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ABSTRACT

Jimenez-Useche, Manuel I. M.S., Purdue University, December 2016. Measurement and Analysis of Agricultural Productivity in Colombia. Major Professor: Philip Abbott.

Worldwide agricultural commodity prices boomed from 2006 to 2011, peaking up 65% in 2008 and 80% in 2011 (IMF, 2015). Consequently, agricultural gross production value expanded 25% worldwide in 2011 relative to its average in 2000-2005, and by 25%-45% in Latin America (FAO, 2015). However, in Colombia it only increased by 10%.

Colombia's agricultural value exhibited this limited expansion likely due to deep structural problems that led to low levels of productivity growth. Colombia is a small trading economy, making it is a price taker in international markets (Tovar, Jaramillo, Maldonado, Jimenez, & Plazas, 2007). There surely was transmission of these high commodity prices to Colombia's domestic prices and so incentives to increase both productivity and input use. This study analyses the weak performance of Colombia's agriculture, conducting a long-term prospective analysis that evaluates how this was determined by productivity growth versus input accumulation. Productivity is the increase in output attributable to technical change (Domar, 1961; Jorgenson & Griliches, 1967; Solow, 1957).

Colombia's agricultural productivity has rarely been analyzed in economics literature (Atkinson, 1970; Avila, Romano, & Garagorry, 2010; Ludena, 2010; Pfeiffer, 2003; USDA, 2015). Existing studies do not reach a consensus, and methods used to measure it are questionable. Accordingly, this study measures and analyzes Colombia's agricultural productivity during the period 1975-2013.

This study begins by analyzing Colombia's agricultural context from 1975 to 2013, identifying six key periods between which economic conditions and policy regimes changed. Then it uses econometric techniques to measure aggregate and disaggregated crop and livestock productivity, an approach that has never been used before to measure Colombia's agricultural productivity. This study finds that Colombia's agricultural productivity grew on average between 0.8% and 1.3% per year from 1975 to 2013, which was mainly driven by livestock productivity. The three different approaches used – Cobb-Douglas and CES production functions and Dual cost function estimation -- yielded mostly similar results. Productivity exhibited different trends in each identified period, and output value was more sensitive to productivity trends influenced by policy regimes and economic circumstances than by input accumulation. Also, stagnant growth of Colombia's agriculture in recent decades was due to low productivity growth. In addition, it exhibited biased technical change according to the methods that can identify bias.

Colombia will be able to raise its agricultural productivity in the future if it steadily increases R&D investment, human capital, and foreign competence in the domestic market. Success will depend on implementing a comprehensive policy regime that includes all three elements and is designed with a long-term perspective.

CHAPTER 1. INTRODUCTION

1.1 Agricultural Commodity Price Boom in 2006 to 2011 and Colombia's Agricultural Backwardness

Worldwide agricultural commodity prices exhibited a boom during 2006-2011. According to the IMF food price index, these prices increased in real terms by 65% in 2008 and by 80% in 2011 relative to 2000-2005 (IMF, 2015), due to: i) biofuel industry development in the US; ii) global imbalances in some commodity markets, due to rapid demand expansion and low stock levels; iii) the dynamic growth of China and India compared to world economic growth (10% vs 4%); iv) climate change and crop diseases, which further worsened the already struggling output of numerous commodities; v) depreciation of the U.S. dollar relative to global currencies; vi) speculation in commodity markets; and vii) isolating trade policies as a response to higher commodity prices (Abbott, Hurt, & Tyner, 2008). As a result, farmers' profits in many countries reached historical levels, as has happened in other commodity booms due to a substantial price transmission of these high prices to the domestic markets, allowing them to increase expenditures on land, machinery, structures, and equipment (Henderson, Gloy, & Boehlje, 2011; Rodriguez, Dahlman, & Salmi, 2008). Agricultural gross production value worldwide expanded by 25% during this period compared to its average levels exhibited during 2000-2005 (FAO, 2015).

In Colombia, however, this expansion was very moderate (see Figure 1). Its agricultural gross production value only increased by 10% as a result of the high commodity prices exhibited during 2006-2011, despite the fact that this expansion was more dynamic in other Latin American countries during this period: Chile (+26.1%), Argentina (+28.6%), Brazil (+43.6%), and Peru (+45.6%) (FAO, 2015). Also, Colombia's investment in agricultural R&D, as a ratio of overall GDP, remained low over 2006-2011, increasing from 0.4% only to 0.7% as a result of this agricultural commodity price boom (Junguito, Perfetti, & Becerra, 2014). In contrast, this ratio was about 1% in other emerging countries and 4% in developed countries (Junguito et al., 2014). In addition, the area equipped with irrigation in Colombia remained around 30% of arable land over this period, while in Peru this ratio was close to 50% and in Chile close to 65% (FAO, 2015). All this evidence suggests that Colombia's agriculture clearly lost a valuable opportunity to update itself and match the advancing agricultural development of other countries, especially in the region. Also, this reaffirms that Colombia's agricultural sector continued showing a clear lag compared to the same sector in other countries (Clavijo, Vera, & Jimenez, 2014).

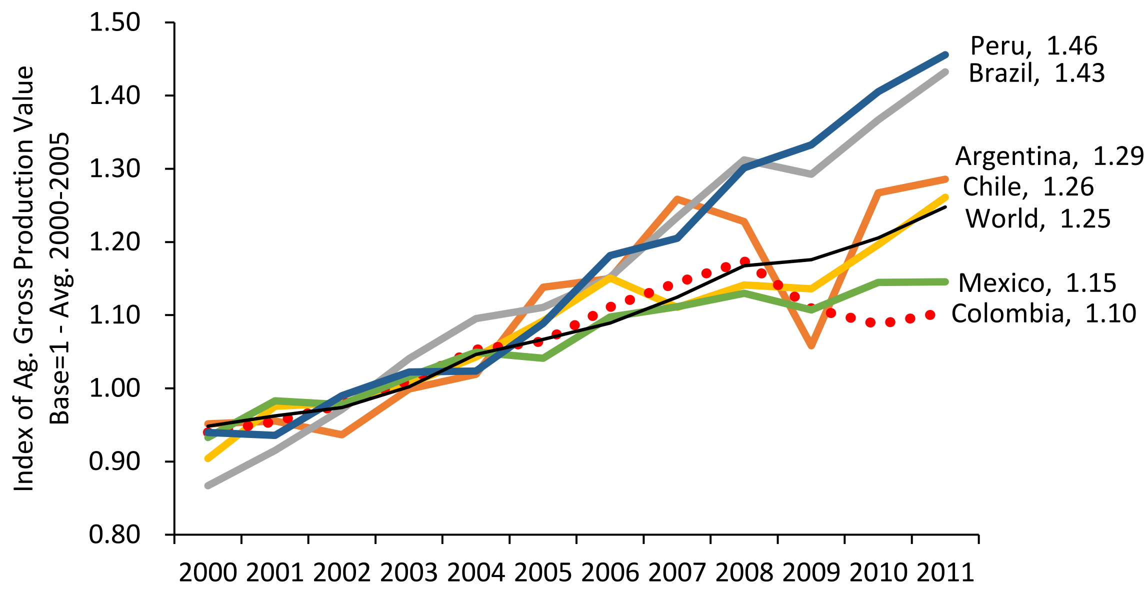

Figure 1: Index of Agricultural Gross Production Value (Source: FAO, 2015)

The problem is that Colombia's agriculture didn't significantly expand due to the agricultural commodity price booms. Accordingly, something else happened that surely explained this limited expansion, both then and in Colombia's earlier history. Thus, the objective is to figure out this, by conducting a long-term prospective analysis.

Two possible issues may explain Colombia's limited agricultural expansion. On the one hand, deep structural problems prevented Colombia from taking advantage of this boom and led Colombia to exhibit low levels of productivity. Moreover, the pass-through of these high commodity prices to domestic prices was partial. However, this study rules out this last reason as being important, because most agricultural prices in Colombia largely depend on international prices (Tovar et al., 2007). Accordingly, this limited expansion was likely due to deep structural problems, which led to low levels of productivity, and slow production growth.

1.2 Colombia's Agricultural Productivity

Colombia's agricultural productivity has rarely been analyzed in economics literature, and little is known about its dynamics (Atkinson, 1970; Avila et al., 2010; Ludena, 2010; Pfeiffer, 2003; USDA, 2015). Also, the results of these studies do not reach consensus, and the methods used to measure it are questionable. Accordingly, this study measures and analyzes Colombia's agricultural productivity during the period 1975-2013.

This study begins by analyzing in detail Colombia's agricultural context during this period, focusing on: i) Colombia's agricultural performance; ii) Colombia's agricultural policy; and iii) the main problems facing Colombia's agriculture nowadays. Based on this, it determines six periods for the subsequent analysis based on the years for which: i) Colombia's agriculture exhibited similar economic conditions; and ii) new agricultural policy regimes are in place. Then, this study estimates Colombia's agricultural productivity growth in aggregate and disaggregated for crop production and livestock production. Agricultural productivity is well recognized in economics literature as a crucial indicator for agriculture development worldwide, because: i) this works as a permanent barometer of the agricultural sector's performance; and ii) improving agricultural productivity is key to designing and executing more efficient agricultural policies.

This study uses primal and dual econometric techniques to measure Colombia's agricultural productivity. The idea is to use a variety of methodologies from the economics literature as strategy to look for more consistent results. This methodology has never been used before to measure Colombia's agricultural productivity, since prior studies have mainly used growth accounting or frontier techniques. It also allows us to determine if Colombia's agriculture exhibited biased technical change during this period, an aspect that nobody has analyzed before for Colombia. In addition, this enables us to assess how Colombia's agricultural productivity growth changed its trend over time relative to policy regimes and economic circumstances. Finally, this study identifies some elements that Colombia's agricultural policy should consider to boost agricultural productivity growth in the coming years.

This study proceeds as follows. Chapter 2 describes Colombia's agricultural context during the period from 1970 to 2014. Chapter 3 examines the importance of agricultural productivity worldwide and its value in designing and evaluating agricultural policy. Chapter 4 presents the methodology used in this study to measure Colombia's agricultural productivity. Chapter 5 describes the data used here. Chapter 6 presents the agricultural productivity growth estimates obtained by this study. Chapter 7 examines certain elements that Colombia's agricultural policy should consider to boost agricultural productivity. Chapter 8 provides concluding remarks.

CHAPTER 2. COLOMBIA'S AGRICULTURAL SECTOR (1970-2014)

2.1 Introduction

Agriculture is one of the most important economic activities in Colombia. About 40% of Colombia's land has been used for agricultural purposes in recent decades Also, its GDP has averaged 8% of Colombia's total GDP, and its exports account for 18% of total exports (DANE, 2015). Thus, agriculture is seen nowadays as one on the most important activities in Colombia, since its reach is not just economic. It also plays a key role into the social development of Colombia, as the most common source of employment in rural areas (COMPITE, 2008; SAC, 2011). In recent decades, agriculture employs 20% of the national labor force and 66% of the rural labor force (DANE, 2015).

Colombia's agriculture is an economic sector with promising future prospects. Along with Brazil, the Congo, Angola, Sudan, and Bolivia, Colombia is one of the few countries with the opportunity to expand their agricultural frontier (FAO, 2013). Its 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 gives priority to developing new technologies for agricultural development in this region (Clavijo & Jimenez, 2011c). Thus, Colombia has the potential to become a global exporter of agricultural products, since: 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 such a large population (FAO, 2009), and iii) Colombia's agricultural GDP per capita will grow on average by 2%-4% in the next decades. Colombia's agricultural GDP is projected to grow 4%-5% annually, and its population will grow by only 1%-1.5% annually, according to official predictions of the National Department of Statistics of Colombia (DANE) and the Colombian Department of Agriculture (MADR) (DANE, 2015; MADR, 2014).

However, Colombia's agriculture has been seriously affected in recent decades due to lack of investment (Junguito, Perfetti, & Becerra, 2014). The discovery of two great oil deposits in Colombia during the 1980's and the 1990's (Caño Limon in 1982 and Cusiana-Cupiagua in 1992) also transformed Colombia into an oil economy and largely directed investment to oil production. Consequently, tradable sectors such as agriculture have lost their competitiveness since then, because Colombia has been suffering serious 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 on 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 1970's to 14% in the 2000's); iv) export concentration in commodities (close to 70% of the total); and v) high NAIRU rate close to 10% (Clavijo, Vera, & Fandiño, 2013). Accordingly, Colombia's agriculture has been facing a difficult macroeconomic framework in recent decades and a steady loss of competitiveness, despite all these promising future prospects.

The aim of this chapter is to examine Colombia's agricultural situation during the period of 1970 to 2014. This chapter answers the following key questions: i) How has Colombia's agricultural performance evolved during this period? ii) What policies have Colombia's government adopted to promote its development, and what are their impacts? iii) What is the land use of the sector? iv) Which are the main products cultivated, produced, exported and imported by Colombia, and v) What problems does Colombia's agriculture face nowadays? These questions are central to an analysis of Colombia's agricultural productivity, the main topic of this study.

2.2 Importance and Dynamics of Colombia's Agriculture

Over the last decades, Colombia's agricultural share in total GDP has steadily decreased. According to the World Bank (2016), agriculture's share in Colombia's total GDP decreased from an average of 24% in the 1970's to 18% in the 1980's, 15% in the 1990's, and 6%-8% in the 2000's. In contrast, Peru's agricultural share fell from 16% in the 1970's to 8% in the 2000's, Brazil's from 12% to 8%, Mexico's from 12% to 3%, and Chile's from 8% to 4% (see Figure 2). Also, agricultural GDP per capita in Colombia decreased from US$320-350 (constant 2005 US$) in the late 1980's to US$300 in the 1990's and US$260 in the 2000's. It is notable that these other countries experienced slight but steady overall growth (see Figure 3). This indicates that agriculture did not continue as the driver for Colombia's economy over the last decades. Service sectors have expanded quickly since the 1990's, due to a "normal" structural transformation exhibited by almost all economies in the world. This period followed the first stage of import substitution in the 1980's. However, Colombia's economy has recently experienced a more accelerated transformation toward the service sector, due to effects of the Dutch Disease symptoms caused by the discovery of large oil deposits in 1980's and 1990's (Caño Limon in 1982 and Cusiana-Cupiagua in 1992) (Clavijo et al., 2013). In addition, Colombia's agriculture was seriously affected by other factors, such as the accelerated manner in which Colombia's government carried out the second package of reforms associated with its Structural Adjustment (SA) program in early 1990's [1] (Ocampo, 2000). This prompted a profitability crisis in agriculture, since this sector was unprepared for these reforms (mainly trade reform) as often occurs and other factors worsened this situation, as is explained below (C. F. Jaramillo, 1998).

[1] Colombia's Structural Adjustment program was executed in two stages. The first stage was executed immediately after the Latin American Debt crisis impacted Colombia in early the 1980's. The Betancur administration (1982-1986) requested supervision and advice from the IMF to restore economic stability (Garay, 1998). Although Colombia did not receive any credit from the IMF, Colombia executed an austere policy during that time which included: i) a strong depreciation of the Colombian Peso against the American Dollar; ii) fiscal reform; and iii) some import restrictions. The second stage was executed in the early 1990's, due to the better economic figures, and included a package of reforms in many areas such as: i) fiscal management; ii) foreign trade; iii) financial market; iv) exchange regime; and v) health system (M. Cardenas & Bernal, 1998; Ocampo, 2000).

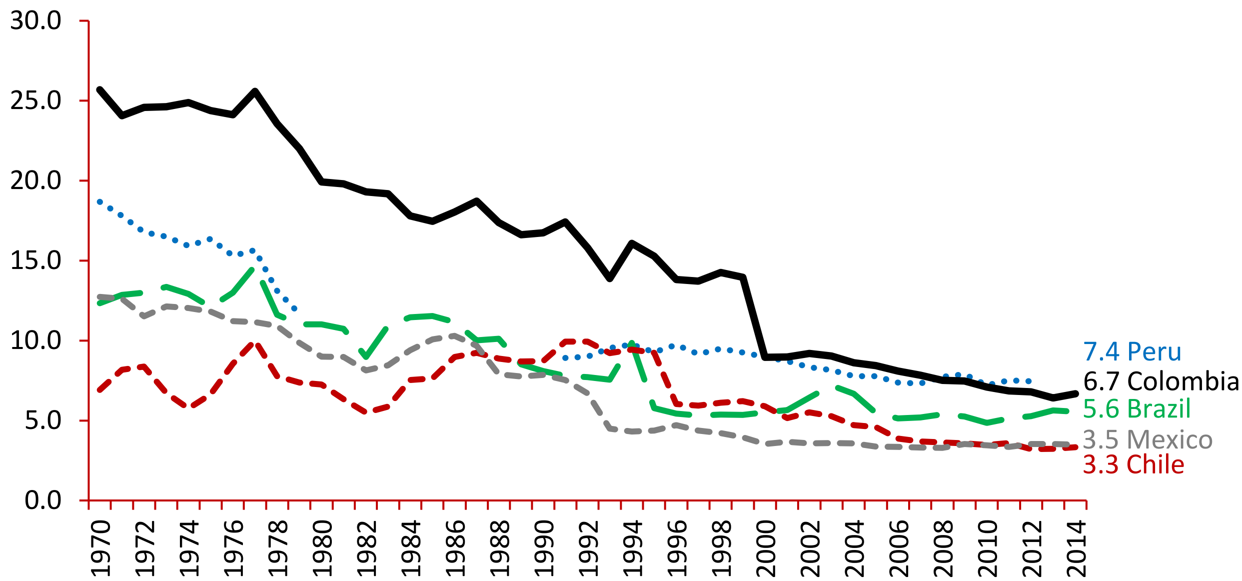

Figure 2. Agriculture's Share (%) in Total GDP

(Source: World Bank, 2016)

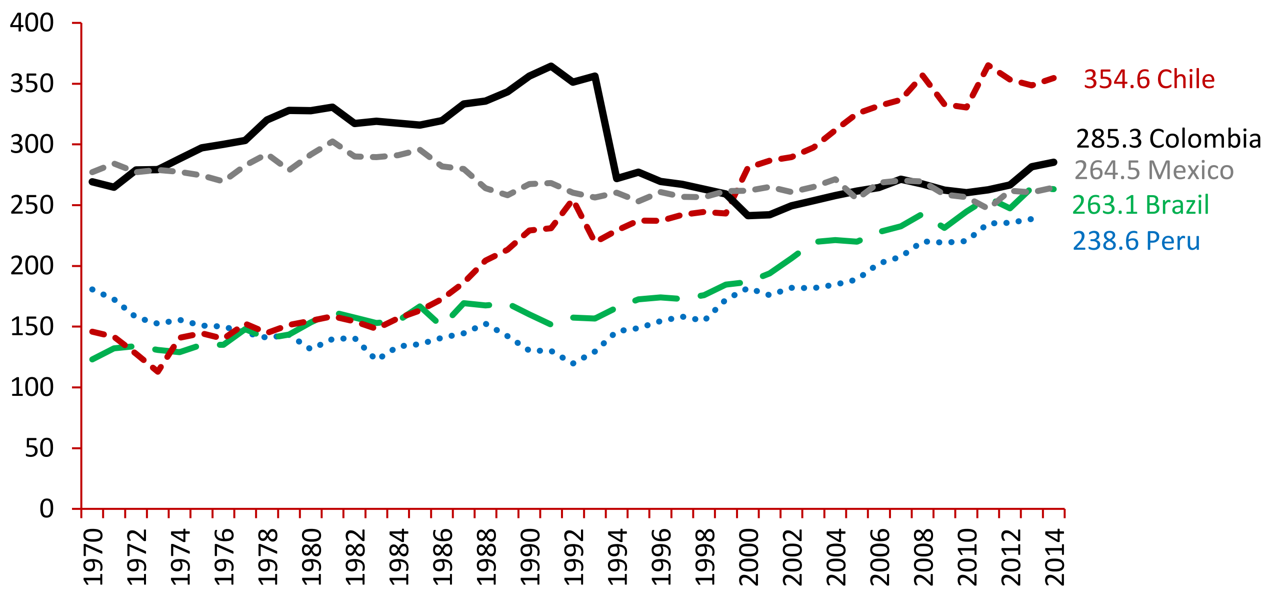

Figure 3. Agricultural GDP Per Capita (Constant 2005 US$)

(Source: Estimates based on World Bank, 2016)

Another reason for this loss in relevance of Colombian agriculture was its slower expansion since the early 1980's. According to the World Bank (2016), its GDP growth averaged 4.5% in the 1970's, but this rate decreased to 2.7% in the 1980's, 1.5% in the 1990's, and 1.9% in the 2000's (see Figure 4). In contrast, agriculture was more dynamic in other countries of the region (see Table 1). For instance, Brazil's agricultural GDP growth stabilized at around 4% during these decades, while in Chile growth varied from 3.5% to 4%. Likewise, in Peru growth increased gradually from 1.1% in the 1970's to 2.5% in the 1980's and almost 4% in the 1990's and 2000's.

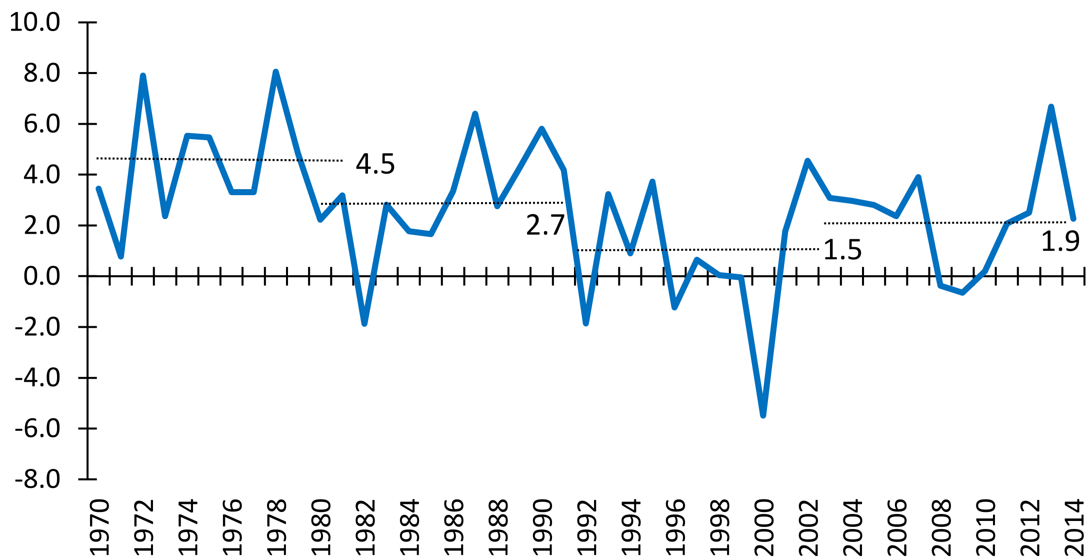

Figure 4. Agricultural GDP Growth (%) by Colombia (1970-2014)

(Source: Estimates based on World Bank, 2016)

Table 1. Average Agricultural GDP Growth (%) in Latin America (1970's-2000's) (Source: estimates based on World Bank, 2016)

	1970-79	**1980-89**	**1990-99**	**2000-14**
Argentina	3.0	0.1	4.2	1.7
Brazil	4.0	4.0	2.6	3.7
Chile	2.6	5.2	3.0	3.9
Colombia	4.5	2.7	1.5	1.9
Mexico	3.2	1.5	2.1	1.6
Peru	1.1	2.5	4.0	3.7

Junguito, Perfetti, & Becerra (2014) believe that this slowdown of Colombia's agricultural GDP is due to: i) policies implemented in Colombia to boost its economic development that mainly focused on promoting other sectors (financial, mining, and utilities); and ii) lower productivity growth of Colombia's agriculture (Ludena, 2010). This suggests that Colombia's agriculture has lost importance due to its poor performance, lacking political support to boost the sector in the long run, and a slowdown in productivity.

It is evident from Table 1 that the worst period for Colombian agriculture was the 1990's (C. F. Jaramillo, 1998). At this time, Colombia was unprepared to carry out trade reform, included in the second package of reforms of its Structural Adjustment program (Ocampo, 2000). As a result, Colombia's agriculture was one of the most affected sectors, since: i) import taxes were removed for agriculture products from an average of 35.3% in 1990 to 15.3% in 1992; ii) many subsidies were removed; and iii) Colombia's government ceased to play an active role in the agricultural market[2] (Guterman, 2007; C. F. Jaramillo,

[2] In prior years Colombia's government used to make frequent interventions in agricultural markets to ensure a minimum income to farmers. For instance, the IDEMA, a state marketing agency, had the monopoly to marketing and importing grains in Colombia in order to control agricultural commodity prices. Also, Colombia's government

1998; Junguito, 1994; Kalmanovitz & López, 2003). As if this were not enough, Colombia's agriculture situation worsened even further, due to i) a severe drought in 1992; ii) a strong revaluation of the Colombian Peso (COP) relative to the US dollar, due to a high interest rate spreads (between 20-25 percentage points), decreased the competitiveness of Colombia's agriculture; iii) a decline in commodity prices during the early 1990's; iv) an expansion of illicit crop areas to produce drugs, and v) a crisis of its main lender "La Caja Agraria," since this bank only used 38% of its resources to fund Colombia's agriculture. "La Caja Agraria" exhibited serious problems in the loan approval process, due to poor risk assessment and general corruption that amounted to daily losses of about one billion pesos (BANREP, 2015; DNP, 2015; C. F. Jaramillo, 1998; Junguito, 1994; Kalmanovitz & López, 2003; Villalba, 2002). Although the Gaviria (1990-1994) and Samper (1994-1998) administrations carried out many policies to promote Colombia's agricultural recovery (explained later in this chapter), their efforts were insufficient (C. F. Jaramillo, 1998; Junguito, 1994; Kalmanovitz & López, 2003). Colombia's agricultural situation worsened in the late 1990s; armed conflict prompted many people to leave the rural areas, and this significantly impact the country's agricultural labor and investment (Alban, 2011; DNP, 2002; FAO, 2000; Montero & Casas, 2012).

