionariedad es examinada a través de la prueba de Dickey Fuller Aumentada (ADF, por sus siglas en inglés). Los resultados de la Tabla 2 sugieren que la hipótesis nula de la presencia de raíz unitaria es rechazada, ya que los valores de los índices bursátiles son mayores que el valor crítico de MacKinnon al 1 % de significancia. Por lo tanto, se confirma que las series son estacionarias tanto en niveles (logaritmos) como en primeras diferencias. Una vez que se cumple con la condición necesaria de que las series no tengan raíz unitaria, se lleva a cabo la modelación, a través de los modelos GARCH y TARCH.

Resultados del modelo GARCH y TARCH. Como se observa en la Tabla 3, todos los parámetros estimados a través del modelo GARCH (1,1) son positivos y estadísticamente significativos, con una probabilidad menor a 0,05. Además, el valor del resultado de la estimación del parámetro β_1 es mayor, en todos los casos, que el de α_1, y en la suma $\alpha_1 + \beta_1$ el resultado es inferior y muy cercano a uno. Esto significa que se garantiza la condición de que el proceso ARCH es estacionario; es decir, la varianza no crece de forma indefinida. El hecho de que el coeficiente de retardo de la varianza condicional β_1 sea mayor que el coeficiente de error α_1 implica que hay persistencia de los *shocks* con efectos en el largo plazo, lo que significa que la volatilidad no decae rápidamente, sino que tiende a permanecer, y su efecto se desvanece poco a poco.

Tabla 3. Resultados del modelo GARCH (1,1)

Coeficientes	IPC	SP500	SP TSX
α_0	5,41E-06	2,18E-06	9,29E-07
	(0,000)	(0,000)	(0,000)
α_1	0,100029	0,112258	0,076145
	(0,000)	(0,000)	(0,000)
β_1	0,877099	0,867702	0,919225
	(0,000)	(0,000)	(0,000)
$\alpha_1 + \beta_1$	0,977128	0,97996	0,99537
ARCH LM (1)	0,158976	0,241087	0,555834
	(0,6901)	(0,6235)	(0,456)

Nota: elaboración propia.

Tabla 4. Resultados del modelo TARCH (1,1)

Coeficientes	IPC	S&P 500	TSX
α_0	5,11E-06	2,39E-06	1,01E-06
	(0,000)	(0,000)	(0,000)
α_1	0,021868	-0,017993	0,026745
	(0,000)	(0,000)	(0,000)
β_1	0,128206	0,206853	0,074159
	(0,000)	(0,000)	(0,000)
RESID < 0 ARCH (1) γ	0,890077	0,887814	0,927845
	(0,000)	(0,000)	(0,000)
$\alpha_1 + \gamma$	0,911945	0,869821	0,95459
ARCH LM test	0,49952	1,929659	1,749611
	0,4798	0,1649	0,186

Nota: valores entre paréntesis representan las probabilidades. Elaboración propia.

Los resultados del modelo TARCH son presentados en la Tabla 4, donde se observa que el término de apalancamiento (γ) representado por RESID<0 ARCH (1) es mayor a cero y estadísticamente significativo, lo cual refuerza el supuesto de que los impactos positivos y negativos tienen efectos diferenciados en la volatilidad de los rendimientos bursátiles diarios. Las noticias buenas tienen un impacto de α_1, mientras que las malas tienen un impacto $\alpha_1 + \gamma$; es decir, su impacto es mayor que el de las buenas en todos los mercados financieros analizados.

Por su parte, los valores del estadístico ARCH-LM con un rezago, para ambos modelos GARCH y TARCH, son no significativos estadísticamente, ya que la probabilidad asociada es mayor al 0,05, rechazando la presencia de efecto ARCH después de la aplicación del modelo, lo cual sugiere que los modelos son adecuados y que proveen buen ajuste. Igualmente, para ambos modelos (GARCH y TARCH) se realiza la prueba Ljung-Box, donde los valores de probabilidad obtenidos, para los tres mercados, son mayores de 5 %, lo cual indica que los residuales del modelo no presentan autocorrelación serial.

Una vez que se estima la volatilidad condicional, los valores de los residuales de ambos modelos son empleados para analizar la estructura de dependencia entre los diversos mercados, a través de tres subperíodos: antes, durante y después de la crisis.

Resultados de la cópula. La Tabla 5 y la Figura 2 muestran los resultados del parámetro de dependencia condicional, empleando los residuales del modelo GARCH, tanto para las cópulas elípticas (t-Student y normal) como para las Arquimedianas (Clayton, Gumbel y Frank). Los resultados señalan que, para todas las cópulas, el parámetro de dependencia es inferior en los períodos previo y posterior a la crisis. Lo anterior evidencia la existencia de contagio bursátil entre el bloque TLCAN.

Tabla 5. Parámetros de dependencia condicional (residuales modelo GARCH)

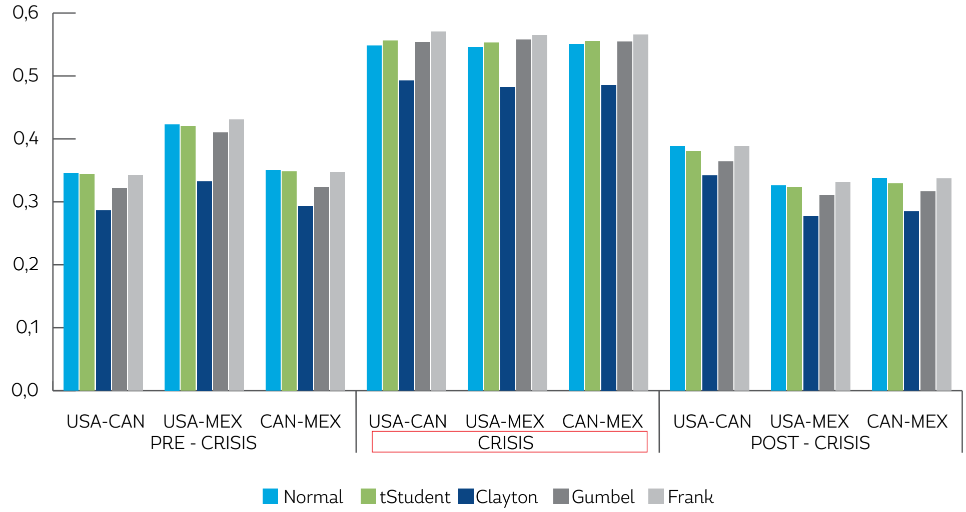
		Normal	t-Student	Clayton	Gumbel	Frank
PRECRISIS	USA-CAN	0,345726	0,343852	0,286281	0,322272	0,342432
	USA-MEX	0,423146	0,420383	0,332646	0,410459	0,430470
	CAN-MEX	0,350443	0,348549	0,293563	0,323251	0,347313
CRISIS	USA-CAN	0,548389	0,556207	0,492676	0,553898	0,570118
	USA-MEX	0,545787	0,552783	0,481962	0,557533	0,564589
	CAN-MEX	0,550328	0,555459	0,485866	0,554499	0,565806
POSCRISIS	USA-CAN	0,388481	0,380827	0,341870	0,363824	0,388367
	USA-MEX	0,326184	0,323604	0,277603	0,310919	0,331728
	CAN-MEX	0,337693	0,329257	0,284403	0,316488	0,337043

Nota: elaboración propia.

Cabe señalar que la estructura de dependencia condicional que muestra mayor fuerza es aquella existente entre los mercados de Estados Unidos y México, la cual registra valores cercanos al 0,4 (promedio de los diversos parámetros de cópula), en el período previo a la crisis; 0,55, en el de crisis; y 0,31, en el posterior a la crisis; dichas cifras representan un incremento de 38 % en el parámetro de dependencia. En segundo lugar, en términos de magnitud, se encuentra la relación de dependencia entre Estados Unidos y Canadá, cuyo valor previo a la crisis es 0,328; durante la crisis, 0,544; y posterior a la crisis, de 0,373; los niveles asociados a dichos períodos, para el caso de la relación Canadá y México, son 0,333; 0,542, y 0,321, respectivamente.