During the 2000's, Reina et al. (2011) argues that Colombia's agriculture exhibited poor dynamism due to a misallocation of resources within the sector. His study explains

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established quantitative restrictions for agricultural imports to protect Colombia's agriculture from foreign competitors. In addition, it gave producer price support to Colombian farmers based on their average production costs (Guterman, 2007).

that although Colombia's government increased its expenditure on agriculture from $300 billion Colombian pesos (COP) (constant 2010 pesos) to $1.2 trillion pesos during the years 2000 to 2010, almost half of these resources were given as direct subsidies to farmers (see Figure 5). As a consequence, Colombia failed to allocate resources to fund improvements in its agricultural productivity, thereby thwarting solid gains in global competitiveness.

Reina et al. (2011) estimate that land development received just 20%-25% of these resources during the 2000's; rural development received 15% and innovation and technological development received 4% (see Figure 6). That study suggests that Colombia hasn't allocated resources for improving the road infrastructure between farms and cities or instructing small and medium farmers on new farming technologies. Also, this outlook has been worsened by other factors, such as: i) violence, mainly in the rural areas, due to armed conflict; ii) problems of land tenure due to a lack of a clear land policy and earlier security problems; iii) poor transportation infrastructure due to a large delay in the execution of infrastructure policy, and iv) lack of innovation and technological development (Clavijo & Jimenez, 2013; Clavijo, Vera, & Jimenez, 2012; Reina et al., 2011).

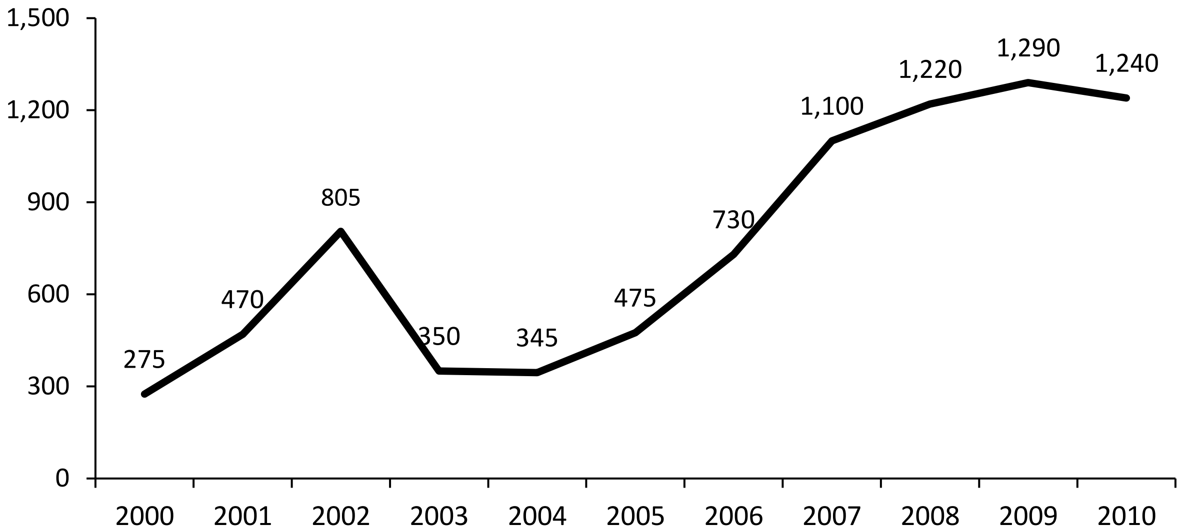

Figure 5. Public Expenditure in Colombia's Agricultural Sector (COP$ Billion, Constant 2010 Prices) (Source: Reina et al.,2011)

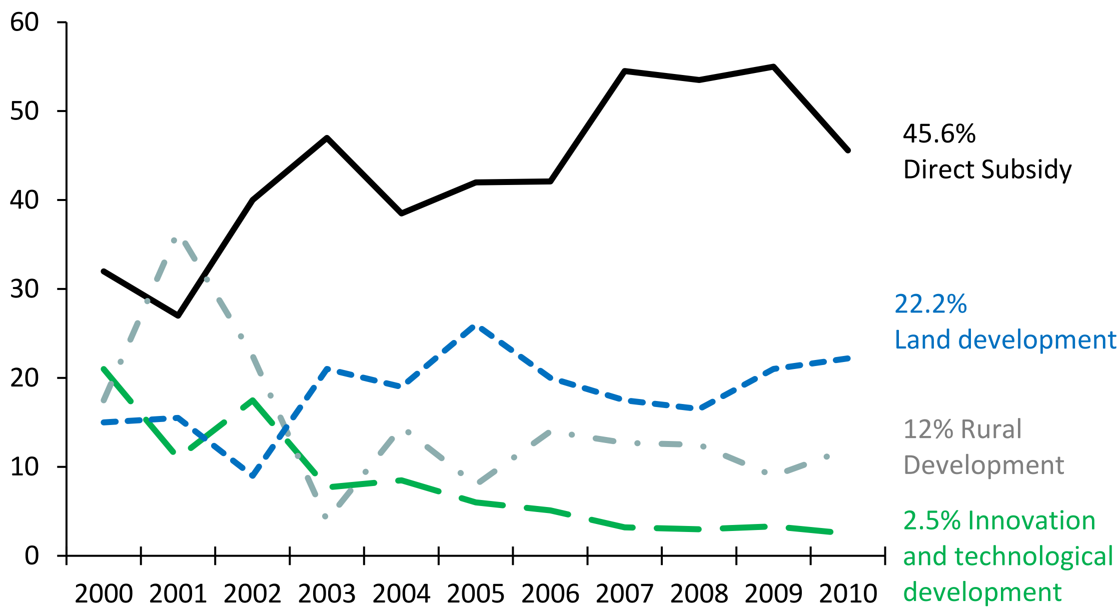

Figure 6. Public Expenditure in Colombia's Agricultural Sector by Type of Program (% of total) (Source: Reina et al., 2011)

2.3 Colombian Agricultural Policy from 1970 to 2015

2.3.1 Political Economy of Agricultural Policy

Over the last 50 years, agricultural policy has exhibited many changes in Colombia. However, these changes were in response mainly to five events: i) the *Banco Internacional de Reconstrucción y Fomento - BIRP* mission led by Lauchlin Currie in the 1950s; ii) the implementation of the model of import substitution (designed by Prebish) that discriminated against tradable agricultural products; iii) the second package of reforms of Colombia's Structural Adjustment program executed in early 1990's; iv) the armed conflict in Colombia during the period 1999-2001; and v) the Free Trade Agreement signed with the USA in 2006 (C. F. Jaramillo, 1998; Junguito, 1994; Kalmanovitz & López, 2003; Montero & Casas, 2012). In response, institutions such as the *Sociedad de Agricultores de Colombia –(SAC)* argue that Colombia has not designed a long term agricultural policy strategy for promoting agricultural growth (SAC, 2014). Also, agricultural policy in Colombia is seen nowadays as inefficient, since it has been designed to face short term problems rather than structural issues (OCDE, 2015)[3].

During the 1970s and 1980's, agricultural policy in Colombia mainly followed the diagnosis and recommendations of the BIRP mission led by Lauchlin Currie. This mission acknowledged that Colombia's agriculture exhibited an imbalance between the number

[3] For instance, Colombia's agriculture fell into crisis in 2012, and the governmental responses consisted of providing direct subsidies to farmers, rather than using those funds to finance productive infrastructure, equipment upgrading, or innovation and technological development. (Clavijo & Fandiño, 2013; Junguito et al., 2014).

of people living in rural areas and their productivity[4]. Also, Colombia's land used was suboptimal, given the amount of unexploited land. BIRP's recommendation was to design a tax for land owners, encouraging them to use their land, or at least force them to sell it (Kalmanovitz & López, 2003).

Based on this diagnosis, the Pastrana (1970-1974) and Lopez (1974-1978) administrations focused their agricultural policy on promoting more efficient land use. Their aims were to raise agricultural productivity by improving land distribution, taking into account the country's varied weather conditions, products and regions (Kalmanovitz & López, 2003). In order to do this, these administrations implemented three Acts. Act No. 4 (1973) established minimum productivity levels for land in Colombia with the objective of boosting land use[5]. Act No. 5 (1973) sought to increase further Colombia's land use, by delegating the *Fondo Financiero Agropecuario* to manage many sources of funding for this sector. Act No. 6 (1975) reaffirmed existing property rights in the Colombian countryside by insisting upon the conditions for participation in contracts for agricultural products and other forms of land use. Both administrations believed that Colombia would be able to reach an expedited export expansion and accelerate urban development, by improving the conditions in this sector, mainly by raising agricultural productivity. Also, public finances would increase, since these administrations continued

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[4] While an important portion of mountain farmers used to exploit their land for producing subsistence crops only, it was more common that farmers in flat areas grew commercial crops or devoted their efforts to livestock grazing (Kalmanovitz & López, 2003)

[5] According to this Act, minimum productivity levels were established for each region based on its climate, ecological, social, and economic conditions.

taxing agricultural exports (mainly coffee) to collect all extraordinary gains from devaluations derived from emergency reforms executed by Colombia in the late 1960's.

In addition, the Lopez administration (1974-1978) established its agricultural policy with a program called *Desarrollo Rural Integrado* – DRI. Its aim was to coordinate actions and investments in the countryside to ensure integrated development, paying special attention to: i) production aspects, such as technical assistance; ii) agricultural funding; iii) agricultural product marketing; iv) infrastructure, such as rural roads, electrification and water supply, and v) social services, such as education and health (Vargas, 1994). The objective was to upgrade agricultural production and improve efficiency in rural areas (Kalmanovitz & López, 2003).

While the Turbay administration (1978-1982) continued to strengthen this program, it lost importance during the early 1980's. At the time, the program was mixed with others, and its administration was transferred from the National Planning Department – (DNP) to the Department of Agriculture – (MADR). The DRI program did not continue being the guideline for agricultural policy in Colombia (Kalmanovitz & López, 2003). Therefore, the Turbay administration (1978-1982) designed its agricultural policy, including policy actions in areas such as: i) research; ii) marketing systems; iii) agro-industry development; iv) prices, and v) foreign trade. However, this administration encountered problems in policy execution, due largely to the Latin American Debt Crisis of 1982 (Kalmanovitz & López, 2003).

Under these circumstances, the Betancur administration (1982-1986) assumed power, with efforts that solely focused on restoring Colombia's economy. The Latin

American Debt Crisis had also affected Colombia and the main interest was to restore macroeconomic stability. Agricultural policy was initially considered a key part of this recovery, but was later ignored. This administration requested supervision and advice from the IMF to execute a Structural Adjustment program (Garay, 1998). Consequently, Colombia's government executed an austere macroeconomic policy which included: i) a strong depreciation of the Colombian Peso against the American Dollar; ii) fiscal reform; and iii) some import restrictions. Also, resources for agricultural institutions were removed, as well as funds to finance development credits (Kalmanovitz & López, 2003). Thus, Colombia's agriculture did not receive much attention or promotion of its development during this period, due to the aftermath of Colombia's Debt Crisis.

This situation completely changed during the Barco administration (1986-1990). This administration understood that Colombia's agriculture needed upgrades. Its agricultural policy focused on promoting private investment, adjusting the price system, raising farmer's margins, and limiting agricultural imports with the aim to protect domestic production (Guterman, 2007). Also, Barco promoted coordination among agricultural institutions to ensure the availability of seeds, inputs, loans, technical assistance and marketing (Kalmanovitz & López, 2003). Thereby, its goal was that Colombia would become self-sufficient in its food production by creating buffer stocks that maintain price stability.

However, the Barco administration (1986-1990) realized that these efforts were not sufficient, and recognized that Colombia would benefit from the execution of the second package of reforms of its Structural Adjustment program, in order to solve several problems in many areas (Junguito, 1994). It was believed that Colombia's agriculture would benefit from economic openness and by allocating its inputs to exportable crops. Agriculture productivity would increase due to higher competence, and a market determined exchange rate (not overvalued) would promote agriculture exports. Also, the agricultural market would be more dynamic if the government removed its intervention policies in the sector (C. F. Jaramillo, 1998; Junguito, 1994). Accordingly, the Gaviria administration (1990-1994) executed liberal reforms in areas such as fiscal management, monetary policy administration, financial markets, foreign trade, and privatization (Ocampo, 2000, 2004).

The Gaviria administration (1990-1994) planned to execute this adjustment gradually to lessen any negative impact on Colombia's economy. However, the government made the decision to accelerate this process, since the economy continued being highly protected from imports and there existed high uncertainty caused by the slow pace of tariff elimination (Guterman, 2007; C. F. Jaramillo, 1998). Import taxes for agricultural products were reduced from 31.5% to 15% in just two years (1990-1992), and almost all agricultural subsidies and regulations were removed. Also, the role of the *Instituto de Mercadeo Agropecuario* (IDEMA)[6] was reduced and limited to poor and isolated areas, where distance from markets, lack of infrastructure and political unrest deterred private sector intervention (Guterman, 2007; C. F. Jaramillo, 1998). In addition,

[6] A state marketing agency that had a monopoly over grain imports (Guterman, 2007).

the producer price support system, based on an average of the production cost, was replaced by a system of minimum guaranteed prices.

The purpose of this second package of reforms of Colombia's Structural Adjustment program was to provide a neutral incentive structure for private decision makers. However, this was not achieved in the agricultural sector. Farmer groups claimed the collapse of the sector was due to these reforms, forcing the government to take further policy interventions. In 1991, the government introduced a price band system for 9 agricultural commodities (wheat, barley, rice, maize, sorghum, soybean, palm oil, milk and sugar), covering a total of 112 products (C. F. Jaramillo, 1998). Its aim was to stabilize producer incomes; however, it later became a protective device, given the way the floor and ceiling prices were fixed. Also, the government started to again protect some products by using the previous licensing system (i.e. quotas, prior licensing and prohibition of certain imports) (Guterman, 2007).

In any case, Colombia's agriculture was one of the sectors most affected by these structural reforms. In 1992, Colombia's agriculture entered a profitability crisis due to the accelerated and abrupt implementation of these reforms. Also, its situation worsened, due to certain factors mentioned earlier. This reaffirmed that Colombia's agriculture was unprepared for this change, and showed that Colombia's farmers depended on: i) loans with subsidized interest rates; ii) the purchase and sale of crops by the IDEMA, and iii) support prices.

In order to solve this situation, the Gaviria administration (1990-1994) implemented a set of reforms, in addition to the price band system, called *Plan de Reactivación del*

Sector Agropecuario, hoping: i) to restore the dynamism of the agricultural sector; ii) to establish the foundation to capitalize upon and improve the competitiveness of this sector; iii) to design a policy for promoting rural development; iv) to promote sustainable development in the sector, and v) to upgrade the Department of Agriculture (DNP, 1994). The Plan included reforms in 3 areas (Junguito, 1994). In order to support farmers income: i) it restored the scheme of supporting prices; ii) it reintroduced the scheme of intervention prices; iii) it restored IDEMA's responsibility to sell, buy, export, import, and store products when there existed imbalances in the agricultural market, and iv) it made mandatory the absorption of domestic production prior to allowing agricultural imports. In order to give funding to farmers: i) it allowed refinancing agricultural loans, when floods, droughts or other special events occur, ii) it maintained interest rate subsidies; and iii) it maintained the scheme that forced banks to invest in FINAGRO[7] securities. In order to boost the sector by increasing the availability of public resources, the reforms raised resources for investment projects with the creation of the Incentive to Rural Capitalization (ICR)[8], and increased the resources to fund agriculture subsidies and the IDEMA. In other words, the Gaviria administration (1990-1994) reinstituted many policies prior to the implementation of this second package of reforms of Colombia's Structural Adjustment program for agriculture (Act No.101, 1993; C. F. Jaramillo, 1998; Junguito, 1994).

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[7] FINAGRO is a second-tier bank in Colombia that provides funding to agriculture through compulsory investments from private banks. Its aim is to offer better funding to Colombian farmers and provide access to those farmers turned away by private banks (FINAGRO, 2015b).

[8] This is a capital subsidy that covers up to 40 percent of the total cost of investments in irrigation and drainage funded by credit (C. Jaramillo & Jimenez, 2008).

The Samper administration (1994-1998) continued these policies, though its agricultural policy gave increased priority to: i) promoting and supporting small farmers, poor farmers, and rural women; and ii) helping farmers to solve their profitability crisis by using trade policy instruments (Kalmanovitz & López, 2003). For instance, this administration promoted Procurement Agreements between farmers and industries to ensure crop absorption (mainly of grains and oils), by giving to industrialists the chance to import at a preferential import tariff. The objective was to ensure for farmers the purchase of their crops, and control crop supply to prevent price imbalances. These contracts were removed in 2003, due to existing agreements between Colombia and the World Trade Organization (WTO) (Kalmanovitz & López, 2003). Also, this administration introduced direct and storage subsidies on sensitive products, import quotas for certain cereals, and Competitive Agreements between the government and the agro-industrialists in order to coordinate actions between farmers and manufacturers for certain products (cotton, rice, sorghum, milk, and oilseeds) (Guterman, 2007). In addition, this administration eliminated IDEMA and its monopoly in the market, and then approved the adoption of a Common External Tariff (CET) that unified Colombia's price band system with other country-members of the Andean Community of Nations (Kalmanovitz & López, 2003)[9].

The new price band system was called *Sistema Andino de Franjas de Precios - SAFP*. This system is in place today, and its main objective is to stabilize the import price of a set

[9] Scandizzo & Arcos (2004) show the inefficiency of having this CET, since it was negotiated following the liberalization interests of each country and not the communitarian interest.

of crops characterized by marked instability in international markets[10]. Overall, the SAFP works by increasing (decreasing) the ad-valorem tariff when international prices, taken as reference prices, are lower (higher) than a floor (ceiling) level (see Figure 7). Also, the system charges the CET to the agricultural imports when the reference prices oscillate between floor and ceiling level (CAN, 1994)[11]. This system allows limiting the transmission of the high volatility exhibited frequently by the prices of these products in international markets to the prices in the domestic market.

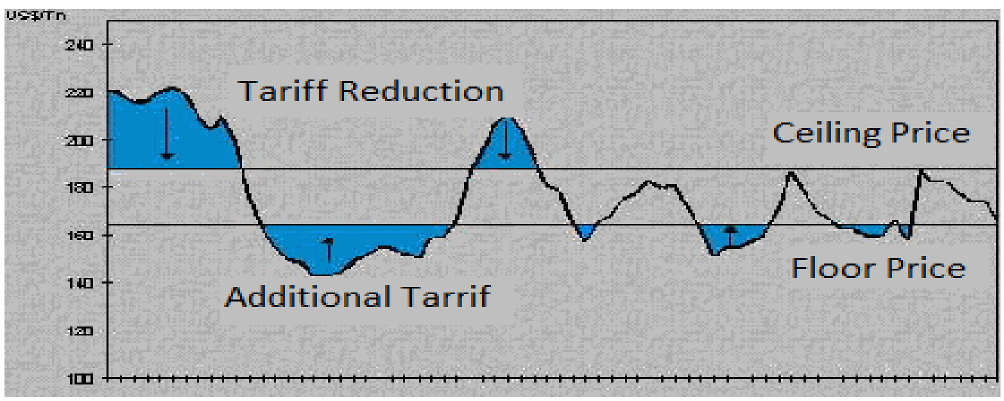

Figure 7. Operation of the SAFP (Source: CAN, 2015)

These policies were altogether insufficient to boost Colombia's agriculture during the 1990's. As is shown above, average growth decreased from 2.7% in the 1980's to 1.5% in the 1990's (see Figure 4 and Table 1). Also, land use for crop cultivation diminished by

[10] Crops protected by the SAFP include: i) rice; ii) barley; iii) yellow corn; iv) white corn; v) sugar; vi) soy bean; vii) soy oil; viii) wheat; ix) palm oil; x) milk; xi) chicken (leg-quarters); and xii) pork (Tovar et al., 2007).

[11] Ceiling price and floor price are estimated using similar methodologies. Both are calculated as the average of the last 60 months of reference price for each product, and in the case of the ceiling price, there is an added adjustment factor; in the case of the floor price, this adjustment factor is subtracted (Tovar et al., 2007).

15.4% (800,000 hectares) during the 1990's (see Figure 13). The Pastrana administration (1998-2002) focused its agricultural policy on the promotion of Colombia's agricultural competitiveness, with a strategy covering 4 areas: i) investing and funding to promote investment in the sector; ii) technological development and agricultural health to increase the efficiency of farming activity; iii) marketing of agricultural products in domestic and external markets; and iv) rural development to encourage small farmers to participate in more productive ventures (Villalba, 2002).

However, the Pastrana administration (1998-2002) could not execute all aspects of this policy. Colombia entered a macroeconomic crisis during the late 1990's. Accordingly, this administration focused its attention on economic recovery. Also, it gave priority to solve the country's worsening armed conflict (Kalmanovitz & López, 2003). Colombia's agricultural development did not receive much attention during this term, and the main achievements of this administration were: i) an expansion of the credit coverage for farmers with the *Banco Agrario* as a replacement of the *Caja Agraria*, and by raising the coverage of the *Fondo Agropecuario de Garantias - FAG*; ii) the introduction of forward contracts through the *Bolsa Nacional Agrropecuaria* (BNA) in order to stimulate investment and reduce uncertainty of agricultural activity, and iii) the promotion of perennial crops such as palm oil (Kalmanovitz & López, 2003; Montero & Casas, 2012; Villalba, 2002).

Under the Uribe-I administration (2002-2006), agricultural policy followed the same guidelines, composed of three main components (Cano & Restrepo, 2003). First, rural employment generation, by developing productive chains in crops such as corn, soybeans, yucca, cotton, palm, cocoa, etc. Second, the improvement of agricultural competitiveness, by encouraging investment, diversifying agricultural production, promoting technological modernization, and promoting domestic and external trade. Third, the promotion of specific activities, such as: i) the development of poultry production; ii) the recovery of cotton production; iii) the promotion of planting perennial crops (oil palm, rubber, fruits, and cocoa), since these crops were considered an alternative to recover Colombia's agriculture and boost employment; iv) the development of fish and shrimp farming, v) the restocking of cattle in special areas; vi) the restructuring and recovery of the coffee sector; vii) the modernization of rural technical assistance services; and viii) the development of biofuels, among other activities. With these measures, the regime planned to promote, encourage, and fund rural development and food security in Colombia. Four principles were used as a guide: i) fairness, by promoting the poor's access to production inputs and public services; ii) competitiveness, by upgrading national production, integrating new markets, signing regional agreements, and increasing farmers' income; iii) sustainability, by promoting the appropriate use of natural resources; and iv) decentralization, by consolidating efficient institutions (Cano & Restrepo, 2003).

The Uribe-II administration (2006-2010) updated this policy during its second term. During this period, this administration focused its agricultural policy on five pillars: i) opening new markets for agricultural products by signing Free Trade Agreements with countries like the US, and the creation of *Agro Ingreso Seguro* (AIS), a program designed to improve the competitiveness of Colombia's agriculture and facilitate an adjustment process of the importable sectors; ii) improving the sanitary status of Colombia's agriculture to facilitate access to new markets; iii) expanding access to funding in order to continue boosting the sector; iv) reducing production costs by promoting research and the use of transgenic seeds; and v) updating the subsidies scheme to farmers to raise protection against all risks (Arias, 2008). Thus, the Uribe-II administration (2006-2010) gave priority to the integration of new markets with this agricultural policy, by adopting policies with more attainable goals that would increase Colombia's agriculture competitiveness.

Recently, the Santos administration (2010-2014) designed its agricultural policy around 7 axes, although for the purposes of this study four are most notable given their special emphasis on promoting the dynamism of agricultural production. The first was to increase agricultural competitiveness via: i) promoting efficient use of land, water, etc.; ii) improving irrigation infrastructure; and iii) promoting the production and use of quality seeds. The second was to generate productive linkages, including transportation and marketing modules via: i) improving post-harvest practices; ii) promoting economies of scale and reducing intermediation; and iii) reducing freight costs. The third component was to diversify domestic and foreign markets. The fourth was to improve risk management by: i) promoting better land use; ii) strengthening information systems (farm price, final prices, costs, etc.); and iii) increasing production financing (Clavijo & Jimenez, 2011b).

2.3.2 Assessment of Agricultural Policy in Colombia

As reviewed above, Colombia has instituted a wide variety of policies to promote its agricultural sector from 1970-2014. Overall, these policies were designed to stimulate agricultural production and guarantee a minimum income level to Colombian farmers. Also, their implementation required an active government and constant intervention in many markets (agricultural products, agricultural inputs, and agricultural credit) (Guterman, 2007). Consequently, Colombia's agriculture have been subject to many market distortions, which have limited its competitiveness in recent decades (Anderson & Valdés, 2008).

While assessing Colombian agricultural policy is not the main purpose of this study, establishing which kind of policies have provided more distortions to Colombia's agriculture is important. This allows us to identify the policies that have most limited the competitiveness of the sector and, therefore, have prevented Colombia's agriculture from realizing strong gains in productivity. Also, this analysis will identify when agricultural productivity growth, the focus in this study, has been determined more by institutional factors rather than by market factors, such as input prices or the international prices of the commodities.

This study uses the World Bank methodology, used to evaluate agricultural distortions worldwide, to assess agricultural policy in Colombia (Anderson & Valdés, 2008). This methodology includes some indicators to recognize the distortions generated by agricultural policy, although its main conclusions are based on the Nominal Rate of Assistance (NRA). This rate is defined as the price of a product in the domestic market less its price at the border, expressed as a percentage of the border price. This captures the effects of ad valorem tariffs, variable tariffs, restrictions on imports, and storage subsidies. Also, it indicates that agricultural production is highly subsidized when it is positive, whereas agricultural production is taxed when it is negative. As long as the NRA moves away from 0, agricultural policy is distorted (Anderson & Valdés, 2008).

This analysis indicates that Colombia has executed a highly distorted agricultural policy during the period 1970-2014 (see Figure 8). Despite all efforts to fix these distortions with the execution of the second package of reforms of its Structural Adjustment program in the early 1990's, Colombia's agricultural policy largely remained the same. Colombia's government continued making constant and sizeable market interventions to address the high dependency of farmers. Thus, Colombia's agriculture has received preferential treatment in almost all trade reforms to support farmers by taxing exportable products and subsidizing importable products (see Figure 9). It is believed that these Structural Adjustment reforms, in particular the trade reform, did not have a significant impact on Colombia's agricultural policy, as it only forced the government to shift its agricultural policy, based on an import substitution model, to a scheme of trade protection with an open economy model (Guterman, 2007). However, government intervention continued in this sector, which explains why agricultural policy in Colombia has been more distorted than the Latin American average since the 1990's (see Figure 8).

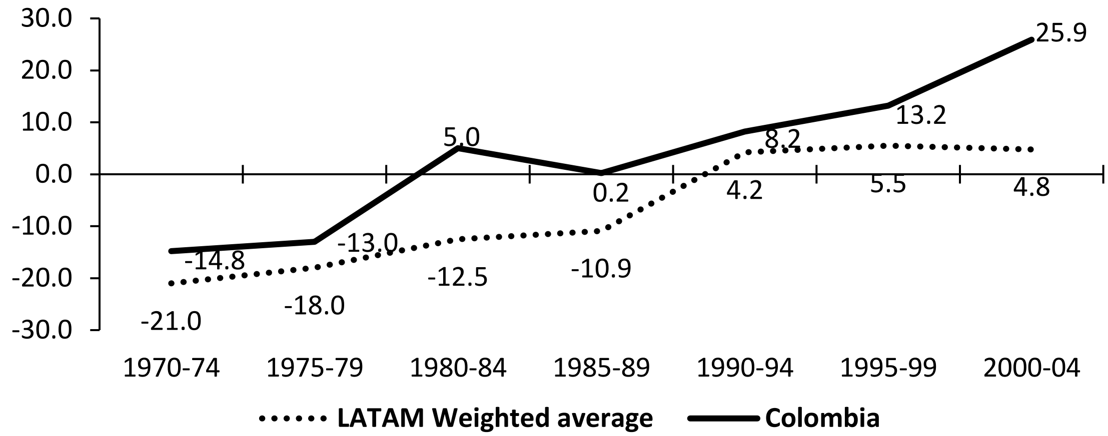

Figure 8. NRA of Colombia versus Latin America (LATAM) (%)
(Source: Anderson & Valdés, 2008)

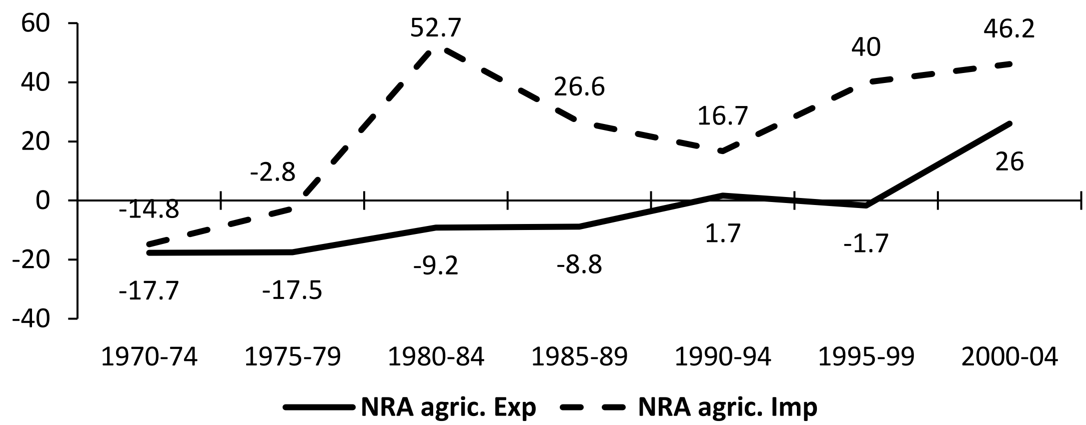

Figure 9. NRA in Colombia by Exported and Imported Products
(Source: Anderson & Valdés, 2008)

Over the 1970's, agricultural policy carried out by the Pastrana administration (1970-1974) and the Lopez administration (1974-1978) was largely distorted. These administrations taxed agricultural exports (mainly coffee) to collect all extraordinary gains resulting from devaluations prompted by the emergency reforms taken by Colombia in the late 1960's (Ordinance No. 444, 1967). In addition, this administration also instituted additional measures to protect coffee production from volatility in the foreign market, since coffee exports represented about 55% of Colombia's exports[12] (J. Cardenas, 1993; GRECO, 2002; Ordinance No. 444, 1967). As a result, the price of agricultural products in the domestic market tended to be 15% lower than the border prices (see Figure 8). This amounted to US$770-830 (constant 2014 prices) in taxes per person engaged in agriculture.

During the 1980's, this situation changed completely. Due to the Debt crisis and a crisis in the world coffee market, commodity prices fell by 30%, in real terms (Dornbusch, 1989). As a result, coffee exports decreased their share in Colombia's exports to less than 30% (Leibovich, 1989). Also, Colombia's agriculture started to subsidize its imports (wheat, rice, maize, sugar, soybeans, and sorghum) by +52.7%, giving farmers direct support by covering partially cost of inputs, credit, price supports and guaranteed absorption, among others (see Figure 8) (Reina et al., 2011). This way, farmers received a subsidy of about US$250 per person engaged in agriculture.

By the late 1980's, the distorting effects of this policy faded. The NRA of importable products decreased to 26.6% and the NRA of exportable products remained at -9.2%. The agricultural policy of the Barco administration (1986-1990) to boost agriculture did not distort the sector's valuation in the same way, since it was surely offset by the rebound exhibited by agricultural commodity prices in the world market at the time (IMF, 2015).

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[12] These measures included a minimum refund price, a withholding coffee tax, and an internal support price (GRECO, 2002).

However, the poor dynamism of Colombia's economy explains why this administration claimed that Colombia needed the execution of the second package of reforms of its Structural Adjustment in order to implement policies more efficiently.

During the 1990's, Colombia executed the second package of reforms of its Structural Adjustment program, but effects were not expected in the agricultural sector. As explained above, this sector was seriously affected due to the reforms' accelerated and abrupt administration, given by Colombia's government. Colombia's agriculture fell into crisis, forcing policy makers to reverse some of these reforms under the Gaviria administration (1990-1994). These measures were highly distorting, and had artificially increased the domestic price of imports by 16.7% in the early 1990's, by 40% in the late 1990's, and maintained the prices of exports close to the border prices. Also, these reforms had a minimal impact on improving sector competitiveness, since they promoted trade defense mechanisms to insulate producers from international markets. In addition, these measures encouraged very little creation of attractive environments for productivity and private investment; they did not allow Colombia to promote a reallocation of productive resources from imports to exports (Anderson & Valdés, 2008; Reina et al., 2011).

Over the 2000's, agricultural policy in Colombia became increasingly distorted. The NRA increased to 26%. It was designed with a paternalistic objective, despite its negative effect on Colombia's competitiveness. The NRA of importable products reached 46.2%, due to Colombia's: i) frequent suspension of the SAFP for some products (milk, corn, etc.); ii) creation of the *Mecanismo de Administracion de Contingentes* - MAC, allowing industrialists to import cheap commodities with the purchase of domestic products (corn, rice, soybean), and iii) introduction of the AIS to protect the products most likely to be affected by signing a Free Trade Agreement with the US (Jaramillo & Jimenez, 2008). Likewise, the NRA for exported products increased to 26%, because the government: i) gave price support to coffee producers, called the AGC, to help them face the downturn of international prices exhibited in the early 2000's, and ii) gave special tax treatment to the producers of perennials (Jaramillo & Jimenez, 2008). Colombia's policy makers continued designing policies to protect the sector, paying little attention to implementing policies with the purpose of increasing agriculture productivity.

Although, NRA estimates for Colombia in more recent years are not yet available, evidence suggests that Colombian agricultural policy has continued much the same. Junguito et al., (2014) indicate that Colombia's agriculture continues exhibiting the same bottlenecks (explained later in this chapter). Also, that study states that Colombia continues with problems with its current aid structures, agricultural trade policy, and the allocation of public sector spending. The result is an imbalance in the distribution of rural rents, which distorts resource allocation and inhibits the development of productive alternatives. In addition, the proper conditions for higher and sustainable growth have not been met. Colombia's agricultural policy continually faces the same historical problems.

2.4 Main Facts about of Colombia's Agriculture

2.4.1 Land Use

During the last two decades, land use for Colombia's agriculture decreased from 45 million hectares in the 1990's to 42-44 million hectares in the 2000's (see Figure 10) (DNP, 2015; FAO, 2015). However, its distribution among agricultural activities has changed very little. Most of Colombia's agricultural land continued being used as permanent meadows and pastures to feed livestock (88% of the total), followed by the land used for perennial crops (5%-7%) and annual crops (4%-5%) (see Figure 11). Nevertheless, land usage decreased to 92% of the total agricultural land in 2001. The intensification of armed conflict in Colombia in the late 1990's and early 2000's prompted many people to leave rural areas and this seemingly caused a reduction of about 6% in land used as permanent meadows and pastures. This was also a disincentive to investment (Alban, 2011; DNP, 2002; FAO, 2000; Montero & Casas, 2012). Then, land use increased slightly to 98% in 2012, with the recovery of the livestock sector and expansion of land used to cultivate perennial crops (+24%). In any case, agricultural land remains highly concentrated in the production of livestock, and the main change was an increase in land used to cultivate perennial crops.

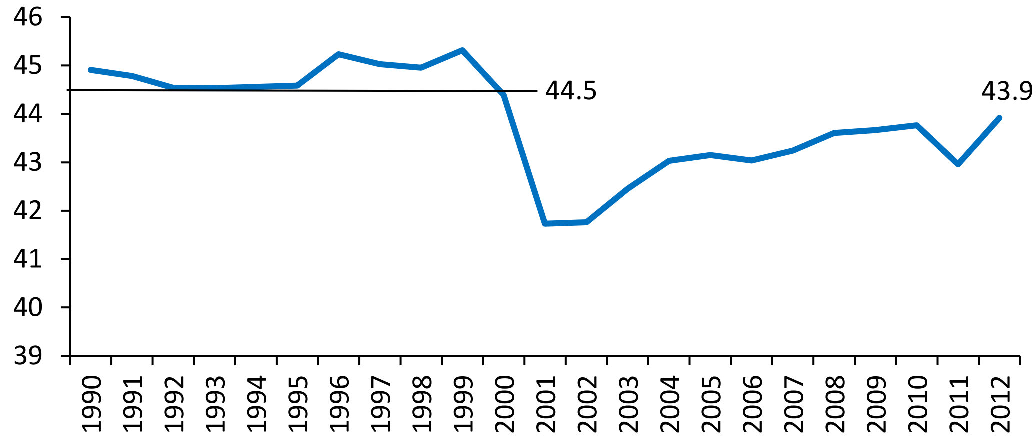


Figure 10. Agricultural Land Used in Colombia (Million Hectares)
(Source: Estimates based on DANE, 2015; FAO, 2015)

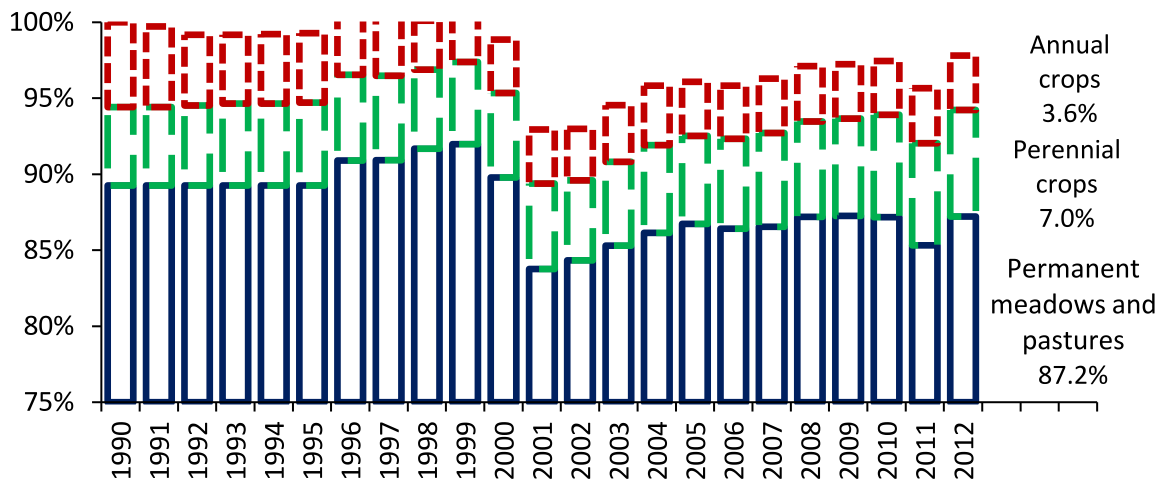


Figure 11. Land Use Distribution by Agricultural Activity
(Source: Estimates based on DNP, 2015; FAO, 2015)

Permanent meadow and pasture areas decreased by 6% during the 1990's. This land diminished from 40.1 million hectares in 1990 to 37.6 million hectares in 2001 due to security problems in Colombia (see Figure 12). Afterwards, land used as permanent meadows and pastures increased by 5% to 39.2 million hectares during the 2000's as a result of: i) the security policy of the Uribe administration (2002-2010) (DNP, 2002, 2006); ii) the return of this land to its production equilibrium level, and ii) strong beef exports to Venezuela (Montero & Casas, 2012). This indicates that land used as permanent meadows and pastures exhibited a structural change between the 1990'and the 2000s, mainly due to the worsening armed conflict in Colombia. Notice that Colombia has not been able to fully recover land use levels from the 1990's since 2001.

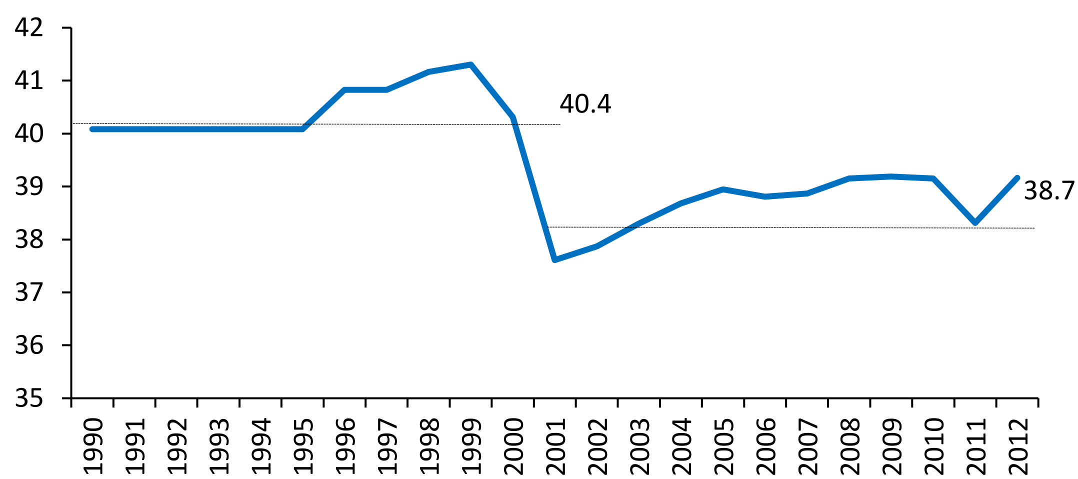


Figure 12. Land Used by Permanent Meadows and Pastures (Million Hectares)
(Source: Estimates based on DNP, 2015; FAO, 2015)

Land used to cultivate agricultural products exhibited a "u" trend from 1990-2014 (see Figure 13). It decreased by 15.4% in the 1990's from 4.8 million hectares in 1990 to 4.1 million hectares in 2000, because Colombia's agriculture exhibited a profitability crisis during this decade, as explained above (C. F. Jaramillo, 1998; Junguito, 1994; Kalmanovitz

& López, 2003). However, annual crop farmers were the most affected; their land used declined by 37% from 2.5 million hectares in 1990 to 1.6 million hectares in 2000 (C. F. Jaramillo, 1998).

This situation completely changed during the 2000’s. Land used to cultivate agricultural products increased by 15.3% in the 2000’s from 4.1 million hectares in 2000 to 4.8 million hectares in 2012, since: i) openness of Colombia’s economy promoted a reallocation of resources toward the cultivation of perennial crops; and ii) the Uribe-I administration (2002-2006) carried out a set of policies to solve the security problems of the late 1990’s and to boost the cultivation of perennial crops (Kalmanovitz & López, 2003; Montero & Casas, 2012). This way, land used to cultivate perennial crops rose by 24% from 2.5 million hectares in 2001 to 3.1 million hectares in 2012.

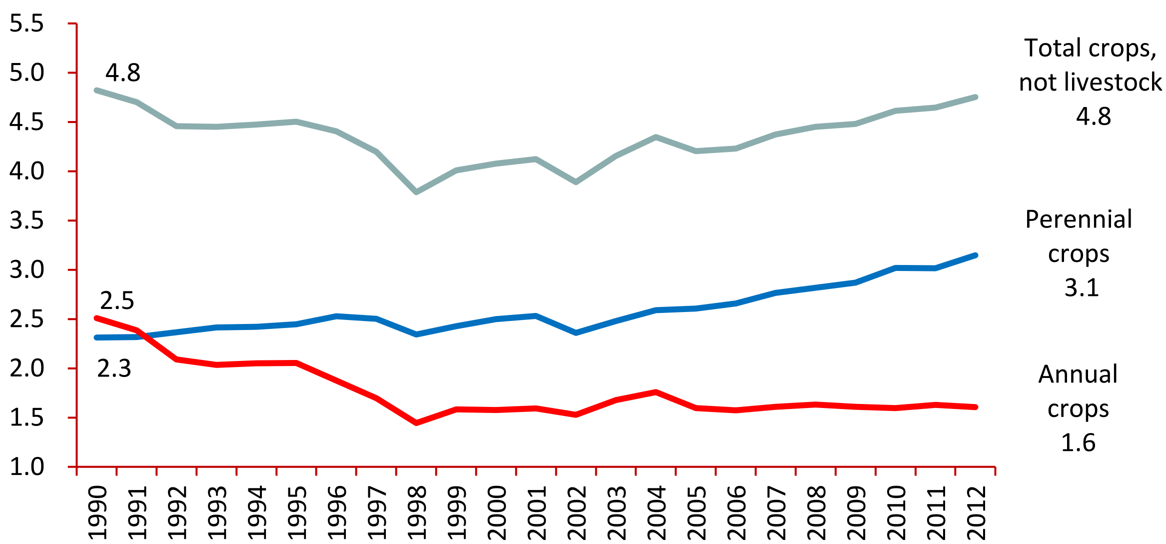


Figure 13. Land Used by Agricultural Crops (Million Hectares)
(Source: Estimates based on DNP, 2015)

As Table 2 shows, land used to cultivate perennial crops grew by 33% during the 2000’s, from almost 2.4 million hectares in 2002 to 3.1 million hectares in 2012. This growth was related to greater expansion in land used to cultivate palm oil (+144%), plantains (59%) and fruits (76%). Land used to cultivate palm increased from 185,165 hectares in 2002 to 452,435 hectares in 2012, mainly due to government policy that encouraged the use of palm oil to produce biodiesel in Colombia (COMPITE, 2008). Likewise, land used to cultivate plantains increased from 280,000 hectares in 2002 to 445,580 hectares in 2012, due to higher domestic consumption, higher demand from industry to produce snacks, meals and frozen plantains, and to substitute for non-profitable activities, such as coffee in certain regions (MADR, 2005c; Montero & Casas, 2012). In addition, land used to cultivate fruits increased from 189,410 hectares in 2002 to 333,640 hectares in 2012, due to higher domestic and external demands and higher investments in this sector (ANIF, 2014; Montero & Casas, 2012). Also, it worth noting that land to cultivate flowers, one of the most important exportable products, remained stable around 6.200-6.500 hectares during this decade. Nevertheless, coffee remains the main perennial crop cultivated in Colombia during the last two decades, involving around 930,000 hectares in 2012 (30% of perennial crop land), followed by palm oil, which used 452,000 hectares (14%) in that year, plantains with 445,000 hectares (14%), and fruits with 333,000 hectares (11%). Thus, although coffee continues to be the main perennial crop cultivated in Colombia, others such as palm oil, plantains and fruit have increased due to higher demand, higher investments in these sectors, and governmental policies implemented to encourage their cultivation.

Table 2. Land Use for Main Perennial Crops Cultivated in Colombia (Hectares)
(Source: DNP, 2015)

	1990	**1998**	**2002**	**2012**
Coffee	951,000	864,000	865,142	931,040
Palm oil	108,040	145,026	185,165	452,435
Plantain	390,824	393,044	280,033	445,584
Fruits	70,843	134,278	189,408	333,637
Yucca	223,541	184,508	171,936	230,161
Panela Cane	213,275	222,839	257,469	239,200
Sugar Cane	152,427	196,276	205,456	224,144
Others	202,219	202,641	206,063	290,896
Total	**2,312,169**	**2,342,612**	**2,360,672**	**3,147,097**

In contrast, land used to cultivate annual crops fell 37% during the 1990's, from 2.5 million hectares in 1990 to 1.4 million hectares in 1998, due to a sharp decline in the land used to cultivate corn. These lands decreased by 45% over this period, from 836,900 hectares in 1990 to 461,490 hectares in 1998, due to the profitability crisis suffered by Colombia's agriculture during this period (see Table 3) (C. F. Jaramillo, 1998). Afterwards, land used to cultivate annual crops remained stable at around 1.4-1.6 million hectares during the 2000s. However, land used to cultivate corn increased by 10% to 607,800 hectares over the period 2002-2012, and land to cultivate rice expanded by 9% to 502,000 hectares, due to: i) government subsidies given to these products over this period; ii) higher commodity prices, and iii) the use of better seeds to increase yield per hectare (COMPITE, 2008). Thus, overall annual crop cultivation decreased during the 1990's. These products were the most affected by Colombia's agricultural crisis. Then, this situation improved during the 2000's, due to the better conditions these farmers faced during that decade.

Table 3. Land Use for Main Annual Crops Cultivated in Colombia (Hectares) (Source: DNP, 2015)

	1990	1998	2002	2012
Corn	836,900	461,491	554,850	607,800
Rice	521,100	490,833	458,758	501,971
Potatoes	161,350	95,477	121,737	155,940
Others	989,993	396,466	393,111	340,149
Total	**2,509,343**	**1,444,267**	**1,528,456**	**1,605,859**

2.4.2 Agricultural Production

Production of agricultural crops in Colombia stagnated at around 20 million tons during the 1990s. Although perennial crop production increased by 28% from 10.9 million tons in 1990 to 13.9 million tons in 2000, annual crop production decreased by 17% from 9.1 million tons to 7.6 million tons over this period, since these crops were the most affected by Colombia's 1990s agricultural crisis (see Figure 14) (C. F. Jaramillo, 1998). Thus, this situation changed the composition of Colombia's agricultural production. Perennial crop production increased its share of total crop production from 54% in 1990 to 65% in 2000, while annual crop production decreased its share from 46% to 35% (see Figure 15).

During the 2000s, agricultural crop production in Colombia resumed its dynamism from earlier to the 1990's. It expanded by 12.8% during this decade, from 21.5 million tons in 2000 to 24.3 million tons in 2012. Production of perennial crops increased by 15.3% over these years, and production of annual crops remained stable at around 7.7 million tons. Some key factors to explain this dynamism of Colombia's agriculture at the time were: i) higher investment in perennial crops with a comparative advantage; ii) the tax exemption to perennial crops since 2005 (Act No. 939, 2004; Ordinance No. 1970, 2005);

iii) the security policy implemented by the Uribe-I administration (2002-2006) to face the worsening armed conflict (DNP, 2002); iv) the adoption of new technology to raise the yield per hectare; and v) the development and usage of genetically modified seeds (Montero & Casas, 2012). Thus, these features allowed Colombia to expand its agricultural production during the 2000's.