Retomando el análisis de los datos presentados previamente, el nivel de dependencia condicional entre Estados Unidos-Canadá y Estados Unidos-México es sumamente parecido. Los resultados difieren en relación con el trabajo realizado por Díaz y Bucio (2018), donde se analiza la dependencia entre los rendimientos diarios de los mercados bursátiles del TLCAN, a diferencia del presente, que investiga la estructura de dependencia condicional, a partir de medir la volatilidad por medio de modelos GARCH. Lo anterior revela que el comportamiento de los mercados, en cuanto a sus variaciones (riesgo) debido a cambios en el mercado estadounidense es casi igual, lo que podría significar que la volatilidad de los mercados de México y Canadá tienen un parámetro de riesgo sistemático casi idéntico ante cambios en la volatilidad del estadounidense.

Figura 2. Evolución de la dependencia condicional (GARCH) en los mercados del TLCAN



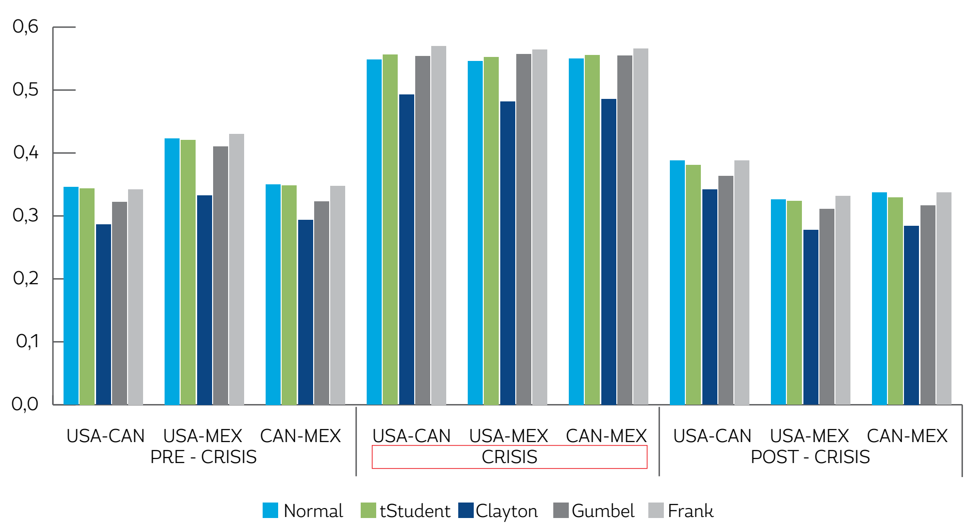
Elaboración propia con datos de la estimación

Tabla 6. Parámetros de dependencia condicional (empleando residuales modelo TARCH)

		Normal	tStudent	Clayton	Gumbel	Frank
PRECRISIS	USA-CAN	0,345726	0,343852	0,286281	0,322272	0,342432
	USA-MEX	0,423146	0,420383	0,332646	0,410459	0,430470
	CAN-MEX	0,350443	0,348549	0,293563	0,323251	0,347313
CRISIS	USA-CAN	0,548389	0,556207	0,492676	0,553898	0,570118
	USA-MEX	0,545787	0,552783	0,481962	0,557533	0,564589
	CAN-MEX	0,550328	0,555459	0,485866	0,554499	0,565806
POSCRISIS	USA-CAN	0,388481	0,380827	0,341870	0,363824	0,388367
	USA-MEX	0,326184	0,323604	0,277603	0,310919	0,331728
	CAN-MEX	0,337693	0,329257	0,284403	0,316488	0,337043

Nota: elaboración propia.

Figura 3. Evolución de la dependencia condicional-TARCH en los mercados del TLCAN.



Elaboración propia con datos de la investigación

Los resultados de la dependencia condicional (Tabla 6 y Figura 3), estimada a partir de los residuales del modelo TARCH, son levemente inferiores a aquellos obtenidos a partir del modelo simétrico GARCH, lo cual significa que la estructura de dependencia considerada a partir de la cópula, teniendo en cuenta asimetría en la volatilidad (las malas noticias tienen mayor impacto en ella que las positivas de la misma magnitud), describe niveles inferiores, en relación a aquella que no toma en cuenta el efecto apalancamiento. Dichos resultados apuntan a que la asimetría en la volatilidad de los mercados bajo estudio es muy parecida, por lo que la dependencia entre los mercados se ve apenas erosionada al incluir la respuesta asimétrica de las series. El hecho de que la dependencia condicional considerando asimetría sea menor que la que no lo hace responde al hecho de que la asimetría en los mercados es de distinta magnitud, como se aprecia en la Tabla 4.