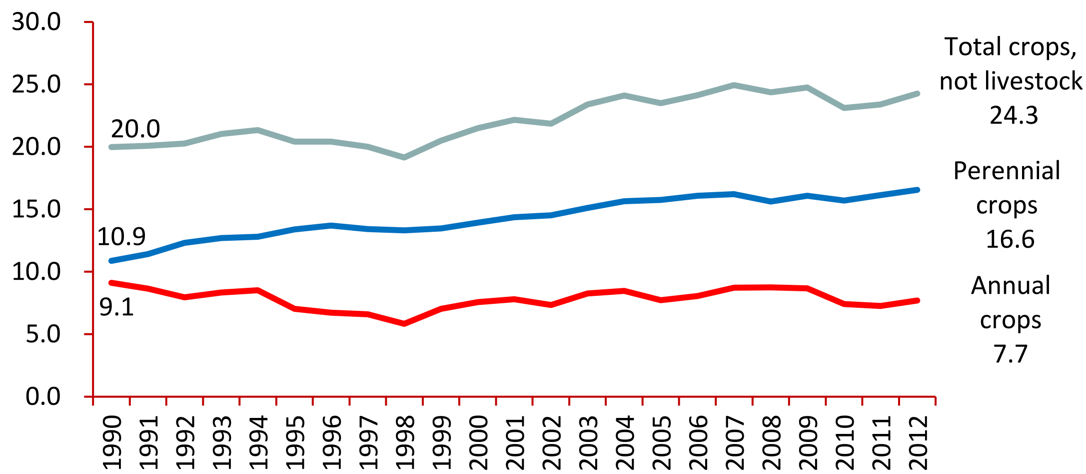


Figure 14. Production of Agricultural Crops (Million Tons)
(Source: estimates based on DNP, 2015)

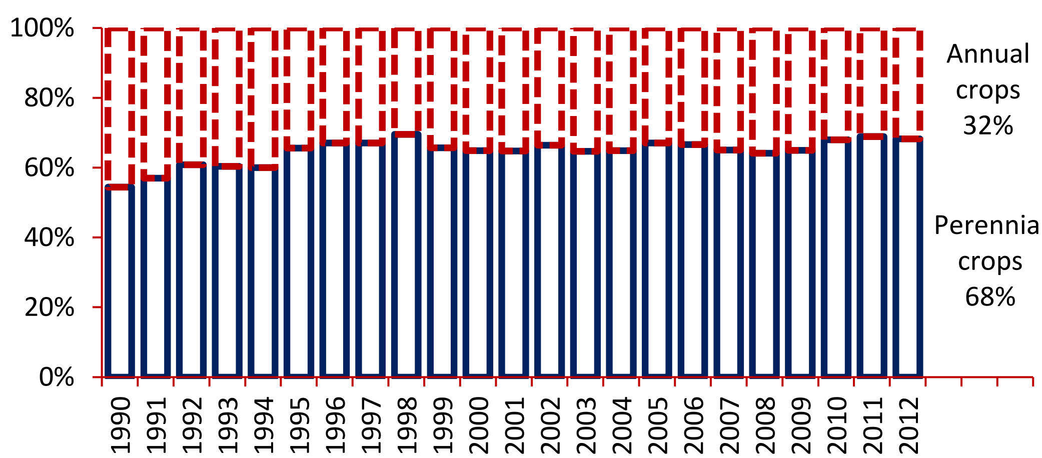


Figure 15. Composition of Colombia's Agriculture Production by Crop Type
(Source: DNP, 2015)

As Table 4 shows, perennial crop production expanded steadily by 52% from 1990-2012. It increased from 10.9 million tons in 1990 to 16.6 million tons in 2012, due to sharp increases of fruit production (+200%), as well as bananas (+58%), plantains (+28%), and sugar (+24%). Fruit production increased from 1.2 million tons in 1990 to 3.6 million tons in 2012, and plantain production grew from 2.5 million tons to 3.2 million tons, due to the increase in the land cultivated with these products. Banana production increased from 1 million tons in 1990 to 1.6 million tons in 2012, due to higher yield per hectare and a decrease in violence in producing zones (Montero & Casas, 2012). Likewise, sugar production increased from 1.7 million tons in 1990 to 2.1 million tons, although it then declined during the 2000s due to sugar cane use in ethanol production (Tovar et al., 2007). In addition, production of flower, which was mainly for exporting (more than 90%), increased from 107.000 tons in 1990 to 215.000 tons in 2012 due to: i) higher productivity resulting from reallocation of varieties according to climate change conditions; ii) the cultivation of more profitable varieties; and iii) the consolidation of new markets (Arbeláez, 1993; Becerra, 2009). Thus, this indicates that Colombia increased its perennial crop production in recent decades, although the most dynamic products (fruits and plantain) were mainly destined for the domestic market.

Table 4. Production of Main Perennial Crops Cultivated in Colombia (Tons) (Source: DNP, 2015)

	1990	1998	2002	2012
Fruits	1,172,500	2,439,974	2,577,935	3,557,680
Plantain	2,502,168	2,560,245	2,853,907	3,202,674
Yucca	1,939,019	1,598,166	1,834,856	2,217,949
Sugar	1,669,386	2,200,544	2,528,756	2,077,653
Banana	1,018,431	1,424,672	1,413,322	1,609,144
Others*	2,576,187	3,089,479	3,313,817	3,894,052
Total	**10,877,692**	**13,313,080**	**14,522,592**	**16,559,152**

*This category includes the production of crops with less than 10% weight in the total production in 2012.

In contrast, the production of annual crops contracted by 36% during the 1990's due to the difficulties that farmers faced during these years (see Table 5). It decreased from 9.1 million tons in 1990 to 5.8 million tons in 1998, mainly due to sharp drops in potato (-55%), corn (-36.7%), and vegetable production (-33.2%). Potato production decreased from 2.5 million tons in 1990 to 1.1 million tons in 1998, and vegetable production from almost 1.3 million tons to 860,000 tons due to severe droughts in 1991-1994 and 1997-1998 and crops lack of technological cultivation practices (Australian Government, 2015; Montero & Casas, 2012). Finally, corn production decreased from 1.2 million tons in 1990 to 770,000 tons in 1998, since farmers experienced the profitability crisis and were most affected by Colombia's agricultural crisis of this period (C. F. Jaramillo, 1998). Therefore, annual crop production declined during the 90s, mostly due to the profitability crisis faced by farmers, extreme climate conditions, and decreased land use.

As was the case with land used by annual crops, production stabilized and increased by 5% during the 2000's, mainly because vegetable production increased by 40.9% over this period, from 1.4 million tons in 2002 to 1.9 million tons in 2012, as a result of an expansion in land used (+40%), better farming practices, higher yield per hectare, and higher investment in research during earlier years (La Republica, 2012; SIC, 2012). Without these gains in production practices, annual crops production wouldn't have increased, since rice production actually decreased slightly, by 6.3% to 2.3 million tons in 2012, and corn production remained stable at around 1.1-1.2 million tons. Thus, annual crop production showed a solid expansion during the 2000s, but it was largely explained by growth in vegetable production.

Table 5. Production of Main Annual Crops Cultivated in Colombia (Tons) (Source: DNP, 2015)

	1990	**1998**	**2002**	**2012**
Rice	2,473,237	2,604,259	2,473,731	2,317,710
Potatoes	2,464,400	1,108,770	1,761,057	1,847,145
Vegetables	1,284,800	858,512	1,360,386	1,916,136
Corn	1,211,500	767,115	1,132,067	1,211,002
Others	1,685,695	497,407	610,599	410,785
Total	**9,119,632**	**5,836,062**	**7,337,840**	**7,702,778**

*This category includes the production of crops with less than 10% weight in the total production in 2012.

Finally, the production of animal products in Colombia exhibited a sharp and steady expansion during 1990-2012. These figures multiplied by 2 from 1.1 million tons in 1990 to 2.3 million tons in 2012, due to rapid growth of the poultry sector (which multiplied by 4). As Figure 16 shows, chicken production increased from 276,630 tons in 1990 to 1.1 million tons in 2012, since: i) input prices to feed the animals (corn, sorghum and soybean) decreased as a result of the Structural Adjustment reforms executed during early 1990's (Kalmanovitz & López, 2003); ii) Colombia's per capita consumption of chicken increased from 8kg a year in 1990 to 24kg a year in 2012 (FENAVI, 2015); and iii) the sector started to use more efficient practices for production (Mojica & Paredes, 2005). Likewise, beef production increased by 23% during the same period, from 796,000 tons in 1990 to almost 979,000 tons in 2012, due to: i) high investments in the sector during the late 1990s; and ii) high volumes exported to Venezuela during the 2000s (DANE, 2015). Finally, pork production multiplied by 2 during the 2000s, from 116,500 tons in 1997 to 243,000 tons in 2012, since: i) pork production continued formalizing during this period (ANIF, 2013a); ii) Colombia’s population increased and per capita consumption increased from 3.3kg a year in 1995 to 6kg a year in 2012; iii) production ceased to be seasonal (ANIF, 2013a), and iv) pork production was bolstered by the drop in cereal prices. Thus, the composition of meat production in Colombia changed sharply in recent decades (see Figure 17). While beef was the most produced meat in Colombia, with a 74% share of the total in the early 1990’s, chicken took its place in recent years with a 48% share in 2012, followed by beef with 42% and pork with the remaining 10%. Thus, the production of animal products in Colombia has increased steadily in recent decades, though it shows a change in the production composition of meats, due to rapid growth in chicken production.

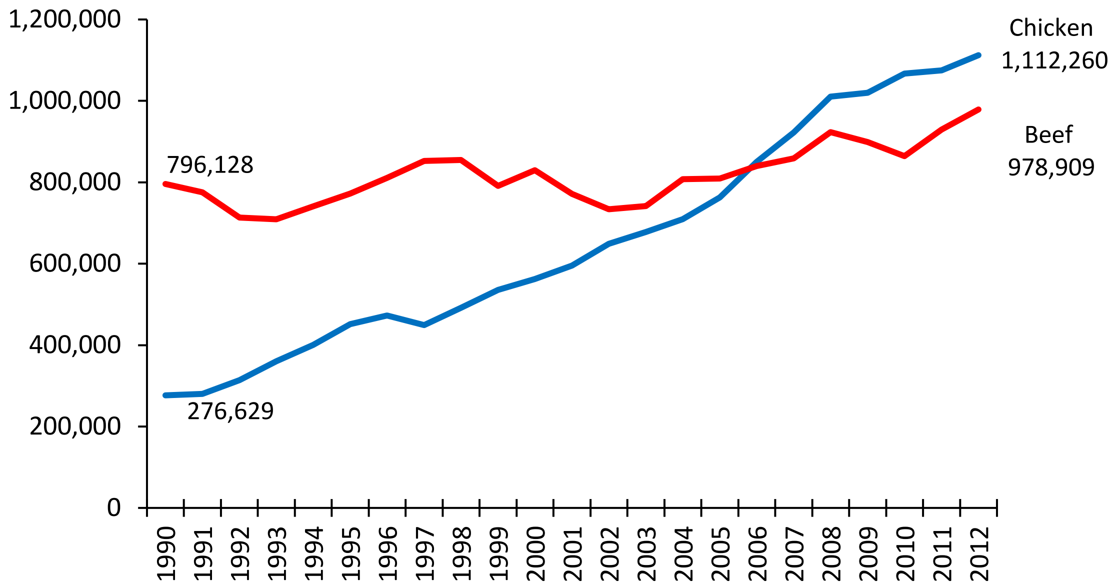


Figure 16. Production of Animal Products in Colombia (Tons)
(Source: FEDEGAN, 2015; FENAVI, 2015)

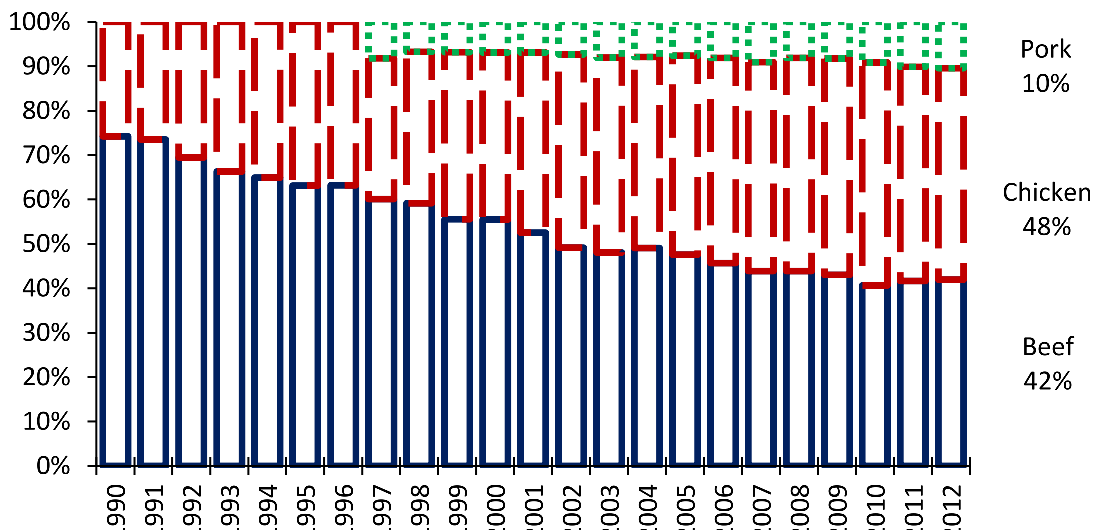


Figure 17. Composition of Meat Production in Colombia
(Source: FEDEGAN, 2015; FENAVI,2015; PORCICOL, 2014)

2.4.3 Value of Agricultural Production

Colombia expanded the value of its agricultural production from US$9.8 billion (constant 2004-2006 prices) in 1990 to US$14.8 billion in 2013, an increase of about 50% (see Figure 18). Also, Colombia expanded its value per capita from US$285 in 1990 to US$310 in 2013. However, this expansion occurred in three different stages. Also, this expansion was not accompanied by a diversification of the main agricultural products of Colombia's portfolio, although some new products arose and their share quickly increased in the value of Colombia's agricultural production (e.g. chicken, citrus fruits and eggs).

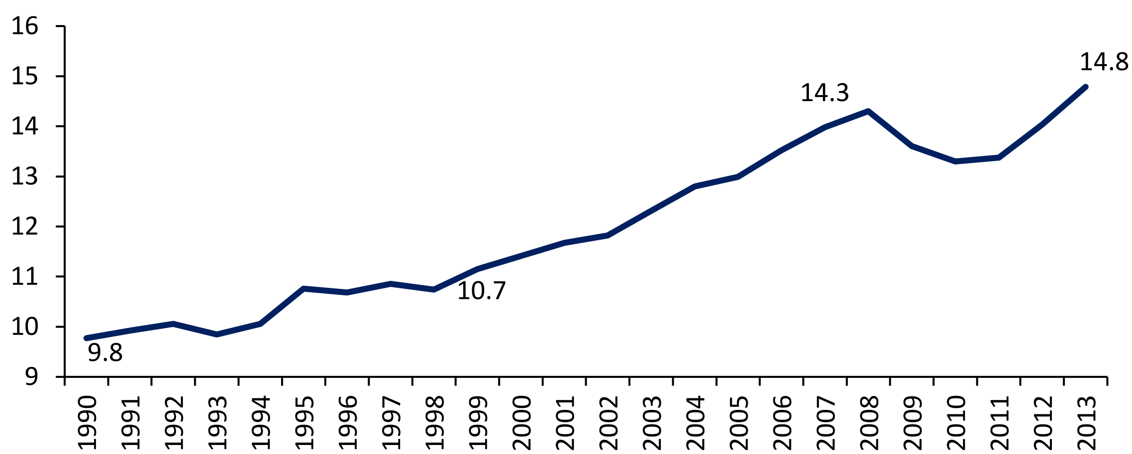


Figure 18. Value of Agricultural Production in Colombia
(Constant 2004-2006 Prices, US$ Billions) (Source: FAO, 2015)

During 1990-1998, the value of Colombia's agricultural production increased from US$9.8 billion to US$10.7 billion, due to: i) a sharp increase in poultry production (+70%), as a result of a decrease in the import taxes of corn and soybeans, a higher consumption per capita and the use of more efficient practices for production, as explained above

(Kalmanovitz & López, 2003; Mojica & Paredes, 2005); ii) high performance exhibited by milk production, since its value increased by 38.5% over this period as a result of innovations in feeding and management of livestock, genetic improvements, and the purchase of highly productive species (MADR, 2005b); and iii) the dynamics of sugar cane production, which increased in value by 19% with the introduction of mechanized harvesting practices, the modernization of production processes and equipment and machinery, and its inclusion as a product covered by the SAFP (C. F. Jaramillo, 1998; Ramirez & Garcia, 2006). However, the overall value of agricultural production changed little during this period (see Table 6). Beef continued to generate more value in agricultural production (20%) in 1998, followed by milk (17%), sugar cane (10%), and coffee (8%). Also, Colombia was able to expand the value of its agricultural production during the 90's, despite the period's agricultural crisis.

Table 6. Value of Agricultural Production in Colombia (1990-1998)
(Constant 2004-2006 Prices, US$ Billions, %) (Source: FAO, 2015)

	1990		**1998**	
	Value (US$ billions)	**%**	**Value (US$ billions)**	**%**
Beef	2,000,000	20.5%	2,100,000	19.5%
Milk	1,300,000	13.3%	1,800,000	16.8%
Sugar cane	912,564	9.3%	1,100,000	10.2%
Coffee	907,834	9.3%	824,013	7.7%
Rice	589,812	6.0%	528,824	4.9%
Plantains	519,428	5.3%	528,367	4.9%
Chicken	423,509	4.3%	719,635	6.7%
Potatoes	415,944	4.3%	429,921	4.0%
Bananas	350,240	3.6%	427,649	4.0%
Others	2,352,176	24.1%	2,285,501	21.3%
TOTAL	**9,771,507**	**100%**	**10,743,910**	**100.0%**

Over the years 1998-2008, the value of Colombia's agricultural production exhibited its most dynamic period. It grew by 33%, from US$10.7 billion to US$14.3 billion, mainly due to: i) the great dynamism that poultry and milk production continued exhibiting; their values expanded by 95% and 28%, respectively; ii) the dynamic of cattle production (+19% over this period), given large investments in new herds and technology (mainly in dual-purpose livestock) in the late 1990's, and higher prices of livestock in the 2000's because of an export boom to Venezuela (Clavijo & Jimenez, 2010; C. F. Jaramillo, 1998); iii) the rapid dynamic of citrus fruit production; its value increased by 18, as a result of the growing demand for these products in Colombia (MADR, 2005a; Tovar et al., 2007); iv) an outstanding pace for cereals, due to higher agricultural prices worldwide during 2006-2011, and the development of seeds to increase yield per hectare (COMPITE, 2008); and v) good performance exhibited by palm oil production; its value increased by 83% due to a government policy that encouraged its production as a biodiesel ingredient (COMPITE, 2008). As a result, the value of agricultural production exhibited a more significant change during this period (see Table 7). Beef and milk generated the most value to agricultural production in Colombia; however, both lost importance during the 2000s. Chicken most increased its relevance from 7% in 1998 to 10%, while sugar cane production dropped (10% in 1998 to 8% in 2008) due to limited land expansion (ANIF, 2013b). In addition, citrus fruits and eggs emerged as new important products, leading to a decrease in the importance of more traditional products, such as coffee and potatoes. Thus, the value of agricultural production in Colombia was increasing during the 2000's. Also, Colombia achieved a slight diversification of its portfolio of agricultural products during this decade.

Table 7. Value of Agricultural Production in Colombia (1998-2008)
(Constant 2004-2006 Prices, US$ Billions, %) (Source: FAO, 2015)

	1998		2008	
	Value (US$ billion)	**%**	**Value (US$ billion)**	**%**
Beef	2,100,000	19.5%	2,500,000	17.5%
Milk	1,800,000	16.8%	2,300,000	16.1%
Sugar cane	1,100,000	10.2%	1,100,000	7.7%
Coffee	824,013	7.7%	739,890	5.2%
Rice	528,824	4.9%	672,365	4.7%
Plantains	528,367	4.9%	697,775	4.9%
Chicken	719,635	6.7%	1,400,000	9.8%
Potatoes	429,921	4.0%	400,494	2.8%
Bananas	427,649	4.0%	559,771	3.9%
Eggs	299,931	2.8%	449,777	3.1%
Citrus fruit	298,356	2.8%	351,818	2.5%
Others	1,687,214	15.7%	3,128,539	21.9%
TOTAL	**10,743,910**	**100.0%**	**14,300,429**	**100.0%**

Finally, the value of Colombia’s agricultural production has almost stagnated during recent years, due to a new profitability crisis (Clavijo, Vera, & Jimenez, 2014). It grew by only 3.4%, from US$14.3 billion in 2008 to US$14.8 billion in 2013 (see Table 8), due to: i) domestic imbalances in some commodity markets (such as rice) for which supply was higher than production; ii) a sharp decrease in international prices; iii) Venezuelan market closures; iv) high fertilizer prices; v) climate change effects; and vi) high transportation cost, due to Colombia’s lagging infrastructure networks (Clavijo, Vera, & Jimenez, 2014). As a result, poultry and pork were among the few sectors that were improving over this period; these sectors experienced a sharp cut in production costs, due to the downturn of commodity prices and higher consumption per capita in Colombia for these meats. In contrast, milk, beef and rice were the most affected, resulting in a lower contribution in almost all products to the value of agricultural production during 2013.

Table 8. Value of Agricultural Production in Colombia (2008-2013)
(Constant 2004-2006 Prices, US$ Billions, %) (Source: FAO, 2015)

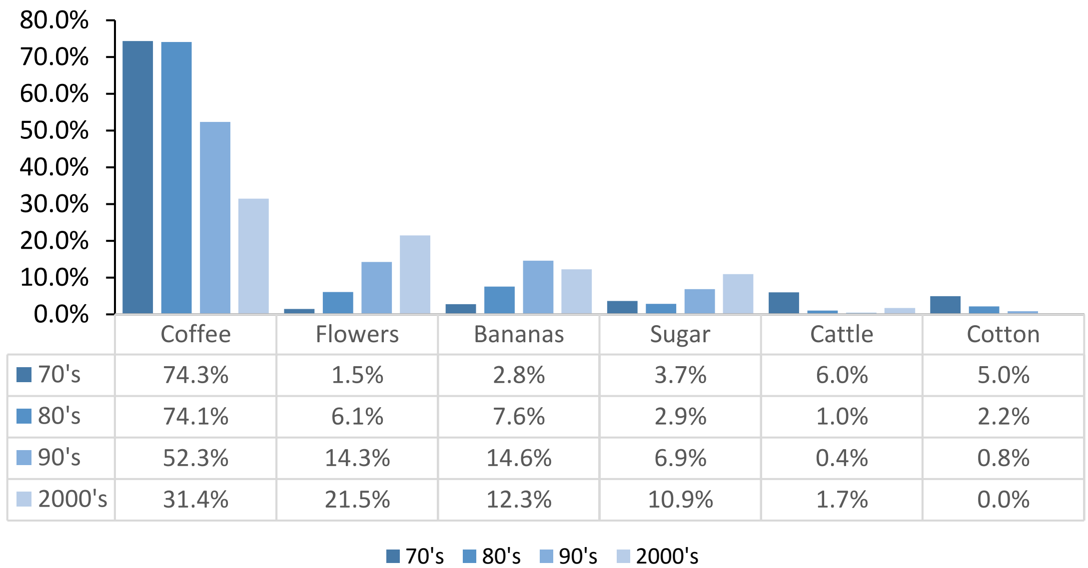
	2008		2013	
	Value (US$ billion)	**%**	**Value (US$ billion)**	**%**
Beef	2,500,000	17.5%	2,400,000	16.2%
Milk	2,300,000	16.1%	2,000,000	13.5%
Chicken	1,400,000	9.8%	1,800,000	12.2%
Sugar cane	1,100,000	7.7%	1,100,000	7.4%
Coffee	739,890	5.2%	701,729	4.7%
Plantains	697,775	4.9%	682,703	4.6%
Bananas	559,771	3.9%	591,038	4.0%
Rice	672,365	4.7%	570,957	3.9%
Eggs	449,777	3.1%	553,741	3.7%
Potatoes	400,494	2.8%	359,389	2.4%
Citrus fruit	351,818	2.5%	294,329	2.0%
Others	3,128,539	21.9%	3,733,701	25.2%
TOTAL	**14,300,429**	**100.0%**	**14,787,587**	**100.0%**

2.4.4 International Trade in Agriculture

2.4.4.1 Agricultural Exports

Colombia nearly doubled its agricultural exports in recent decades. Export value increased from US$3.6 billion in 1970 to US$6.5 billion in 2012 (constant 2014 prices) (see Figure 19). However, this dynamism was strongly dependent on coffee market conditions. Colombia exported mostly coffee for many years, and the exports of other products were marginal (see Table 9). Over the 1970's-1980's, coffee exports represented about 70%-80% of Colombia's agricultural exports, followed by cattle (6.0%), cotton (5.0%) and sugar (3.7%) in the 1970's, and bananas (7.6%) and flowers (6.1%) in the 1980's. During the 1990's, coffee exports started to decrease in importance, averaging 50%-55% of Colombia's agricultural exports, since bananas (14.6%) and flowers (14.3%) were expanding as a result of better exchange-rate conditions and the development and cultivation of more productive varieties. Finally, during the 2000's, the value of coffee exports continued decreasing in importance to just 30%. Flowers (21.5%), bananas, (12.3%) and sugar (10.9%) exports continued gaining relevance. Thus, there is no doubt that the change in coffee exports had a direct effect on the Colombia's agricultural exports during the last decades, but this has been changing once again in recent years.

Table 9. Main Exportable Agricultural Products from Colombia (% of Total) (Source: FAO, 2015)



	Coffee	Flowers	Bananas	Sugar	Cattle	Cotton
70's	74.3%	1.5%	2.8%	3.7%	6.0%	5.0%
80's	74.1%	6.1%	7.6%	2.9%	1.0%	2.2%
90's	52.3%	14.3%	14.6%	6.9%	0.4%	0.8%
2000's	31.4%	21.5%	12.3%	10.9%	1.7%	0.0%

Colombia's agricultural exports exhibited strong expansion during the 1970's. These increased from US$3.6 billion in the early 1970's to US$8.6 billion in the late 1970's, due to a coffee boom caused by severe frost in Brazilian coffee regions (see Figure 19) (GRECO, 2002). This raised coffee prices to levels close to US$3/lb (versus its historical average of US$1/lb), which increased the value of coffee exports from US$2.8 billion in 1970 to

US$7.2 billion in 1978. Hence, Colombia's agricultural exports exhibited a boom in the late 1970's, despite the fact that the coffee volume exported did not show a sharp increase at the time (GRECO, 2002). These volumes remained around 9-12 million bags (60Kg each), since these were limited by the agreed upon quotas between coffee exporters and importers under the International Coffee Quota Pact (ICQP) (Bohman & Jarvis, 1990; FEDECAFE, 2015)[13].

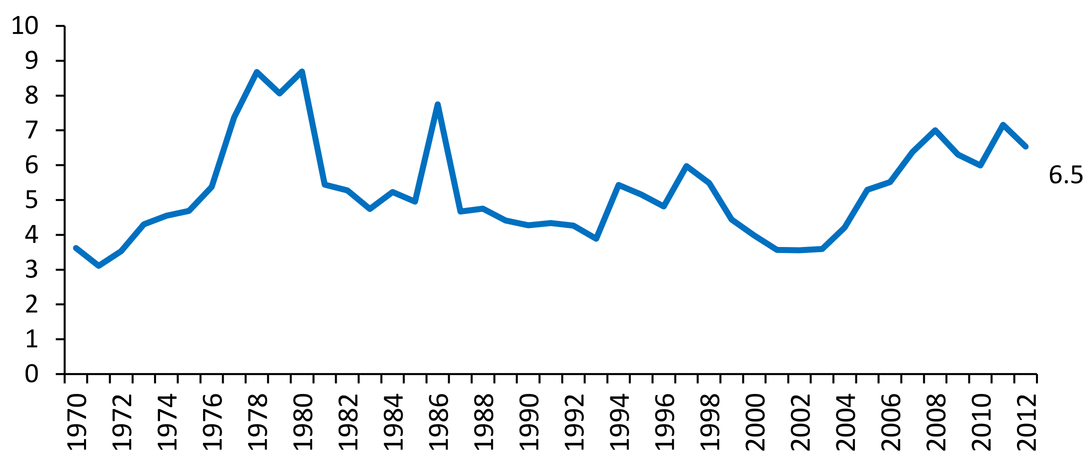


Figure 19: Colombia's Agricultural Exports
(Constant 2014 Prices, US$ Billion) (Source: FAO, 2015)

This situation changed in the early 1980's. Colombia's agricultural exports exhibited a downturn to almost US$5 billion in 1985, due to the Debt and coffee crises (see Figure 19). In 1986, this drop halted temporarily, and agricultural exports increased to US$7.8 billion, due to a new coffee boom resulting from another frost in Brazil (GRECO, 2002;

[13] Under this Pact, coffee exporters committed themselves to regulate their exports under a system of production quotas, while importers committed themselves to buy it. The aim was to stabilize coffee prices worldwide (Bohman & Jarvis, 1990).

Leibovich, 1989). However, its effect only lasted for that year. So, Colombia's agricultural exports started to fall again in 1987, reaching US$4.4 billion in 1989, since coffee prices continued decreasing during this period. These fell from US$2.1-2.4/lb in 1986 to US$0.7-0.9/lb in 1989, due in part to high uncertainty about the renewal of the ICQP (IMF, 2015).

Over the 1990's, Colombia's agricultural exports continued losing pace. Export value bottomed out at US$3.9 billion in 1993, due to: i) coffee prices decreased by 30% between 1990-1992 as a consequence of the elimination of ICQP and historically high coffee production in Colombia (18 million bags versus a historical average of 12 million bags); and ii) a real appreciation (+15%) of the Colombian Peso between 1990 and 1993 (BANREP, 2015; FEDECAFE, 2015). Agricultural exports expanded and stabilized around US$5-6 billion until 1997, due to the dynamism shown by flowers (6.4% yearly) and bananas exports (2.1%) from 1993-1997. Flowers exports increased from US$640 million in 1993 to US$820 million in 1997, due to: i) a strong nominal depreciation (+45%) of the Colombian peso against the USD dollar during this period; ii) an expansion of cultivated area; iii) higher productivity per hectare resulting from reallocation of the varieties according to climate conditions; iv) the cultivation of more profitable varieties (such as roses); v) higher competence in the market, and vi) the consolidation of new markets (Arbeláez, 1993; Becerra, 2009). Likewise, banana exports increased from US$695 million in 1993 to US$740 million in 1997, due to: i) expansion of European consumption; ii) higher productivity per hectare; iii) greater abundance of unskilled labor; and iv) a strong nominal depreciation of the Colombia peso against the USD dollar (GRECO, 2002).

Finally, Colombia's agricultural exports strongly expanded during the 2000's. These increased from US$4 billion in 2000 to US$6.5 billion in 2012, due to the fact that agricultural commodity prices exhibited a boom during this decade; flowers and bananas also exhibited higher prices. Colombia's agricultural exports successfully faced the strong real appreciation exhibited by the Colombian peso during this decade, since coffee export value increased by 92% from US$1 billion in 2002 to almost US$2 billion in 2012, due to in higher prices; flower exports increased by 51% from US$890 million to US$1.4 billion in the same period, and banana exports increased by 50% from US$530 million to almost US$800 million.

2.4.4.2 Agricultural Imports

Colombia's agricultural imports were strongly determined by the economic liberalization carried out in the early 1990's. Over the 1970's and 1980's, before Colombia executed this process, imports value remained stable around US$900 million (see Figure 20). Import substitution policies in force at that time were used to control agricultural imports, since importable products (cereals, livestock product, and dairy) were largely produced domestically and were considered as key food sources for urban centers in the future. These policies only allowed large imports of wheat (20-25% of the total imports) and limited imports of soybean oil (5.9%), tallow (5.8%), rubber (4.6), milk (4%) and barley (3.7%) in the 1970's, and soybean oil (9.6%), soybeans (5.6%), rubber (4.2%) and tallow (4.0%) in the 1980's (see Table 10).

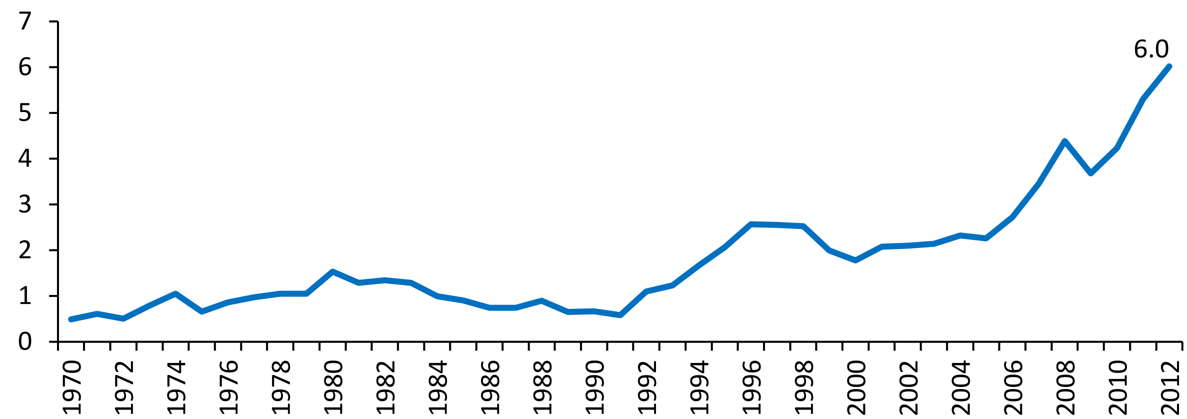


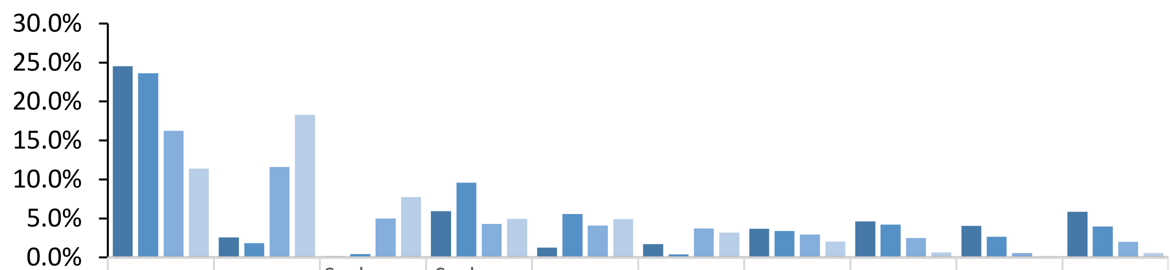
Figure 20. Colombia's Agricultural Imports
(Constant 2014 Prices, US$ Billion) (Source: FAO, 2015)

Over the 1990's, agricultural imports exhibited a sharp increase. These increased from US$660 million in 1990 to almost US$2 billion, following the Structural Adjustment's trade reform, which removed almost all constraints to importing agricultural products. Colombia's exposure to foreign agricultural competitiveness increased suddenly, and a problem was the poor preparation (Illera, 2009). As a result, cereal imports expanded, despite the efforts to control these with the SAFP. Therefore, the lower competitiveness that Colombia exhibited in the cultivation of these crops was evident, since the yield per hectare on these crops was insufficient to offset higher imports. Wheat imports continued being most important (16.2% of Colombia's agricultural imports), followed by the imports of maize (11.6%), soybean cake (5%), soybean oil (4.3%), soybeans (4.1%), and cotton (3.7%) (see Table 10).

Finally, during the 2000's, agricultural imports continued growing quickly in Colombia even with protection of the price band system known as *Sistema Andino de*

Franjas de Precios – SAFP. These increased from US$1.8 billion in the 2000 to US$6 billion in the 2012, since: i) Colombia's production of cereals was still unable to meet domestic demand (FENALCE, 2015); ii) agricultural commodity prices exhibited a boom during the period 2006-2011 (Abbott et al., 2008; Reina et al., 2011), increasing the value of these imports; and iii) poultry and pork industries continued expanding quickly during the 2000's, resulting in a steady increase in demand for feed grains. Consequently, maize imports became most important (18.3%) during the 2000's, followed by the imports of wheat (11.4%), soybean cake (7.8%), soybean oil (5%), soybeans (4.9%), and cotton (3.2%). Colombia continued its dependence on cereal imports to meet this demand, despite farmers' efforts to increase the yield per hectare in the production of these crops and its increasing domestic demand (see Table 10).

Table 10. Main Importable Agricultural Products to Colombia (% of Total)
(Source: FAO, 2015)



	Wheat	Maize	Soybeans Cake	Soybean oil	Soybeans	Cotton	Barley	Rubber	Milk	Tallow
70's	24.5%	2.6%	0.1%	5.9%	1.2%	1.7%	3.7%	4.6%	4.0%	5.8%
80's	23.6%	1.8%	0.4%	9.6%	5.6%	0.4%	3.4%	4.2%	2.6%	4.0%
90's	16.2%	11.6%	5.0%	4.3%	4.1%	3.7%	2.9%	2.5%	0.5%	2.0%
2000's	11.4%	18.3%	7.8%	5.0%	4.9%	3.2%	2.0%	0.6%	0.1%	0.6%

■ 70's ■ 80's ■ 90's ■ 2000's

2.5 Main Problems for Colombia's Agriculture

It is clear that Colombia's agriculture has exhibited sluggish and stagnant growth in recent decades, due to its low competitiveness. One of the main causes of this has been a lack of public resources for Colombia's agriculture. In recent decades, these resources have just represented 0.2%-0.4% of Colombian GDP, while in other emerging markets have reached 1%, and in 4% developed countries (Junguito et al., 2014) (see Figure 21).

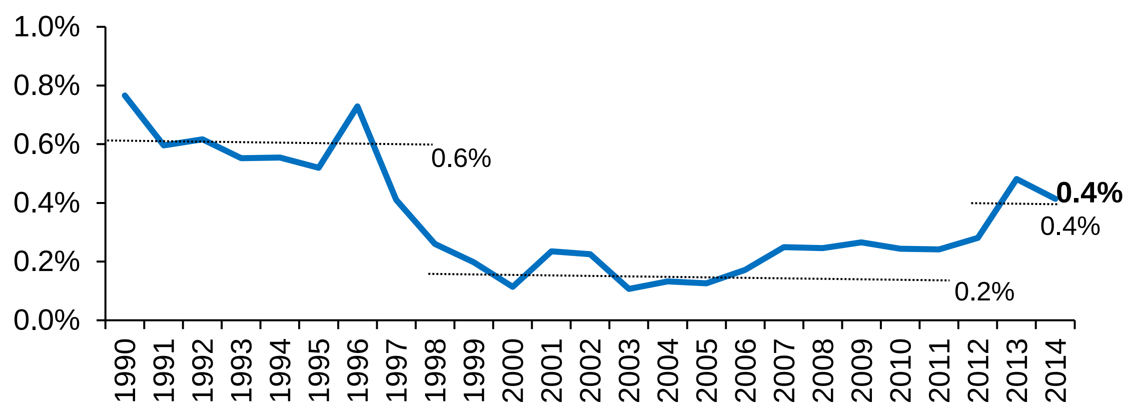


Figure 21. Public Resources for Colombia's Agriculture (1990-2014) (Source: Estimates based on: World Bank, 2016; DNP, 2015)

In order to know what exactly has determined this situation, COMPITE (2008) applied the methodology of bottlenecks for growth to Colombia's agriculture sector (Hausmann, Rodrik, & Velasco, 2008). The approach allows us to see that Colombia's agriculture exhibits a set of bottlenecks that impede its growth, such as: i) insecurity due to an armed conflict; ii) uncertainty of property rights; iii) inadequate infrastructure; iv) lack of innovation and technological development, and v) lack of access to funding. Some of these bottlenecks restrict Colombia's agricultural growth more than others. Thus, it is essential to identify and analyze these bottlenecks in order to understand why Colombia's agriculture has exhibited this poor performance.

COMPITE (2008) found that the main bottlenecks that determine low investments in Colombia's agriculture, and therefore cause its slow growth, are: i) low expected returns of projects developed in this sector, and ii) funding problems to develop projects in this sector. COMPITE (2008) found that each of these bottlenecks are explained by other factors (see Figure 22). For instance, low expected returns are mainly due to lacking human-capital in the sector, land misallocation, minimal exploitation of economies of scale, poor infrastructure (transport and irrigation), and lack of access to external markets. Also, funding problems are more associated with the fact that credit to Colombia's agriculture is segmented and restricted (Cuevas et al., 2003). This is because agriculture exhibits more inherent risks for loans than do other sectors; these risks include weather, pests, volatile commodity prices and their high incidence in domestic prices, and volatility of border prices due also to changes in exchange rate. Thus, COMPITE (2008) suggests that Colombia's agriculture will improve its performance in the future if its agricultural policy is designed to address and solve these bottlenecks. These efforts will allow Colombia to increase investment in the agricultural sector.

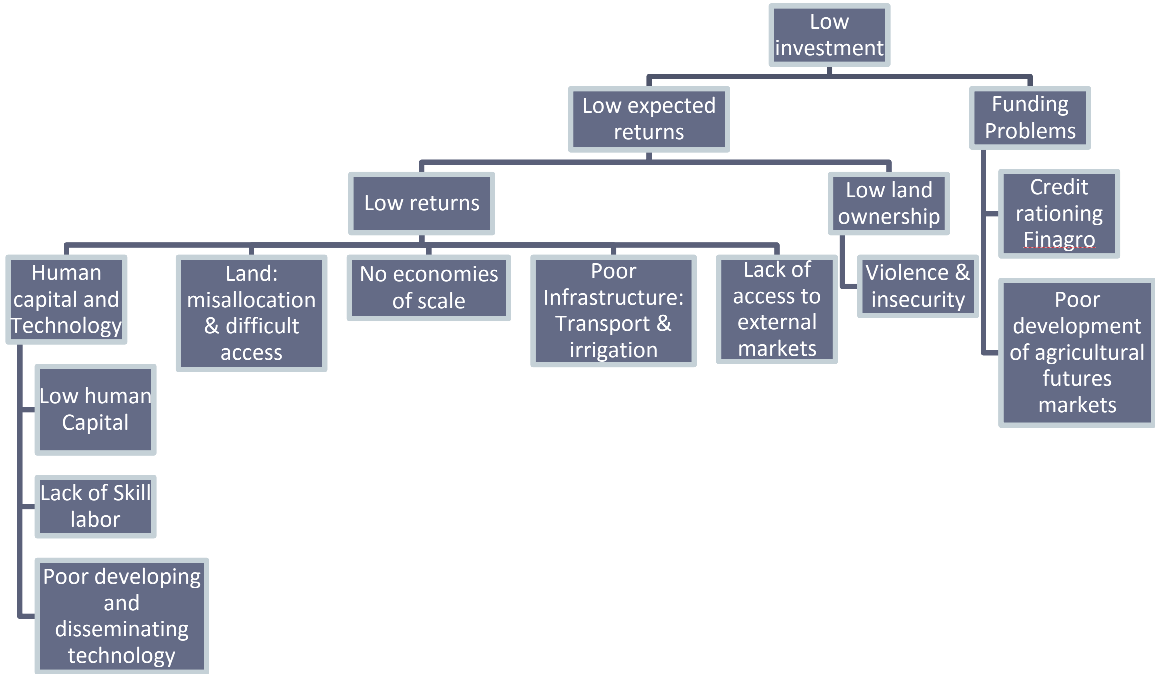


Figure 22. Bottlenecks Present in Colombia's Agriculture (Source: COMPITE, 2008)

2.5.1 Low Expected Returns

2.5.1.1 Low Returns

COMPITE (2008) argues that Colombia's agriculture exhibits low expected returns, due to the low returns this sector generates and problems related to land ownership. These low returns are due to a lack of human-capital in the sector, land misallocation, minimal exploitation of the economies of scale, poor infrastructure (transport and irrigation), and lack of access to external markets; land ownership problems are more attributable to violence and security problems. The following are the detailed analyses of each of these bottlenecks.

2.5.1.1.1 Human Capital

Colombia exhibits low levels to human-capital due to three factors (COMPITE, 2008). First, the low education levels of the rural communities (older than 15 years). This population only attend school for five years on average (the elementary school term), and this rate has only increased 3 years during 1970-2014 (see Figure 23). Second, a low enrollment in careers related to agriculture (2%), because wages in this field are typically low[14] (see Figure 24). Third, a decline in the ratio of investment in R&D for agriculture to total public resources for agriculture from 28% in 2002 to 13% in 2014[15], due to the fact that government spending on direct subsidies given to farmers increased from 37% to 48% in this period (see Figure 25). Thus, these three factors have impeded Colombia's agriculture from the potential for abundant human capital that would boost its competitiveness (Reina et al., 2011).

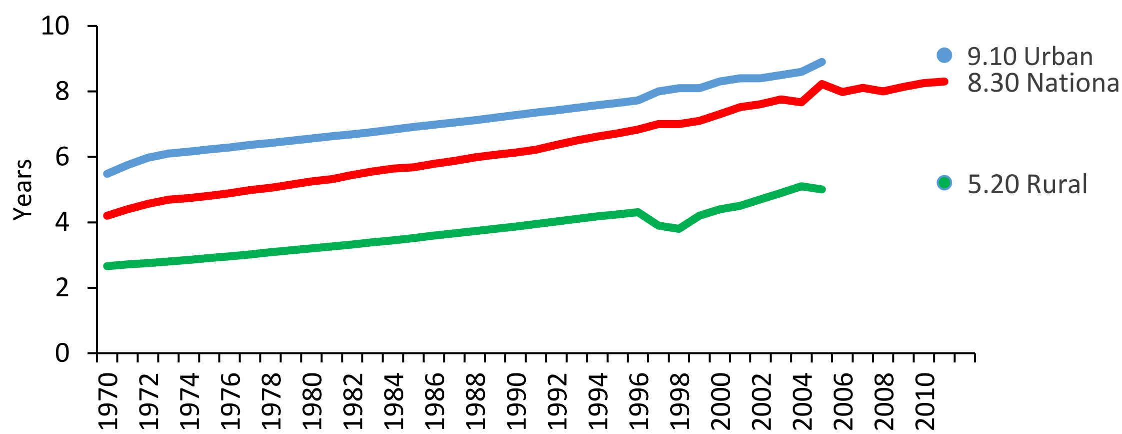


Figure 23. Average Years of School Attendance in Colombia (Source: DANE, 2015; DNP, 2015)

[14] About 65% of workers in rural areas receive less than minimum wage (COMPITE, 2008).

[15] This data doesn't include the investment that sectors such as coffee, palm, banana, etc. give to support their own research centers.

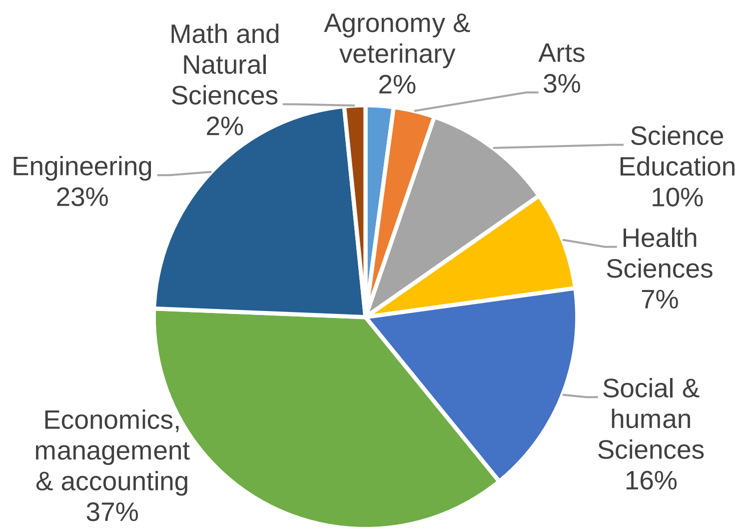


Figure 24. University Degrees Awarded by Field in 2013

(Source: Estimates based on SNIES, 2015)

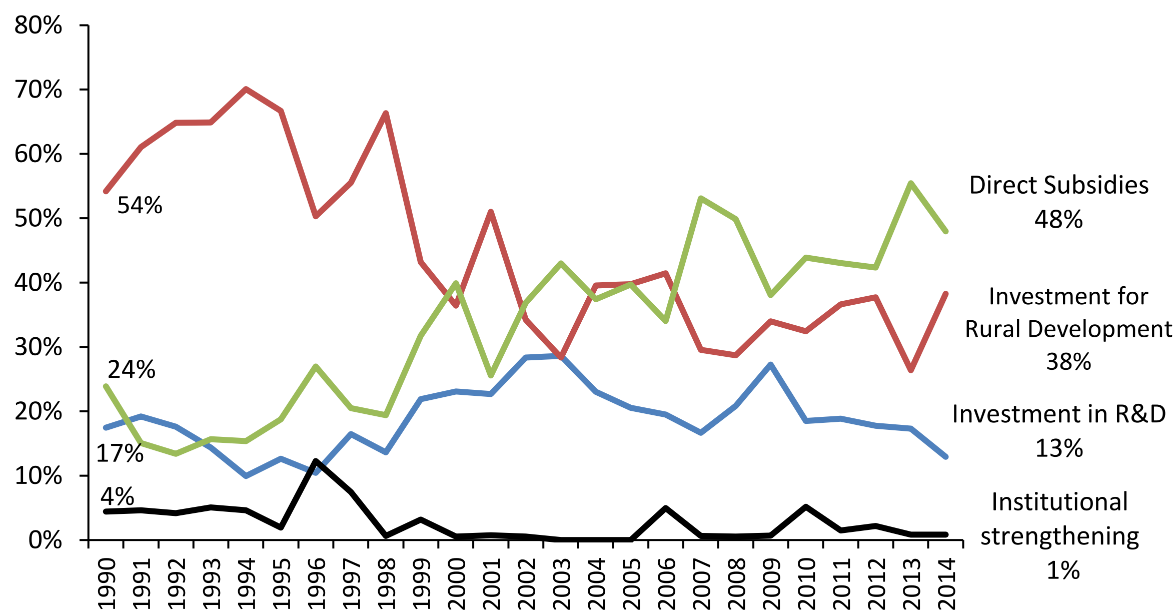


Figure 25. Public Resources for Colombia's Agriculture by Program Type (% of total) (Source: Estimates based on DNP, 2015)

2.5.1.1.2 Land Use

Colombia exhibits mainly two problems regarding its land use (COMPITE, 2008). Colombia exhibits land misallocation, since most of its agricultural land is used as pasture and forage to feed livestock. This activity used more than 30 million hectares in 2013, while IGAC-Corpoica estimates that this activity should only use about 10 million hectares (see Figure 26) (COMPITE, 2008; DNP, 2007). As a result, land used to cultivate agricultural products remains below its optimal usage as determined by IGAC-Corpoica (5.0 million hectares vs. 10.4 million hectares), as well as land for agro-forest activities (10 million hectares vs. 21.9 million hectares) and forests (9.9 million hectares vs. 21.9 million hectares). Also, 16% of Colombia's agricultural land is overexploited in central Colombia, and 13% is underused mainly in the northern and eastern regions, where the majority of pastures are located (see Figure 27).