Conclusiones

Las crisis financieras son fenómenos sumamente trascendentales. Uno de los espacios en los cuales se manifiestan afectaciones importantes es el mercado de valores, lugar de interconexión y obtención de recursos, sobre todo, para las unidades productivas de una economía. Los cambios en los precios de los títulos, que se derivan de la transmisión de desequilibrios, añaden riesgo a los mismos, incrementando el rendimiento asociado a dichos instrumentos y, por ende, el costo ligado al financiamiento. En referencia a lo anteriormente señalado, la presente investigación es de gran relevancia para los inversionistas, empresas que cotizan en bolsa y para aquellos tomadores de decisiones y hacedores de política económica.

El objetivo de la presente investigación es analizar la dependencia condicional entre los mercados de valores del bloque TLCAN, permitiendo identificar la existencia de efecto contagio a través del incremento en el nivel de dependencia en momentos de inestabilidad bursátil. Para lograr dicho fin, se modeló la volatilidad de las series a partir de un modelo simétrico GARCH y uno asimétrico. Una vez que fue modelada la volatilidad condicional, se estimó la estructura de dependencia a partir de cópulas Arquimedianas y elípticas, para tres subperíodos: antes, durante y después de la crisis financiera global.

Los resultados de los modelos GARCH y TARCH apuntaron a que ambos son idóneos para la modelación de la volatilidad de las series, las cuales presentan memoria larga y asimetría; es decir, que el efecto de un *shock* tarda mucho en desvanecerse y que las noticias malas tienen mayor impacto en la volatilidad que aquellas positivas de la misma magnitud. Los modelos fueron probados y señalaron la existencia de un ajuste adecuado.

La dependencia condicional, estimada a partir de los residuales del modelo GARCH, señaló que existe un incremento de alrededor de 38 % en el período de crisis, respecto al período previo y posterior. Igualmente, los resultados sugirieron que la dependencia condicional entre México-Estados Unidos y Canadá-Estados Unidos es muy parecida, lo cual implica que la volatilidad de ambos mercados tiene el mismo nivel de respuesta ante variaciones del mercado estadounidense. Esta conclusión es sumamente relevante, en términos de la construcción de portafolio y la localización de inversiones, con miras de diversificar el riesgo.

Para los gestores de inversión, el incremento de la dependencia entre mercados durante períodos de crisis disminuye el efecto de la diversificación de portafolio internacional. Lo anterior debería ser tomado en cuenta para realizar estrategias en función de la etapa del ciclo económico en el que se encuentre. Igualmente, la medición del riesgo del mercado debe ajustarse, ya que en épocas de crisis existe mayor volatilidad y asimetría en la misma, teniendo mayores efectos, en el mercado, las malas noticias (caídas en los índices) que aquellas positivas.

Por otra parte, la dependencia condicional, calculada mediante los residuales del modelo TARCH, es levemente inferior a la estimada a partir de modelos GARCH, lo cual significa que la modelación de la asimetría en la volatilidad tiene un leve efecto en el nivel de dependencia.

Finalmente, cabe anotar que el contagio financiero es un tema que debe seguir siendo estudiado, ya que aún existen aspectos que no se han descifrado en torno al mismo. Una mayor comprensión del fenómeno llevará a un mejor diseño de los planes y programas de prevención de crisis, aminorando el efecto de las mismas e, incluso, permitiendo que se eviten. En este sentido, algunas líneas de investigación futura podrían ser el análisis del contagio financiero con otras metodologías —como el cálculo de la matriz de correlación incondicional—, estudiar la dependencia entre diversos mercados a nivel global, e investigar las relaciones entre diversos activos (bonos, acciones, mercaderías, etc.).

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Instructions for Authors

Aims and Scope

Ecos de Economia is an international journal of applied economics, with a particular interest in the quantitative analysis of economic, financial, and public policy issues and/or themes related to Latin America. Articles that include and analyze national data are particularly welcome, since these data are often unavailable to international researchers outside the region. The journal is not interested in manuscripts that are solely conceptual in nature.

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Manuscripts in English are preferred, but manuscripts in Spanish are acceptable. Authors should be aware that articles in English have an international audience, while articles in Spanish have a regional audience. Communication with authors and reviews of manuscripts will proceed in the language in which the authors initially contact the journal and/or in the language used in the manuscript.

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