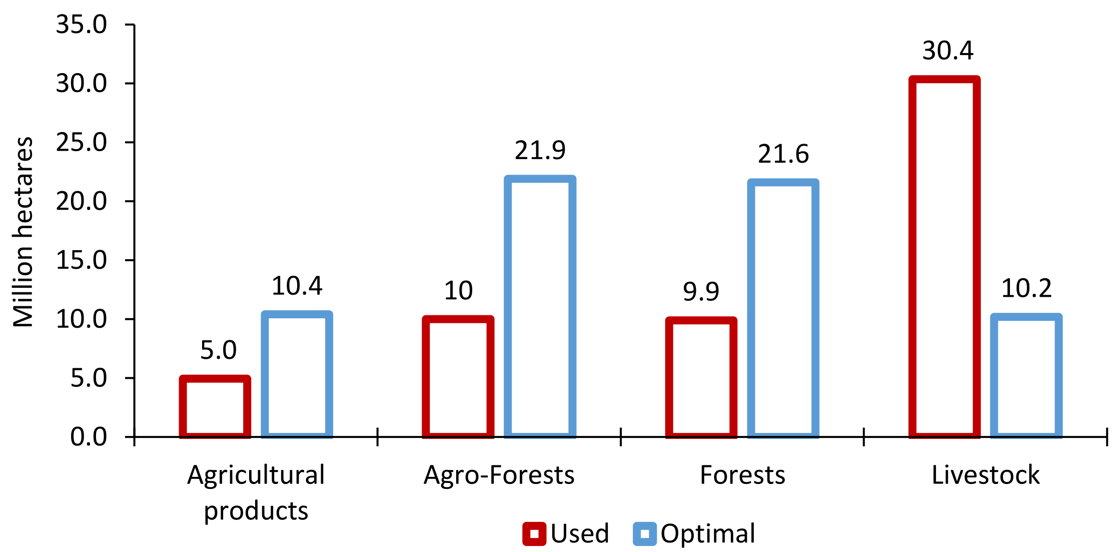


Figure 26. Land Used versus Optimal Land Use by Activity in Colombia (Source: DNP, 2007)

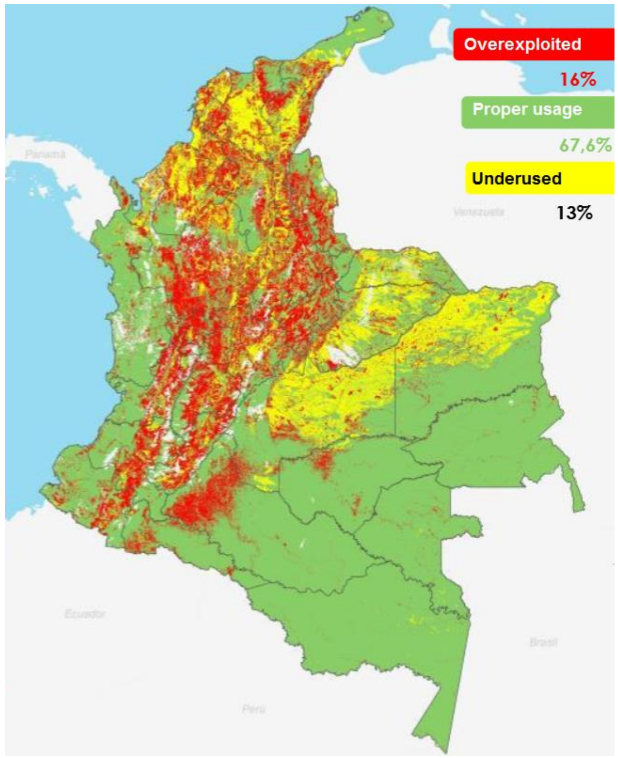


Figure 27. Exploitation Levels of Colombia's Land (Source: UPRA, 2014)

On the other hand, land management in Colombia is inflexible. Colombian law doesn't allow one person be the owner of a plot with a size greater than a Family Agricultural Unit (UAF)[16] (Act No. 160, 1994). Accordingly, Colombian agriculture is unable to exploit economies of scale, since the UAFs size has been small since the 1990's (see Table 11). For instance, in the Andean region (center side of Colombia), its size averages 26 hectares; in the Caribbean region (northern), 49 hectares; in the Pacific region (Western), 16 hectares; and in the Amazon region (Southern), 122 hectares. Likewise, in the Orinoco region, where Colombia has yet to expand its agricultural frontier by about

[16] A UAF is defined as the land needed by a farmer and their family to survive and earn a surplus, according to the agro-ecological conditions of the land and appropriate technology (Act No. 160, 1994).

3-5 million hectares, the UAFs size is about 565 hectares (Clavijo & Jimenez, 2011c). Although this size is the largest (in comparison to other regions according to its agro-ecological conditions of the land), it limits large-scale agricultural production in Colombia, and does not make Colombia's agriculture attractive for investment. This is significant, given the experience of *El Cerrado* in Brazil shows that Colombia would need large investment to develop its Orinoco region, and this investment will only arrive to Colombia when large-scale agriculture is allowed (Clavijo & Jimenez, 2011c).

Table 11. Maximum Size of Family Farms Units (UAF) by Region in Colombia (Source: Resolution No. 41, 1996)

Region	UAF (hectares)
Amazon	122
Andean	26
Caribbean	49
Orinoco	565
Pacific	16

2.5.1.1.3 Agricultural Infrastructure

Colombia also exhibits poor agricultural infrastructure (COMPITE, 2008). Colombia is behind on the development of irrigation and drainage systems. In 2012, the land areas equipped with irrigation in Colombia represented 32% of its total arable land, while in Chile this land reached 62%, and in Peru 47% (see Figure 28). Also, public resources to increase this area has lost relevance recently in Colombia, decreasing from an average of 16%-18% in the 1990's and 2000's to 3% during the period 2010-2014 (DNP, 2015). This low irrigation of Colombia's agricultural land, only surpassing the irrigated land in Brazil

(7%) and Mexico (25%), has become one of the main barriers to Colombia's agriculture competitiveness.

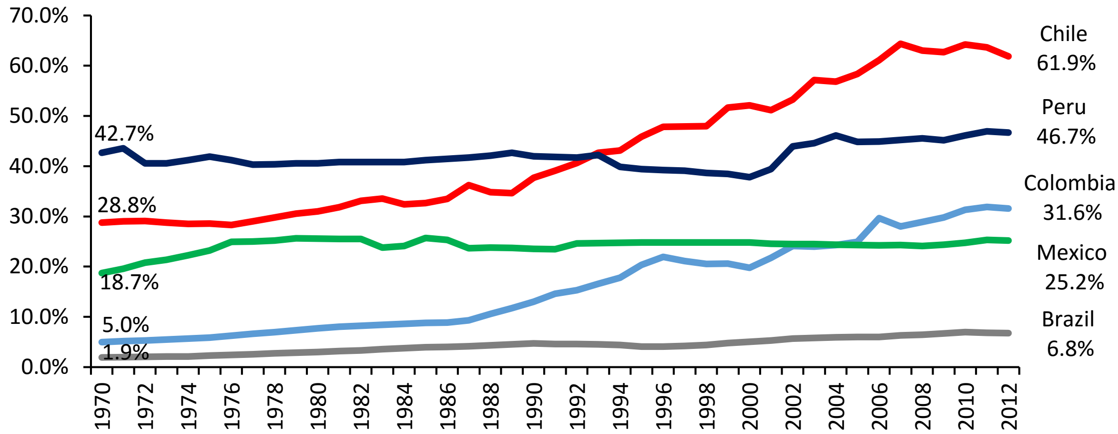


Figure 28. Ratio of Agricultural Land Equipped for Irrigation to Total Arable Land (%)
(Source: Estimates based on FAO, 2015)

COMPITE (2008) argues that Colombia's agriculture is also affected by its outdated and precarious transport infrastructure. Colombia does not have an adequate multimodal transport infrastructure to properly connect production centers to domestic and external consumption centers. Consequently, agricultural products are mainly transported by roads, which is more costly. Moreover, Colombia's road network is one of the most precarious worldwide (Clavijo, Vera, Malagon, et al., 2014)[17]. This delay in transport infrastructure development has become excessively costly for farmers, and directly affected their competitiveness.

[17] WEF (2014) assessed the quality of Colombia's roads, by giving a 2.9 grade in 2014, in a scale for which 1 means extremely underdeveloped and 7 extensive and efficient.

2.5.1.1.4 Access to External Markets

Another factor that explains the low returns for Colombia's agriculture is its lack of access to external markets. Although the value of Colombia's agricultural exports increased from US$4.3 billion (constant 2014 prices) in 1990 to US$6.5 billion in 2012, its share of Colombia's total exports decreased from 21.7% in 1990 to 9.4% in 2012, and its share in Colombia's agriculture GDP remained almost stagnant, around 25%-30% over this period (see Figure 29). This is because the main agricultural exportable products were the same in 2012 as the early 1990's (coffee, flowers, bananas, and sugar), although the ratio to total agricultural exports became more balanced (see Table 9). Also, the main destinations for agricultural exports was still the US (receiving 35%-40%), since Colombia reduced its exports to Venezuela in 2010 (a natural market)[18] due to political issues (Jimenez, 2010). In addition, Colombia exhibited certain limitations to export agricultural products, due to its limited sanitary management and low competitiveness (Tovar et al., 2007).

[18] Venezuela used to buy 21% of the Colombia's agricultural exports in 2008, and this country bought just 8.1% in 2012 due to political issues (DANE, 2015)

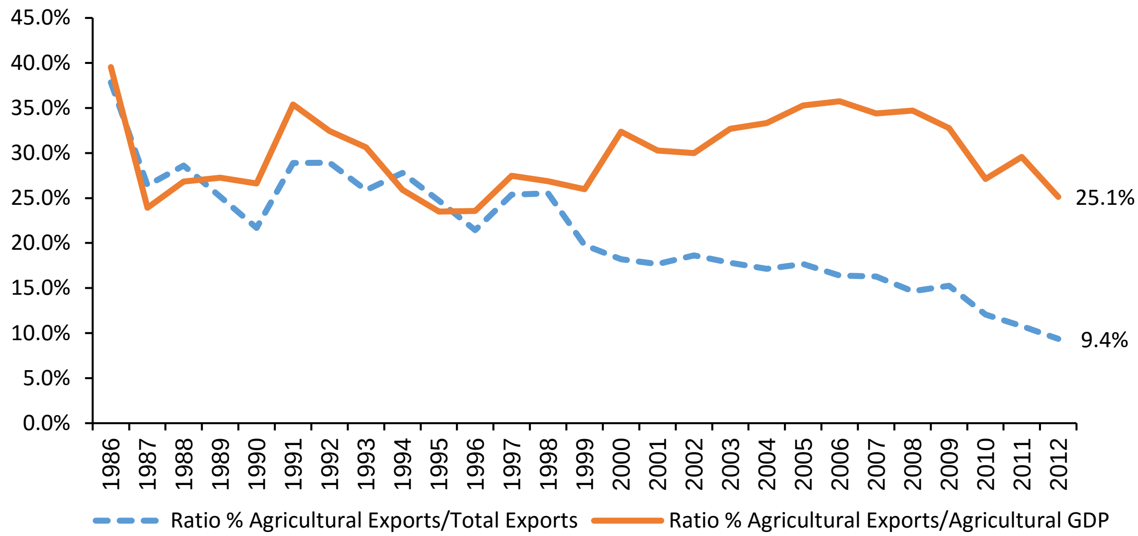


Figure 29. Ratio of Colombia's Agricultural Exports to its Total Exports and Agricultural GDP (%) (Source: Estimates based on FAO, 2015; World Bank, 2016)

2.5.1.2 Low Land Ownership

COMPITE (2008) indicates that Colombia's agriculture exhibits low land-ownership, due to higher levels of violence and serious security problems. Domestic and external investment in Colombian agriculture was discouraged during the late 1990's and early 2000's, due to: i) a high violent crime rate, at around 60-70 per 100,000 habitants in the late 90's which decreased to 35-40 in 2005-2007 (see Figure 30), but was still higher in comparison to the rates in Argentina (5.3) and Chile (1.9); ii) a sharp increase in kidnapping rates in Colombia, which increased from 1,200 people in 1994 to 3,700 people in 2000, and decreasing to just 520 by the 2000's; iii) a solid increase in the number of illegal checkpoints managed by armed groups, so called "*Pesca Milagrosas"*, which reached around 420 in 2002 and became common places to kidnap people; and iv) the high terrorist activity, which reached 1,650 events in 2002. As a result, Colombia's agriculture acquired low private investment during late 1990's and early 2000's.

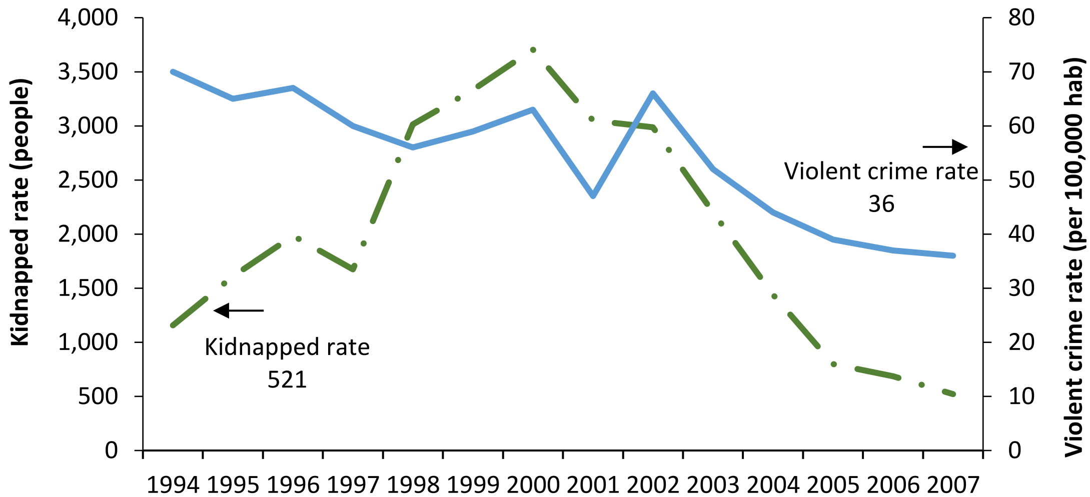


Figure 30. Violence and Security Indicators in Colombia
(Source: Own estimates based on DNP, 2015; COMPITE, 2008)

2.5.2 Funding Problems

Colombia's agriculture also exhibits funding problems (COMPITE, 2008). The country's private funding has been segmented and restricted, since agriculture exhibits high risks, such as climate change, pests, volatility of international prices, and the exchange rate (Cuevas et al., 2003). Also, private banks have avoided funding Colombia's agriculture on a large scale, since: i) they were forced to forgive and refinance many loans to farmers during the 1990's; ii) collateral for loans is harder to meet in rural areas, and iii) transaction costs tend to be higher in rural areas than in urban areas. Therefore, Colombia's agriculture has received on average 6%-8% of private banking resources during last decade (DNP, 2014). Also, these resources are preferably given to agricultural industry rather than to farmers, since they show more solid collateral and less risk (COMPITE, 2008). This was the case during 2012-2014, when Colombia's agriculture experienced a profitability crisis, and private funding focused its loan portfolio on agricultural industry (see Figure 31). Nowadays, Colombia's agriculture is not fully funded by private banks. Also, Colombia's government has been expending more public resources on agriculture in the form of direct subsidies for farmers. Colombia's government is aware that these subsidies are the only way for some farmers to receive funding.

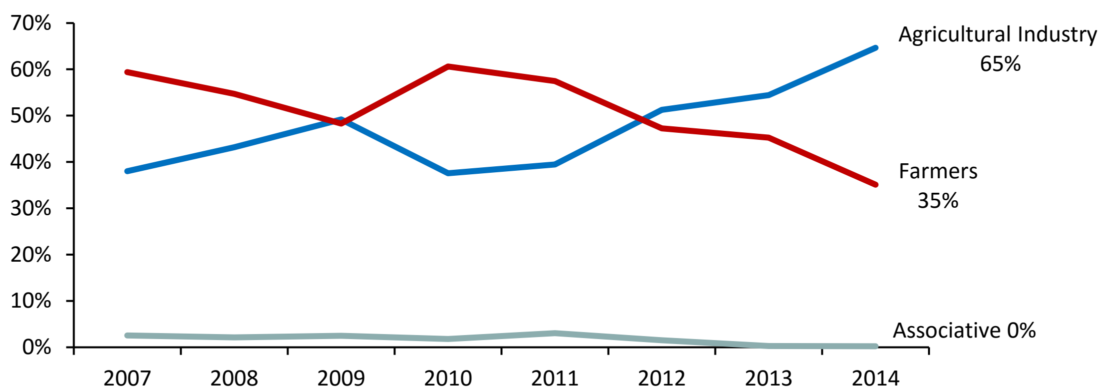


Figure 31. Portfolio Composition of FINAGRO by Type of Customer
(Source: Estimates based on FINAGRO, 2015a)

This problem has become serious during the last decade. Although Colombia' agriculture policy has in theory mainly privileged funding small farmers, these farmers received just 20% of the resources[19]. Medium and large farmers received most of these

[19] FINAGRO classifies farmers as small, medium and large according to the value of their assets. These values are compared to pre-established income ranges for each category. An important issue is that these ranges change yearly, since these are indexed to the minimum monthly wage (FINAGRO, 2016).

resources, despite the fact that they could receive funding by private banks given their solid collateral (see Figure 32). As if this was not enough, FINAGRO resources haven't been used to modernize Colombia's agriculture by investing in infrastructure and equipment. Although FINAGRO increased its loans by almost 4 times to COP$8.1 trillion (constant 2014 prices) during 2000-2014, these resources have been mainly used to fund livestock purchases (27.6%), and planting and crop renovation (26.7%) (see Figure 33 and Figure 34). Consequently, infrastructure (11.9%) and machinery and equipment (4.1%) remain among the least funded areas of Colombia's agriculture—explaining, in part, its poor performance during recent decades.

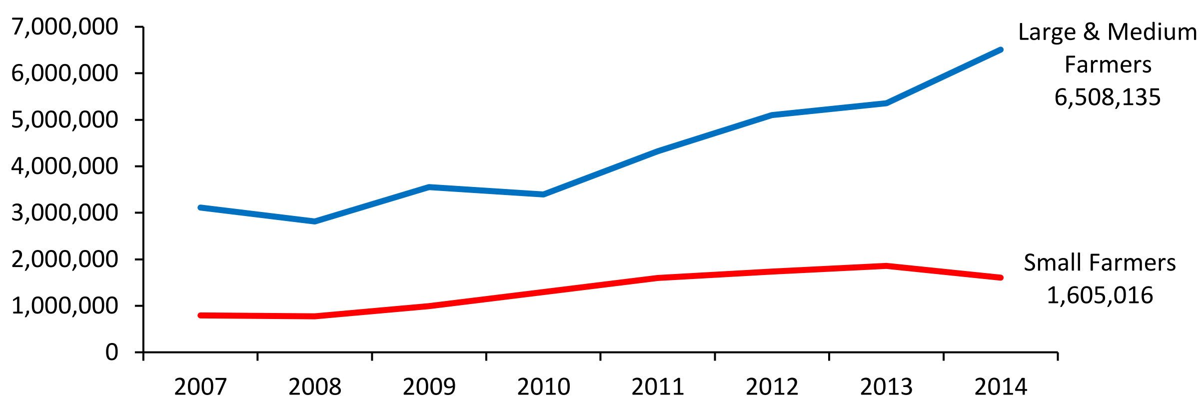


Figure 32. FINAGRO's Portfolio by Farmer Type
(Constant 2014 Prices, COP$ Millions) (Source: Estimates based on FINAGRO, 2015a)

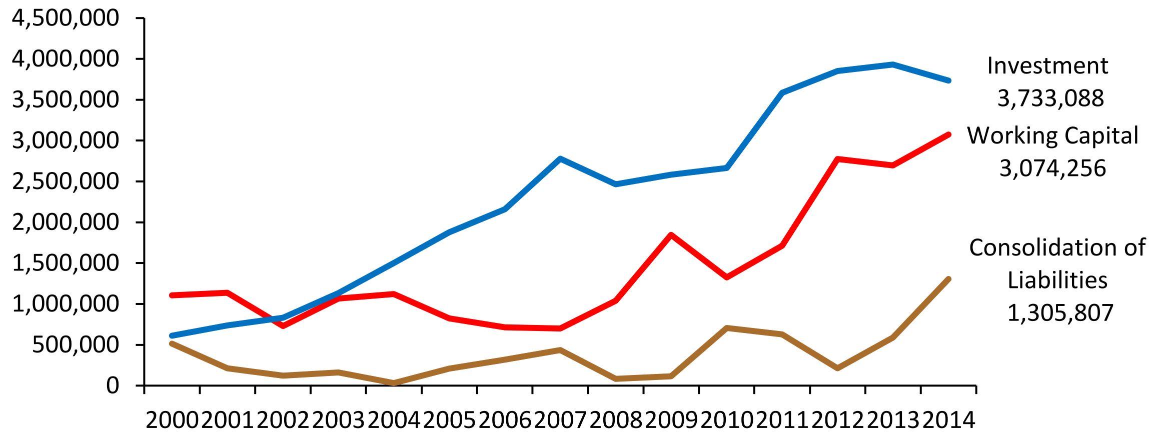


Figure 33. FINAGRO's Portfolio by Line of Credit
(Constant 2014 Prices, COP$ Millions)
(Source: Estimates based on FINAGRO, 2015a; SAC 2015)

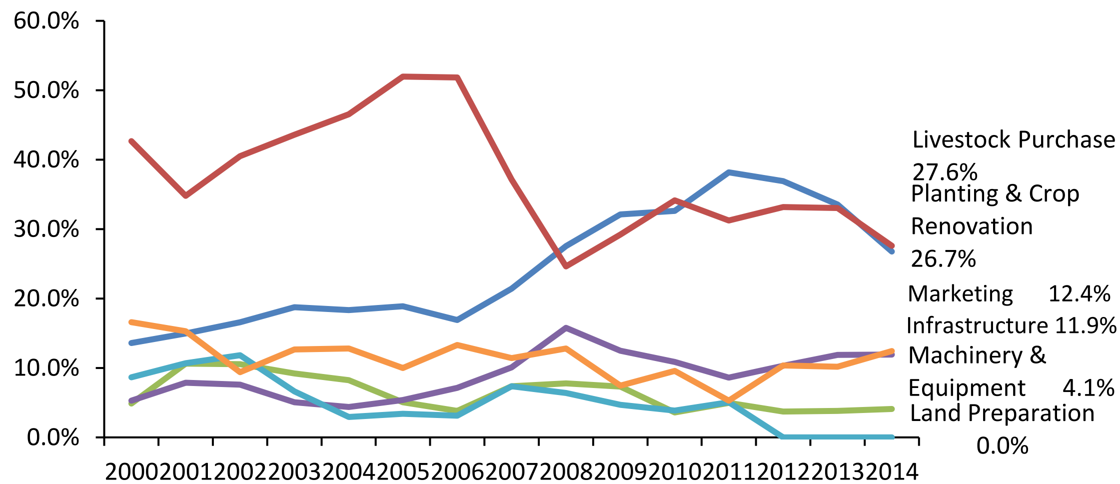


Figure 34. FINAGRO Investment Loans by Type (% of Total)
(Source: Estimates based on FINAGRO, 2015a; SAC, 2015)

Finally, COMPITE (2008) indicates that although Colombia's government, with the support of the *Bolsa Mercantil de Colombia* - (BMC)[20], has been designing instruments to mitigate market risk, their usage is minimal. Currently, Colombia doesn't have mature and

[20] The BMC is the entity for trading commodities in Colombia (BMC, 2015).

deep market to negotiate for commodities, and investors' confidence has been reduced by the BMC. The size of this market is very small, and it has been involved in many scandals in recent years (World Bank, 2013). As if this were not enough, some studies indicate that the BMC's potential is poor in the coming years, even in optimistic scenarios (Clavijo, Jimenez, & Rios, 2014)[21].

2.6 Conclusions

In brief, this chapter indicates that Colombia's agriculture encountered serious difficulties during the period 1970 to 2014. This is demonstrated by its very low performance in recent decades. Colombia's agricultural GDP only grew by 1.5% on average in the 1990's, and by 1.9% in the 2000's (World Bank, 2016), due to: i) the type of policies implemented in Colombia to boost its economic development, mainly focused on promoting of other sectors, such as finance, mining, and utilities (Junguito et al., 2014); ii) a misallocation of resources within the agricultural sector, despite the fact that Colombia's government increased its investment during the 2000's (Reina et al., 2011); iii) the accelerated and abrupt implementation of the second package of reforms associated with Colombia's Structural Adjustment (SA) program during the 1990's (Ocampo, 2000), and iv) a significant structural transformation of Colombia's economy toward the services sector by effects known as the Dutch Disease (Clavijo et al., 2013). As a result, agriculture did not continue as the driver for Colombia's economy in the last decades, since its share

[21] This study explains that even in a scenario on which traded amount in the BMC grows by 10%, this is still very low in comparison to the traded amount in similar entities in Latin America such as BOVESPA in Brazil or Rosario Future Exchange in Argentina.

in Colombia’s total GDP decreased steadily from an average of 24% in the 1970’s to 6%-8% in the 2000’s and agricultural GDP per capita in Colombia declined from US$330-350 (constant US$ of 2005) in the late 1980’s to US$260-280 in the 1990’s and in the 2000’s.

Second, agricultural policy in Colombia has been historically designed to face short term problems, instead of a long term strategy for sector development (SAC, 2014). Colombia has carried out a wide variety of policies to promote its agricultural sector during the period 1970-2014. However, their execution has required an active role of the government as the main agent for carrying out constant interventions in different markets (agricultural products, agricultural inputs, and agricultural credit), to guarantee a minimum income level to farmers (Guterman, 2007). Consequently, Colombia’s agriculture has been subject to many distortions, which have limited its competitiveness in recent decades (Anderson & Valdés, 2008).

Third, Colombia’s agriculture exhibits a serious lack of public resources. These resources have represented about 0.2%-0.4% of overall GDP in the last decades, while these have reached 1% in others emerging markets, and 4% in developed countries (Junguito et al., 2014). In addition, Colombia shows two types bottlenecks that have discouraged agricultural investment in recent years (COMPITE, 2008). On the one hand, projects developed in this sector usually have low expected returns, due to lack of human-capital in the sector, land misallocation, little exploitation of economies of scale, poor infrastructure (transport and irrigation), and lack of access to external markets. On the other hand, Colombia’s agriculture has funding problems, because credit to this sector is segmented and restricted (Cuevas et al., 2003).

This study determines six periods for subsequent analysis based on the findings of this chapter (see Table 12). Facts presented above highlight the importance of classifying in each period all years for which: i) Colombia's agriculture exhibited similar economic conditions; and ii) agricultural policy regimes did not sharply change. For instance, the accelerated implementation of the second package of reforms of Colombia's Structural Adjustment (SA) by Gaviria administration in the early 1990's had a direct impact on Colombia's agriculture performance. These reforms changed market conditions for Colombian farmers over a short period of time, which caused jointly with other factors a profitability crisis in this sector. Moreover, Colombia's macroeconomic crises presented during the early 1980's and in the late 1990's are other events that cannot be ignored. Agricultural development did not receive much attention in both crises, and, in fact, Colombia's government cut the agricultural budget to restore Colombia's economic stability. Furthermore, the worsening armed conflict from the late 1990's, the security policy executed by Uribe-I administration in early 2000's, as well as the behavior of Colombia's agriculture during the agricultural commodity price boom 2006-2011 are other factors that cannot be overlooked. Its omission for analyzing Colombia's agriculture might lead to misguided conclusions. Hence, the idea with these periods in this study is to consider that Colombia's agriculture exhibited structural changes during recent decades, and therefore agricultural productivity and/or overall performance might have been determined by different particular circumstances in each period.

Table 12: Main Facts about Colombia's Agriculture during 1975-2013

PERIOD	MAIN FACTS
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)

Table 12: Main Facts about Colombia’s Agriculture during 1975-2013 (continued)

PERIOD	MAIN FACTS
1990-1997	• Colombia's government accelerated the execution of the second package 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).

Table 12: Main Facts about Colombia's Agriculture during 1975-2013 (continued)

PERIOD	MAIN FACTS
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) (DNP, 2002, 2006) • 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).

All these factors have surely had an impact on agricultural productivity growth in Colombia's from 1970-2014. In order to estimate their significance, this study estimates agricultural productivity growth of Colombia's agriculture, and includes analysis on which are the most important factors that explain it. The idea is to identify those elements that Colombia's government should consider in their agricultural policy to boost productivity growth in this sector. Thereby, this study contributes to a better design of agricultural policy in Colombia, by identifying those elements which Colombia's policy makers should work on to: i) reach higher growth and development of its agriculture; and ii) take advantage of all available opportunities for Colombia's agriculture in the following decades.

CHAPTER 3. RELEVANT LITERATURE

3.1 Introduction

Agricultural productivity has been widely analyzed worldwide, following the pioneering work of Solow (1957) and Griliches (1963a, 1963b, 1964). Agricultural productivity improvement has been well recognized as an essential source of growth, since it encompasses output gains attributable to technological change (Pfeiffer, 2003). Development economists have also stated that agricultural productivity is particularly critical in developing countries, by boosting their economic growth and improving their social conditions[22] (Johnson & Mellor, 1961). In addition, studies have also shown that agricultural productivity is a factor that explains part of the dynamics of worldwide trade, by contributing to the development of comparative advantages among countries (Ball, Butault, San Juan, & Mora, 2010). Accordingly, agricultural productivity has been the focus of a significant number of studies during the last decades.

During the 1970's and 1980's, economics literature concentrated on the differences in agricultural productivity among countries and regions, the induced innovation process and its effect for bolstering agricultural growth, and the factors that better explain

[22] Agricultural productivity usually improves social conditions, by promoting: i) a substantial increase in the demand for agricultural products, since technical change pushes down its prices; ii) an expansion of agricultural export products; and iii) a reallocation of labor to other sectors (Johnson & Mellor, 1961).

agricultural productivity (Hayami & Ruttan, 1970, 1971; Kawagoe & Hayami, 1983, 1985). These studies often based their analyses on partial productivity indices such as labor productivity and land productivity, which resulted in a partial understanding of agricultural productivity. Interest in measuring agricultural productivity by estimating Total Factor Productivity (TFP) increased during the 1980's, since this variable captures the productivity of all inputs simultaneously (Ball, 1985). Also, agricultural productivity was considered a major factor behind US agricultural growth during the postwar period, and was used to measure the economic reforms in China toward capitalism (Capalbo, 1988; McMillan, Whalley, & Zhu, 1989).

During the 1990's and 2000's, studies focused on how to relax certain assumptions behind methods used to estimate agricultural productivity, such as the existence of competitive markets and constant returns to scale (Capalbo, 1988). Also, several studies were conducted worldwide, mainly with a country-level focus and were used as a barometer: i) to monitor agriculture performance; ii) to evaluate policy actions, and iii) to analyze certain economic events, such as the dynamics of trade patterns. Also, other studies analyzed the main determinants of agricultural productivity with the objective of obtaining better information for designing agricultural policies.

In order to illustrate the importance of agricultural productivity worldwide and its value in designing and evaluating agriculture policy, the following sections report : i) the most common applications of agricultural productivity in the economics literature; ii) the main determinants of agricultural productivity worldwide, and iii) a brief summary of such research on Colombia.

3.2 Most Common Applications of Agricultural Productivity Measurement

Worldwide, agricultural productivity analysis is used to measure the impact of technical change on agricultural growth. In this sense, several studies have been developed to determine if agricultural productivity is a major factor behind agricultural growth. For instance, Ball, Bureau, Nehring, and Somwaru, (1997) and Ball (1985) measure agricultural growth in the US during the postwar period (1948-1994), reaffirming that agricultural productivity contributed significantly to agricultural growth during this period. Fan and Zhang (2002), Fan (1991), Jin, Huang, Hu and Rozelle (2002) and Lin, 1987) present a similar analysis for China's agricultural sector after its transition to Capitalism (1976-1986). These studies conclude that institutional change and the adoption of new technology boosted agricultural productivity and led to more rapid agricultural growth (+4%). Also, Evenson, Pray and Rosegrant (1999) and Fuglie (2010) analyze the role of agricultural productivity in the agricultural performance of India (1956-1988) and Indonesia (1961-2006). These studies conclude that its effects were highly dependent on the Green Revolution in Indonesia, and on research and investment in extension programs and irrigation in India. Hence, there exists strong consensus on the importance of agricultural productivity.

Due to this fact, agricultural productivity has also been the subject of analysis in countries where agricultural growth has stagnated. Fuglie and Rada (2013) examine the sub-Saharan countries (1961-2008) and conclude that low agricultural productivity was due to the countries' low investment in land development, numerous armed conflicts, and the spread of HIV/AIDS in rural areas. Also, Wang, Schimmelpfennig and Fuglie (2012) conducted a similar analysis for Western European countries using data from 1973-2002. They found that the agricultural sector exhibited low growth during this period due to withdrawals of resources in rural areas, mainly drops in labor, and not as a consequence of low agricultural productivity growth. These findings reaffirm that while agricultural growth is highly dependent on agricultural productivity, other factors contribute to its performance.

Evenson and Fuglie (2009) explain that agricultural productivity often has a positive impact on the agricultural growth of countries that invest in R&D and are actively developing and adopting capital improvements. These issues allow for improved technology use and ensures the dissemination and transmission of such technical knowledge. Otherwise, improvements in extension services and education are insufficient to boost agricultural productivity and agricultural growth. Australia's livestock sector is an apt example, since its growth has slowed since the early 1990's due to less investment in R&D, among other factors (Zhao, Sheng, & Gray, 2012).

Additionally, agricultural productivity measures have been used to analyze the impact of the disintegration of the USSR. Many studies have estimated the effect of this structural change for the agricultural sectors of the former USSR provinces, as well as Central and Eastern European countries (Cungu & Swinnen, 2003; Swinnen, Van Herck, & Vranken, 2013). These studies found that agricultural productivity exhibited a U-shape in all countries after this adjustment, although the duration of the decline was longer in the ex-USSR countries, due to the pace of reform implementation (too fast or to slow). Hence, the disintegration of the USSR sharply impacted agricultural productivity in these ex-

Soviet countries, as well as in Central and Eastern European countries. Accordingly, this transition that ex-Soviet countries exhibited from Communism to Capitalism is another reason why Europe exhibited stagnant agricultural productivity growth during these previous decades.

Despite this, European countries maintained a comparative advantage in the trade of agricultural products with the US. Ball, Butault, San Juan, and Mora (2010) examine this pattern by analyzing the competitiveness of 11 European countries with the US for the period 1973-2002. Their study includes the variation of the exchange rate, relative prices, and relative growth of agricultural productivity as control variables. This study finds that agricultural productivity was the most important factor in determining competitiveness patterns, although the exchange rate's influence on relative input prices was also acknowledged. Thus, agricultural productivity is a critical consideration in developing comparative advantage and determining worldwide trade flows.

Agricultural productivity has also been used to evaluate the impact of trade in agriculture. Fernandez-Cornejo and Shumway (1997) estimate agricultural productivity in Mexico over the period 1940-1990, and analyze the data for evidence on the transmission of technology from the US to Mexico via foreign trade. They conclude that the evidence exists, although agricultural productivity has also been explained by higher investment in research in Mexico. This study demonstrates the usefulness of using agricultural productivity to measure and evaluate the impact of trade and research on agricultural performance.

This literature review highlights the importance for each country to have a robust indicator of agricultural productivity. This allows one to have a reliable indicator of agricultural performance, as well as a valuable index for designing and executing better agricultural policies. This has been the case for the US, Canada and Australia in recent decades (Ball et al., 1997; Ball, 1985; Cahill & Rich, 2012; Zhao et al., 2012). The experiences of these countries suggest the importance for achieving a robust measure of agricultural productivity of: i) development of a good information system and ii) improving measurement methods. This literature also encourages the analysis of countries which have put in practice an agricultural policy supported by an indicator of agricultural productivity, with the aim to identify best practices for developing their own agriculture.

Brazil's agriculture is one of those successful cases that has been widely analyzed (Garcia, Teles, Valdes, & Rumenos, 2012; Rada & Valdes, 2012). Its agricultural sector has exhibited a sharp modernization over the last few decades, as a result of reforms that began in the 1970's. Basically, its government created the "*Programa de Desarrollo del Medio Oeste* - *(Polocentro)*" to encourage the development of the *"El Cerrado"* region. Under this program, the Brazilian government provided: i) cheaper land to farmers; ii) loans and subsidies to farmers; iii) extensive resources for research; and iv) technical assistance to farmers and their crops through the Brazilian Agricultural Research Corporation (*Embrapa*). *Embrapa* carefully developed a long-term strategy for this region in five stages: i) elimination of excessive acidity from soils; ii) development of grass varieties with more productive potential; iii) development of genetic improvements for soybean seed; iv) implementing new planting methods for growing cereals; and v) strengthening integrated farming models, using soil for grain crops and cattle (Clavijo & Jimenez, 2011a). In addition, Brazil changed its development model from one that is based on import substitution to a model of economic openness. This literature concludes that Brazilian success relied on greater agricultural R&D investment for research, infrastructure improvements, and better loan access to farmers. Also, it shows the importance to design and execute agricultural policies with a long-term perspective.

In summary, agricultural productivity is a crucial indicator for agriculture development worldwide, since: i) this works as a permanent barometer of the agricultural sector's actual performance, and ii) it is key for designing and executing more efficient agricultural policies. Likewise, this research indicates that agricultural productivity often boosts agricultural performance, since: i) there exists a positive relation between these variables; and ii) it increases countries' global competitiveness, by developing their comparative advantage. Thus, it is very important to identify the main determinants of agricultural productivity.

3.3 Determinants of Agricultural Productivity

Over the last decades, the importance of increasing agricultural productivity has been widely recognized. Potentially accessible agricultural underutilized land is unevenly distributed worldwide, and concentrated at about 90% in Latin America and sub-Saharan Africa. Brazil, the Republic of the Congo, Angola, Sudan, Argentina, Colombia and Bolivia are mainly the countries in the world with the opportunity to expand their agricultural frontier over the next decades (FAO, 2013). Also, the United Nations predicts that by 2050, the world population will grow by 30% to 9,100 million (UN, 2015). The Food and Agriculture Organization (FAO) estimates that global food production must increase by 70% (5% per year) to meet those needs (FAO, 2009). Thus, increasing agricultural productivity is one solution to address this land constraint and this potential imbalance between the world's food supply and demand.

Several studies have analyzed agricultural productivity, and found that it usually depends on: i) investment in agricultural research and agricultural extension programs; ii) efficiency gains through the use of high quality factors, as well as more human capital[23]; iii) scale economies via trade openness[24] and higher competence in the domestic market[25]; and iv) miscellaneous factors, such as weather and commodity prices (Suphannachart & Warr, 2012). Most research analyzed agricultural productivity using different proxy variables for these factors.

Sun, Ball, & Fulginiti (2009) analyze the impact of public investment in R&D for US agriculture during 1980 to 2004, as well as the role of the extension service, transportation network, and human capital on agricultural productivity. They find that these factors positively impact agricultural productivity, by allowing farmers to reduce

[23] Some studies include resource allocation as a key factor for efficiency gains. The idea is that overall productivity growth of an economy could increase if production factors move from sectors exhibiting low marginal productivity rates to sectors with higher rates (Suphannachart & Warr, 2012). However, literature has shown that this growth is due to factor mobilization rather productivity growth (Jorgenson, 1988).

[24] Trade openness allows any economy to develop economies of scale by expanding their market size through export increments (Suphannachart & Warr, 2012).

[25] Higher competitiveness usually encourages countries to develop technological improvements (Suphannachart & Warr, 2012).

production costs. Likewise, Fan (1991), Jin (et al., 2002) and J. Y. Lin (1992) conclude that China increased its agricultural productivity during the transition to Capitalism with higher investment in agricultural research and extension services, institutional change, and the adoption of new technology, in particular modern machinery and more efficient fertilizers.

Ekbom (1998) analyzed the determinants of agricultural productivity in Kenya during 1995-1997. This study concluded that agricultural productivity exhibits a positive relation with investments in soil, quality of soil conservation, human capital and credit availability, as well as a negative relation with farm size and distance to water and infrastructure (roads). Likewise, Desai & Namboodiri (1998) do similar research for India from 1966 to 1990. They add that agricultural productivity also depends on factors such as barter terms of trade, government expenditure on agricultural research and education, land distribution, and annual average rainfall. This study finds that public investment in R&D and education, land distribution, and marketing and banking infrastructure density boost agricultural productivity in India, while higher barter terms of trade (higher prices) has a negative impact. Hence, this study reaffirms the role of investment in extension services, irrigation systems, and crop technology as factors behind the increase in India's agricultural productivity (Evenson et al., 1999).

These results are aligned with Kumar, Mittal, and Hossain (2008), who present a literature review on agricultural productivity in South Asia. They find that India's agricultural productivity is not explained by the same factors as in other countries in the region. This study finds that agricultural productivity accelerated in Bangladesh during 1980-2000, due to an increase in irrigation. In Pakistan, it increased by 1.5% per year during 1974-1994, due to a change in livestock diet, the use of high-yield seed varieties and an increase in human capital. In Nepal, it augmented by 0.5% yearly from 1980-2000, but it was explained by an unknown factor. Sri Lanka's agricultural productivity growth stagnated during the 80's, due to low investment in R&D and a civil war.

Avila, Romano, and Garagorry (2010) show that agriculture productivity in Latin America and the Caribbean (LAC) has been explained mainly by other factors. Their study analyzes agricultural productivity in 20 countries of this region, and finds that agricultural productivity strongly and positively depends upon the adoption of modern crop varieties, growth in literacy, and improved dietary energy[26].

Fuglie and Rada (2011) explain that these differences observed in the agricultural productivity of South Asia and LAC could be result of the size of the respective countries. In an analysis of agricultural productivity in 32 Sub-Saharan countries in Africa from 1977-2005, they find that agricultural productivity strongly depends on national investment in agricultural research; however, it seems to be constrained by the size of each economy. Larger countries realized higher payoffs from investing in agricultural research than did smaller countries, by developing scale economies in research, since larger countries are able to afford larger research systems. In addition, Fuglie and Rada (2013) conclude that investment in agricultural R&D, certain economic reforms, higher farm education, and widespread irrigation have also been key factors in the agricultural productivity of these countries.

[26] This study uses the Dietary Energy Sufficiency (DES) index (published by the FAO) to test if there is a relation between the consumption of calories per capita and agricultural productivity in LAC.

Clearly, there exists some consensus on the factors that contribute to agricultural productivity. As explained above, factors such as public investment in R&D, human capital, irrigation, the usage of high-yielding crop varieties, credit availability, agricultural extension services, etc., are some of these factors. However, there exists a widespread issue in many of these studies. Some of them consider determinants that are more related to factor (capital) accumulation than to technical change, such as labor availability, land use, irrigation, credit availability, total length of road network and farm size, as well as input reallocation across sectors (Atkinson, 1970; Ekbom, 1998; Rada & Valdes, 2012; Sun et al., 2009; Suphannachart & Warr, 2012; Thirtle, Piesse, & Schimmelpfennig, 2008). Therefore, agricultural productivity has been sometimes analyzed considering determinants that are not directly related to technical change. Consequently, these studies have likely drawn misguided conclusions about determinants that could have explained agricultural productivity but instead explain investment, and haven't determined the factors that really explain it.

Recently, studies have focused on analyzing the dynamic relations between these factors and agricultural productivity over the time. Identifying which of those factors have short-term effects and which have long-term effects is relevant and currently in question. For instance, Suphannachart and Warr (2010) analyze the determinants of agricultural productivity in Thailand in the short and long term over the period 1970-2006. They present a model in which agricultural productivity is a function of real agricultural expenditure on research and extension services, infrastructure (roads and irrigated areas), trade openness, weather, etc. This study finds that almost all variables have an impact on crop productivity in the short-term and the long-term, while only agricultural research has an impact on livestock productivity. Likewise, Ali, Mushtaq, Ashfaq, Abedullah and Dawson (2012) completed a similar study for Pakistan. This study finds that agricultural productivity is explained by macroeconomic stability and the openness of agriculture in the short term, while improvements in human capital and infrastructure development are most important in the long-term. However, they emphasize that the short term effects of these variables are less significant than the long term effects.

Aside from these studies, another research interest is identifying better instruments that work as proxy variables to explain changes in agricultural productivity. For instance, Wang, Heisy, Huffman and Fuglie (2013) analyze the impact of agricultural R&D expenditure on agricultural productivity by distinguishing between public and private investment. This study recognizes that private sector expenditure on agricultural R&D has been growing more rapidly than public sector expenditure in the US over the last several years (Fuglie et al., 2011). Accordingly, they include them in an empirical model to analyze agricultural productivity. This study finds evidence of a complementary relationship between public and private agricultural research. However, the study is unable to estimate the separate impact of these two types of expenditure to agricultural productivity, due to their high collinearity.

Indicated here is a general agreement on the factors that explain agricultural productivity. Also, highlighted is the importance of using proper model specification to capture the dynamic effects of each factor. In addition, this current research mainly aims to: i) determine more accurate variables to explain changes in agricultural productivity;

and ii) analyze the dynamic relationship among these factors and agricultural productivity. The importance of country level studies is apparent, given that agricultural productivity factors vary by country. Likewise, it suggests that there is a widespread problem in this research related to the fact that some studies consider determinants of agricultural productivity that are more related to factor (capital) accumulation than to technical change. Thus, these research findings are potentially inaccurate.

3.4 Agricultural Productivity in Colombia

Colombia's agricultural productivity has been considered in very few studies. Over the last two decades, Colombia has usually been analyzed in the context of multi-national studies (Bravo-Ortega & Lederman, 2004; Coelli & Rao, 2005; Fuglie, 2015; Fulginiti & Perrin, 1998; Trueblood & Coggins, 2003), and a couple of times at the national level (Atkinson, 1970; Avila et al., 2010; Ludena, 2010; Pfeiffer, 2003). Thus, little is known about the dynamics of agricultural productivity in Colombia, and its main determinants.

Atkinson (1970) is the pioneering work on agricultural productivity in Colombia. This study analyzed trends from 1950 to 1967, in order to evaluate the impact of governmental policy implementation to promote industry and lessen its dependence on agriculture. Atkinson (1970) found that agricultural productivity growth is uneven across crops in Colombia and largely dependent on farms' ability to mechanize their production practices. Also, large farms usually exhibit higher agricultural productivity than small farms, since large farms can afford to pay for better seeds, pesticides, and fertilizers. Thus, Atkinson

(1970) explains agricultural productivity dynamics in terms of factors that are more related to a factor accumulation.

Pfeiffer (2003) also analyzed agricultural productivity in Colombia. She does this jointly for other Andean countries (Venezuela, Ecuador and Bolivia) from 1972 to 2000. Her aim is to evaluate if developing countries exhibited negative growth in agricultural productivity during that period, as found previously (Kawagoe & Hayami, 1983; Lau & Yotopoulos, 1989; Suhariyanto, Lusigi, & Thirtle, 2001). This study finds that Andean countries showed positive growth in agricultural productivity, at a pace comparable to the one exhibited by agricultural productivity in the US and G7 countries. Also, the main causes of this growth are identified as agricultural research, and the introduction of new technology and new products to the region.

Avila et al. (2010) examine in detail agricultural productivity in Colombia from 1961-2001. They identify four stages over this period: i) a take-off period in the 1960's, due to the creation of the national agricultural research institute[27]; ii) an acceleration period during the 1970's, due to the diffusion and adaptation of agricultural research, and greater governmental funding of agricultural research and extension programs; iii) a stagnant period during the 1980's, due to Colombia's Debt crisis; and iv) a decreasing period in the 1990's, as a result of less government support of agriculture, and institutional changes in agricultural research, due to the execution of the second package of reforms of Colombia's Structural Adjustment program.

[27] This study explains that this allowed the development of improved varieties of crops and modern production practices

Finally, Ludena (2010) supports Pfeiffer (2003), since he indicates that agricultural productivity grew in Latin America and Caribbean countries by an average of about 1.7% per year from 1961-2007. This study indicates the importance of cost saving technologies in the region, such as: i) genetically modified crops; ii) zero tillage; iii) global positioning systems (GPS); and iv) better fertilization and harvesting practices. In addition, the study estimates that agricultural productivity in countries with land availability, such as Colombia, grew an average of 2.1% annually during this period.

This literature suggests that Colombia's agricultural productivity has grown positively over the last decades, although there is not any consensus related to the magnitude. Factors that account for this growth include: i) agricultural research; ii) development and adaptation of new technology; and iii) the usage of better seeds, pesticides and fertilizers. Likewise, others mention the mechanization of production practices and land availability, factors more related to factor accumulation than to technological change.

3.5 Conclusions

In summary, this chapter shows agricultural productivity is a key indicator of agriculture sector performance in any country, since it works to: i) monitor agriculture performance; ii) evaluate policy actions, and iii) analyze certain economic events, such as the dynamics of trade patterns. Thus, it is an essential indicator that should be taken into account when designing and executing more efficient agricultural policies. Also, agricultural productivity plays a key role for boosting agricultural performance, since: i) there exists a positive relation between these variables; and ii) it allows countries to increase their global competitiveness by developing comparative advantages relative to trade partners. Therefore, it is very important to identify what are the main determinants of agricultural productivity.

This chapter indicates there exists a general consensus on the main factors that explain agricultural productivity. These factors are primarily public investment in R&D, human capital, the adoption of high-yielding seed varieties and trade openness. Also, there exists a widespread problem in the literature: many studies consider certain factors more related to a factor accumulation (mainly of capital) than to a technical change. This emphasis might be feasible if these studies assumed that technical change is capital embodied or at least were interested in testing this hypothesis. However, this assumption is never tested by these studies. Thus, this problem may lead to misguided conclusions about determinants that could have explained agricultural productivity. In addition, current research mainly aims to: i) determine more accurate variables to identify variables that explain changes in agricultural productivity; and ii) analyze the dynamic relationship among these factors and agricultural productivity.

With regards to Colombia, its agricultural productivity growth has been the focus of very little research, and is usually analyzed in the context of multi-national studies (Bravo-Ortega & Lederman, 2004; Coelli & Rao, 2005; Fuglie, 2015; Fulginiti & Perrin, 1998; Trueblood & Coggins, 2003). Colombia has been evaluated just a few times at the country-level (Atkinson, 1970; Avila et al., 2010; Ludena, 2010; Pfeiffer, 2003). Little is known about the dynamics of agricultural productivity in Colombia, and its main determinants.

It is only known that Colombia exhibited positive agricultural productivity growth over the last decades, due to: i) agricultural research; ii) development and adaptation of new technology; and iii) the usage of better seeds, pesticides and fertilizers. Hence, the purpose of this study is to contribute to such research on Colombia, by estimating agricultural productivity growth of Colombia and providing an analysis of its main determinants.

The next chapter reviews the most common methodologies used in the economics literature to estimate agricultural productivity, and the methods used by this study to measure Colombia's agricultural productivity.

CHAPTER 4. METHODOLOGIES FOR MEASURING AGRICULTURAL PRODUCTIVITY

4.1 Introduction

Accurate measurement of agricultural productivity largely depends on its definition. This study defines productivity as all changes in production attributable to technological change rather than by changes in inputs (Domar, 1961; Jorgenson & Griliches, 1967; Solow, 1957). Thereby, it denotes productivity as the efficiency level exhibited by an economy to transform inputs into outputs (Diewert & Nakamura, 2002; Syverson, 2011). This implies that productivity changes can result from three possible factors: i) improvements in production practices, given a set of resources, so-called *disembodied technical change*; ii) changes in input quality, so called *embodied technical change*, or iii) introduction of new production processes or inputs (Antle & Capalbo, 1988). Thus, the measurement of agricultural productivity largely consists of the usage of appropriate methodologies to quantify these effects, being aware of all estimation problems well recognized by economic literature [28](Antle & Capalbo, 1988).

[28] Antle & Capalbo (1988) explains that *disembodied technical change* depends strongly on the inputs level at which it is measured, and *embodied technical* change depends on how input quality is measured.

4.2 Theoretical Framework

Early studies used to measured agricultural productivity as the rate of output produced per unit of input. Productivity measures such as output per acre and per worker were very common in this research (Hayami & Ruttan, 1970, 1971; Kawagoe & Hayami, 1983, 1985). Interest in measuring agricultural productivity by estimating Total Factor Productivity (TFP) has grown in recent decades, since this allows: i) the measurement of productivity relative to all inputs (Ball, 1985); ii) to use a productivity concept that is invariant to intensity of input used (Syverson, 2011); and iii) to measure productivity when technological change is Hicks neutral[29]. Otherwise, this is a biased technological progress and input-specific productivity growth rates are necessary (Wu, 2012). Simultaneously researchers also worked toward making certain strong assumptions more flexible; for example: i) competitive markets; and ii) constant returns to scale (Capalbo, 1988). It was well known that agricultural productivity measurement should be based largely on a valid representation of the production function, since this will allow dividing agricultural production into these components: i) technology; ii) production efficiency, and iii) scale of production (Antle & Capalbo, 1988).

There exist three types of methodologies often used in economics literature for the measurement of agricultural productivity worldwide (see Table 13). The first is growth accounting techniques, based on the pioneering work of Tinbergen (1942), Solow (1957), Kendrick (1961) and Denilson (1962). Broadly speaking, these techniques assume that

[29] Hicks (1963) defined neutral and biased technological change by whether their effects increase, remain unchanged, or diminish the ratio of the marginal products among inputs.

agricultural productivity is the output growth unexplained by input growth. Then, the measurement of agricultural productivity basically involves a simple accounting exercise, on which a production function is assumed and agricultural output growth, input growth and cost shares of each input are estimated using actual data from farmer budget. Subsequently, input growth is subtracted from output growth considering the cost shares calculated, and the residual is denoted as agricultural productivity growth. This simple approach for the measurement of productivity makes such techniques very attractive. However, these techniques rely on very strong assumptions, such as: i) competitive markets for both outputs and inputs; ii) constant returns to scale; iii) technical change is Hicks neutral; iv) input-output separability[30]; and v) Cobb-Douglas production function[31] (Antle & Capalbo, 1988; Diewert, 1992). Thus, this limits the scope and relevance of accounting results. The most common accounting techniques used in literature are: i) Tornqvist- Theil Index (Ball, 1985; Evenson et al., 1999; Fan & Zhang, 2002; Garcia et al., 2012; Thirtle et al., 2008); ii) Fisher Index (Cahill & Rich, 2012; Zhao et al., 2012); and iii) USDA Methodology for Measuring International Agricultural Total Factor Productivity (TFP) Growth (Evenson & Fuglie, 2010; Fuglie & Rada, 2013; Fuglie, 2010; Rada, 2013). The main differences are in the procedure used to aggregate the data into two general

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

[31] The main difference in calculating agricultural productivity using a growth accounting technique versus using an econometric techniques and assuming a Cobb-Douglas production function is that growth accounting techniques cost shares calculate cost shares using observed accounting data, while econometrics techniques estimate these parameters using statistical methods.

indexes, one for output growth and other for input growth, both employed to estimate agricultural productivity growth.

A second type of methodology used in economics literature for the measurement of agricultural productivity is frontier techniques. These techniques rely on the assumption that economic activities are not always located on their best practice frontier[32] (Farrell, 1957). Thus, the measurement of agricultural productivity involves the estimation and posterior sum of two components: i) technical change, which captures shifts in the production possibility frontier when firms are efficient; and ii) efficiency change, which considers all movements exhibited by a firm or economic activity within its production possibility frontier toward a better position closer to that frontier (Sena, 2003). This implies that agricultural productivity measurement largely depends on a robust measurement of this production possibility frontier. This ensures an unbiased estimation for its components: technical change and efficiency change. Also, this guarantees credibility for these estimates in comparison to other methods. Researchers have developed two types of methodologies to measure this production possibility frontier: i) parametric techniques based on stochastic analysis, and ii) non parametric techniques based on lineal programming techniques such as Data Envelopment Analysis (DEA) (Murillo-Zamorano, 2004; Sena, 2003). These methodologies allow measuring productivity, by analyzing where production efficiency of a firm or economic activity is

[32] 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 that time (Sena, 2003).

located related to this frontier. In addition, these determine endogenously the returns to scale (Severgnini, 2010).

The Malmquist Index is one of the most popular frontier techniques utilized in economics literature for the measurement of agricultural productivity. This technique measures agricultural productivity by comparing the position of agriculture in two adjacent periods with respect to a production frontier, using distance functions (Caves, Christensen, & Diewert, 1982). The Malmquist Index does not rely on any stochastic procedure to measure agricultural productivity and has the following advantages: i) to determine easily the main sources of productivity growth, and ii) to separate agricultural productivity in terms of technical change and scale components (Sena, 2003). In addition, it is very attractive when data is a constraint, since it only requires data from output and input quantities[33] (Sena, 2003). Despite this, it is well known that this methodology exhibits two serious problems: i) it requires a very accurate estimation of the frontier production function, which is not always possible to ensure due to limited available information and poor quality data; and ii) its results are very sensitive to the chosen adjacent periods, data quality and outliers, which means that this methodology cannot provide robust results for a sector such as agriculture, which often exhibits strong volatility (Thirtle et al., 2008). Nevertheless, many studies have used this methodology, because it does not require data for output and input prices. Also, this methodology is

[33] This is because the methodology is based the measurement of agricultural productivity for distance functions, and these require data for input and output quantities only (Sena, 2003).

popular among the few studies devoted to measuring and analyzing agricultural productivity growth in Colombia (Ludena, 2010; Pfeiffer, 2003).

Finally, the last type of methodology used by economics literature is econometric techniques (E. Berndt & Christensen, 1973). Broadly, these techniques base the measurement of agricultural productivity on the usage of econometric methods to estimate a production function or its dual (Antle & Capalbo, 1988). For this purpose, these techniques rely on economic theory, which establishes that productivity can be measured directly from a given functional form of the production function (so-called primal techniques) or indirectly from the cost function (so-called dual techniques). The main advantages are that econometric techniques allow relaxing certain assumptions required by accounting techniques. For instance, Antle & Capalbo (1988) explain that production can be estimated without assuming Hicks neutral technical change or returns to scale. Also, these techniques allow one to estimate confidence intervals around the estimates. In addition, it is not necessary to assume a particular form for the production function, although that is necessary to estimate biased technical change. However, these techniques assume a production function with input-output separability, as do growth accounting techniques. Also, these techniques require aggregating the input data into a few general indexes, in order to have sufficient degrees of freedom to run the estimation and to avoid multicollinearity problems. In addition, these techniques assume competitive markets and efficient firms or economic activities, as assumed by growth accounting techniques[34]. In brief, these techniques estimate productivity growth with fewer assumptions. Also, these have been successfully used by many studies devoted to analyzing agricultural productivity (Cungu & Swinnen, 2003; Fan, 1991; Sun et al., 2009).

Table 13 presents a summary of research conducted to measure agricultural productivity worldwide, based on: i) the theoretical framework followed by the USDA to design its Methodology for Measuring the International Agricultural Total Factor Productivity (TFP) Growth (USDA, 2016); and ii) the book "*Productivity Growth in Agriculture: an International Perspective*" (Fuglie, Wang, & Ball, 2012). This table also includes research carried out to measure agricultural productivity in Colombia.

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[34] Firm or economic activities are located on their production frontier (Sena, 2003).

Table 13: Studies on Agricultural Productivity Growth Worldwide

Author	Method*	Country-Region	Period
World			
Ball, 1985	GAcT-TT	USA	1948-1979
Fernandez-Cornejo & Shumway, 1997	GAcT-TT	Mexico	1940-1990
Evenson et al., 1999	GAcT-TT	India	1956-1987
Fan & Zhang, 2002	GAcT-TT	China	1952-1997
Suphannachart & Warr, 2012	GAcT-TT	Thailand	1970-2006
Thirtle et al., 2008	GAcT-TT	UK	1983-2005
Garcia et al., 2012	GAcT-TT	Brazil	1970-2006
Evenson & Fuglie, 2010	GAcT-USDA	87 Developing Counties	1970-2005
Fuglie, 2010	GAcT-USDA	Indonesia	1961-2006
Rada, 2013	GAcT-USDA	India	1980-2008
Fuglie & Rada, 2013	GAcT-USDA	Sub-Sahara Africa	1961-2005
Cahill & Rich, 2012	GAcT-F	Canada	1961-2006
Zhao et al., 2012	GAcT-F	Australia	1977-2009
Tong, Fulginiti, & Sesmero, 2012	F-M & F-SA	China	1993-2005
Rada & Valdes, 2012	F-SA	Brazil	1985-2006
Fan, 1991	E-Pr	China	1965, 1970, 1975, 1976-1986
J. Y. Lin, 1992	E-Pr	China	1970-1987
Cungu & Swinnen, 2003	E-Pr	Central and Eastern Europe Countries	1992-1999
Cungu & Swinnen, 2003	E-Pr	Former Soviet Union Countries	1992-1999
Sun et al., 2009	E-DC	USA	1980-2004
Colombia			
Pfeiffer, 2003	F-M	Andean Countries	1972-2000
Ludena, 2010	F-M	Latin America and the Caribbean	1961-2007
Avila et al., 2010	GAcT-TT	Latin America and the Caribbean	1960-2001

Methods: GAcT-TT: Growth Accounting Techniques - Tornqvist - Theil Index; GAcT-USDA: Growth Accounting Techniques - USDA; GAcT-F: Growth Accounting Techniques - Fisher Index; F-SA: Frontier Techniques - Stochastic Frontier Approaches; F-M: Frontier Techniques - Malmquist Index; E-Pr: Econometric Techniques - Primal; and E-DC: Econometric Techniques - Dual Cost.

4.3 Measurement of Agricultural Productivity

This study uses econometric techniques to measure agricultural productivity in Colombia. As explained above, econometric techniques make the fewest assumptions, and therefore imply more robust results. These techniques have also been successfully used by many studies devoted to analyzing agricultural productivity in the USA, China and Russia (see Table 13). In addition, almost all studies carried out for Colombia have used either growth accounting techniques, such as the Tornqvist - Theil Index, which generates results that require very strong assumptions and are very sensitive to the sample period and the data quality; or frontier techniques such as the Malmquist Index, which requires a very accurate estimation of the frontier production function and does not provide robust results for a sector such as agriculture (see Table 13).

To this end, this study estimates agricultural productivity in Colombia using both primal and dual econometric techniques. The idea is to use a variety of methodologies from the economics literature as strategy to look for more consistent results. For the primal techniques, this study experimented with the following functional forms of the production function: i) Cobb-Douglas; and ii) Constant Elasticity of Substitution – CES. This allows for analyzing the consistency of the estimates by assuming different possibilities for the production behavior of Colombia's agriculture. Also, this permits the consideration of different degrees of elasticity of substitution among inputs and incorporates technical change in different ways. In addition, the CES production function potentially captures biased technical change (Wu, 2012). For the dual techniques, this study assumes a trans-log cost function, a second-order approximation of an arbitrary twice-continuously differentiable function. The main advantage for doing this is to avoid the necessity of assuming a particular functional form for the production function. Also, dual techniques potentially allow measuring scale effects.

Agricultural productivity in Colombia is estimated as an aggregate and also disaggregated for crops and livestock, because their respective production processes are quite different. Also, overall agricultural productivity is estimated as a weighted average between crop and livestock productivity. This allows one to calculate a more reliable estimate for Colombia's agricultural productivity, since this represents more closely the different dynamics exhibited by crop productivity and livestock productivity. In addition, I include dummy variables in all models for the periods established in Chapter 2, in order to consider in this analysis that Colombia's productivity growth exhibited structural changes during the last several decades (see Table 12). Thus agricultural productivity might have been determined by particular circumstances in each period, and technical change might have varied over time. Results will show this is indeed a relevant consideration.

Below, I describe in detail the estimation of Colombia's agricultural productivity using both types of econometric techniques. First, the primal methods for each assumed production function are shown. Then, the estimation using dual techniques is presented.

4.3.1 Primal Techniques

4.3.1.1 Cobb-Douglas Production Function

The measurement of agricultural productivity in Colombia, assuming a Cobb-Douglas production function, assumes that technical change is not biased (Wu, 2012). Its assumed unitary elasticity of substitution does not permit identifying when an economic activity exhibits biased technical change. Thus, this functional form has this limitation and assumes that technological change is Hicks-neutral.

Consider the following Cobb-Douglas production function with four inputs (i.e. labor, capital, fertilizer, and animal feed) for agriculture in period t:

$$Q_t = A_t K_t^{\alpha} L_t^{\beta} F_t^{\gamma} S_t^{\theta} \tag{1}$$

where Q_t is total agriculture output in period t, A_t is agricultural productivity measured as Total Factor of Productivity (TFP) in period t, 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, and S_t is animal feed employed by agriculture in period t. Also, α, β, γ and θ are the cost shares of capital, labor, fertilizer and animal feed used by agriculture in period t, respectively, when the following strong assumptions are satisfied: i) perfect competition; ii) firms maximize their profits; iii) perfect information; and iv) constant returns to scale in period t. This means one must impose the restriction that $\alpha + \beta + \gamma + \theta = 1$. Otherwise, these parameters are only the marginal effect of each input on agricultural output.

Now, assuming that TFP grows at a constant rate equal to g, $A_t = A_0 e^{gt}$, this production function can be written as:

$$Q_t = A_0 e^{gt} K_t^{\alpha} L_t^{\beta} F_t^{\gamma} S_t^{\theta} \tag{2}$$

By taking natural logarithms, this production function can be written as:

$$\ln(Q_t) = \ln(A_0) + gt + \alpha \ln(K_t) + \beta \ln(L_t) + \gamma \ln(F_t) + \theta \ln(S_t) \tag{3}$$

Now, by iterating one period backward using this expression and by subtracting one expression from the other, the growth of total agriculture can be written as:

$$\ln\left(\frac{Q_t}{Q_{t-1}}\right) = g + \alpha \ln\left(\frac{K_t}{K_{t-1}}\right) + \beta \ln\left(\frac{L_t}{L_{t-1}}\right) + \gamma \ln\left(\frac{F_t}{F_{t-1}}\right) + \theta \ln\left(\frac{S_t}{S_{t-1}}\right) \tag{4}$$

Therefore, agricultural productivity growth can be calculated as:

$$\frac{dTFP_t}{dt} = g + e_t = \ln\left(\frac{Q_t}{Q_{t-1}}\right) - \alpha \ln\left(\frac{K_t}{K_{t-1}}\right) + \beta \ln\left(\frac{L_t}{L_{t-1}}\right) + \gamma \ln\left(\frac{F_t}{F_{t-1}}\right) + \theta \ln\left(\frac{S_t}{S_{t-1}}\right) \tag{5}$$

where e_t is the residuals component from the estimation.

This implies that agricultural productivity growth, measured as TFP, is a residual variable defined as the output growth in period t not explained by input growth in period t. Thereby, TFP captures all productivity gains exhibited by Colombia's agriculture (e.g. technical change, organizational improvements, etc.).

The same theoretical basis is followed when using growing accounting techniques to measure TFP. The only difference is that econometric techniques use input data to estimate a model of a production function such as in this case, while growth accounting techniques use budget data to estimate cost shares (in this specification α, β, γ and θ) following a simple accounting procedure.

This study uses Ordinary Least Squares (OLS) to estimate equation 3, which yields the average growth of technical change (g) and allows one to measure TFP growth based on equation 5. The Durbin Watson index was also used to test for the possible presence of serial autocorrelation among residuals, which is a common problem when using time series data. When this problem was detected, the model is estimated including the right hand side variable (in this case, the output) lagged one period as another regressor.

The results of this model are compared to the results obtained by replicating the USDA methodology of accounting techniques (USDA, 2016). The aim is to analyze the robustness of their TFP index estimate for Colombia, and to determine if Brazil's cost shares--used by the USDA to measure agricultural TFP for Colombia--look similar to those obtained using Colombia's data. Large differences in α, β, γ and θ from cost shares indicate a lack of robustness in the TFP index measured by the USDA.

4.3.1.2 Constant Elasticity of Substitution – CES Production Function

The measurement of agricultural productivity when the elasticity of substitution is non-unitary is crucial, since it allows for the analysis of cases with biased technical change (Wu, 2012). The problem is that the elasticity of substitution and technical change cannot be identified simultaneously from time series data (Diamond, McFadden, & Rodrigues, 1978). Thus, many studies have imposed particular functional forms, such as the CES, and established certain assumptions, such as perfect competence, in order to solve this problem (Leon-Ledesma, McAdam, & Willman, 2010; Wu, 2012).

This study follows the approach developed by Klump, McAdam, & Willman (2007b) and Leon-Ledesma, McAdam, & Willman (2011) for the measurement of productivity. This relies on the following normalized structure of a nested CES production function in cases with four inputs and technical change[35]. This way, one estimates the technical change associated with each input and the elasticity of substitution among them simultaneously. In this case, primary inputs for agriculture (capital and labor) are allocated in the first nest, and intermediate inputs (fertilizer and feed) in the second nest, yielding:

$$Q_t = \left\{ \left[(E_{Kt}K_t)^{\frac{\eta-1}{\eta}} + (E_{Lt}L_t)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}\frac{\sigma-1}{\sigma}} + \left[(E_{Ft}F_t)^{\frac{\zeta-1}{\zeta}} + (E_{St}S_t)^{\frac{\zeta-1}{\zeta}} \right]^{\frac{\zeta}{\zeta-1}\frac{\sigma-1}{\sigma}} \right\}^{\frac{\sigma}{\sigma-1}} \quad (6)$$

where Q_t is agricultural output in period t, K_t is 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, and S_t is animal feed used by agriculture in period t. Also, the efficiency level of capital is denoted by E_{Kt}, efficiency level of labor by E_{Lt}, efficiency level of fertilizer by E_{Ft}, and efficiency level of animal feed by E_{St}. In addition, the elasticity of substitution between capital and labor (i.e. for inputs in first nest) is η, between fertilizer and feed (i.e. inputs in second nest) is ζ, and between nests is σ.

[35] This production function is normalized in order to ensure that all parameters share the same fixed point, and that they only differ by different elasticities of substitution at that point (Klump, McAdam, & Willman, 2011).

To circumvent problems related to the Diamond-McFadden Impossibility Theorem (Diamond et al., 1978), this study assumes the following functional forms for efficiency growth exhibited by each input based on Klump, McAdam, & Willman (2011):

$$E_{Kt} = E_{K0}e^{\gamma_K(t-t_0)} \tag{7a}$$

$$E_{Lt} = E_{L0}e^{\gamma_L(t-t_0)} \tag{7b}$$

$$E_{Ft} = E_{F0}e^{\gamma_F(t-t_0)} \tag{7c}$$

$$E_{St} = E_{S0}e^{\gamma_S(t-t_0)} \tag{7d}$$

where efficiency growth exhibited by each input is denoted by γ_i, and i corresponds to K, L, F, and S. Also, initial efficiency levels (E_{i0}) are defined as the corresponding ratio between output and each input in period $t = 0$. Thereby, the initial efficiency levels exhibited by each input can be written as:

$$E_{K0} = \frac{Q_0}{K_0}(1-\beta)^{\frac{\eta}{\eta-1}}(\alpha)^{\frac{\eta-1}{\eta}\frac{\sigma}{\sigma-1}} \tag{8a}$$

$$E_{L0} = \frac{Q_0}{L_0}(\beta)^{\frac{\eta}{\eta-1}}(\alpha)^{\frac{\eta-1}{\eta}\frac{\sigma}{\sigma-1}} \tag{8b}$$

$$E_{F0} = \frac{Q_0}{F_0}(1-\pi)^{\frac{\zeta}{\zeta-1}}(1-\alpha)^{\frac{\zeta-1}{\zeta}\frac{\sigma}{\sigma-1}} \tag{8c}$$

$$E_{S0} = \frac{Q_0}{F_0}(\pi)^{\frac{\zeta}{\zeta-1}}(1-\alpha)^{\frac{\zeta-1}{\zeta}\frac{\sigma}{\sigma-1}} \tag{8d}$$

where Q_0 is total output of agriculture in the initial period, K_0 is stock of capital in agriculture in the initial period, L_0 is labor hired by agriculture in the initial period, F_0 is fertilizer used by agriculture in the initial period, and S_0 is animal feed used in the initial period. Also, the distribution parameter between nests is denoted by α, within the first nest by β, and within the second by π.

Therefore, the nested CES production function for Colombia's agriculture can be written as the following expression, substituting equations (7) and (8) in equation (6):

$$Q_t = Q_0 \left\{ \alpha \left[(1-\beta) \left(e^{\gamma_K (t-t_0)} \frac{K_t}{K_0} \right)^{\frac{\eta-1}{\eta}} + \beta \left(e^{\gamma_L (t-t_0)} \frac{L_t}{L_0} \right)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}\frac{\sigma-1}{\sigma}} + \right.$$

$$\left. (1-\alpha) \left[(1-\pi) \left(e^{\gamma_F (t-t_0)} \frac{F_t}{F_0} \right)^{\frac{\zeta-1}{\zeta}} + \pi \left(e^{\gamma_S (t-t_0)} \frac{S_t}{S_0} \right)^{\frac{\zeta-1}{\zeta}} \right]^{\frac{\zeta}{\zeta-1}\frac{\sigma-1}{\sigma}} \right\}^{\frac{\sigma}{\sigma-1}} \qquad (9)$$

From this, the measurement of agricultural productivity in Colombia consists of a typical profit maximization problem, with this functional form assumed for the production function. Also, each equation derived from this optimization is normalized and linearized[36] (i.e. the functional form on the nested CES production function, and the first order conditions). In addition, this optimization is solved assuming that Colombia's agriculture faces a demand function $Y_{it} = \left(\frac{P_{it}}{P_t}\right)^{-\varepsilon}$, its mark-up in equilibrium is $1 + \mu = \frac{\varepsilon}{1-\varepsilon}$, and its income is $Q_t = (1+\mu)(R_t K_t + W_t L_t + fP_t F_t + sP_t S_t)$, 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.

[36] This study uses natural logarithms for the linearization, and uses the geometrical mean for the normalization following the suggestions of earlier studies (Klump et al., 2007; Kreuser et al., 2015).

$$\ln\left(\frac{Q_t}{Q_0}\right) = \frac{\sigma}{\sigma-1} ln\left\{\alpha\left[(1-\beta)\left(e^{\gamma_K(t-t_0)}\frac{K_t}{K_0}\right)^{\frac{\eta-1}{\eta}} + \beta\left(e^{\gamma_L(t-t_0)}\frac{L_t}{L_0}\right)^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}\frac{\sigma-1}{\sigma}} + \right.$$

$$\left. + (1-\alpha)\left[(1-\pi)\left(e^{\gamma_F(t-t_0)}\frac{F_t}{F_0}\right)^{\frac{\zeta-1}{\zeta}} + \pi\left(e^{\gamma_S(t-t_0)}\frac{S_t}{S_0}\right)^{\frac{\zeta-1}{\zeta}}\right]^{\frac{\zeta}{\zeta-1}\frac{\sigma-1}{\sigma}}\right\} \qquad (10)$$

$$\ln(R_t) = ln\left[\frac{\alpha(1-\beta)}{1+\mu}\frac{Q_0}{K_o}\right] + \frac{(\eta-1)}{\eta}\gamma_K(t-t_0) + \frac{1}{\sigma}ln\left(\frac{Q_t}{Q_o}\right) - \frac{1}{\eta}ln\left(\frac{K_t}{K_o}\right) +$$

$$+ \frac{\sigma-\eta}{\sigma(\eta-1)} ln\left[(1-\beta)\left(e^{\gamma_K(t-t_0)}\frac{K_t}{K_0}\right)^{\frac{\eta-1}{\eta}} + \beta\left(e^{\gamma_L(t-t_0)}\frac{L_t}{L_0}\right)^{\frac{\eta-1}{\eta}}\right] \qquad (11)$$

$$\ln(W_t) = ln\left[\frac{\alpha\beta}{1+\mu}\frac{Q_0}{L_o}\right] + \frac{(\eta-1)}{\eta}\gamma_L(t-t_0) + \frac{1}{\sigma}ln\left(\frac{Q_t}{Q_o}\right) - \frac{1}{\eta}ln\left(\frac{L_t}{L_o}\right) +$$

$$+ \frac{\sigma-\eta}{\sigma(\eta-1)} ln\left[(1-\beta)\left(e^{\gamma_K(t-t_0)}\frac{K_t}{K_0}\right)^{\frac{\eta-1}{\eta}} + \beta\left(e^{\gamma_L(t-t_0)}\frac{L_t}{L_0}\right)^{\frac{\eta-1}{\eta}}\right] \qquad (12)$$

$$\ln(fP_t) = ln\left[\frac{(1-\pi)(1-\alpha)}{1+\mu}\frac{Q_0}{F_o}\right] + \frac{(\zeta-1)}{\zeta}\gamma_F(t-t_0) + \frac{1}{\sigma}ln\left(\frac{Q_t}{Q_o}\right) - \frac{1}{\zeta}ln\left(\frac{F_t}{F_o}\right) +$$

$$+ \frac{\sigma-\zeta}{\sigma(\zeta-1)} ln\left[(1-\pi)\left(e^{\gamma_F(t-t_0)}\frac{F_t}{F_0}\right)^{\frac{\zeta-1}{\zeta}} + \pi\left(e^{\gamma_S(t-t_0)}\frac{S_t}{S_0}\right)^{\frac{\zeta-1}{\zeta}}\right] \qquad (13)$$

$$\ln(sP_t) = ln\left[\frac{\pi(1-\alpha)}{1+\mu}\frac{Q_0}{s_o}\right] + \frac{(\zeta-1)}{\zeta}\gamma_S(t-t_0) + \frac{1}{\sigma}ln\left(\frac{Q_t}{Q_o}\right) - \frac{1}{\zeta}ln\left(\frac{S_t}{S_o}\right) +$$

$$+ \frac{\sigma-\zeta}{\sigma(\zeta-1)} ln\left[(1-\pi)\left(e^{\gamma_F(t-t_0)}\frac{F_t}{F_0}\right)^{\frac{\zeta-1}{\zeta}} + \pi\left(e^{\gamma_S(t-t_0)}\frac{S_t}{S_0}\right)^{\frac{\zeta-1}{\zeta}}\right] \qquad (14)$$

In econometric terms, this system of equations is estimated using Iterative Feasible Generalized Non-Linear Least Squares (IFGNLS) as recommended by Kreuser, Burger, & Rankin (2015). This technique prevents the estimation of inconsistent parameters and an elasticity of substitution biased towards unity often exhibited when this system of equations is estimated as a Seemingly Unrelated Regression model (SUR) (Luoma & Luoto, 2011). This study estimates parameters for technical change γ_i and elasticities of substitution (σ, η, and ζ) simultaneously from this optimization. It estimates this system of equations under two scenarios: i) Hicks-neutral technical change ($\gamma_K = \gamma_L = \gamma_F = \gamma_S = \gamma$); and ii) biased technical change ($\gamma_K \neq \gamma_L \neq \gamma_F \neq \gamma_S$). Also, it measures Colombia's agricultural productivity growth, denoted by TFP, as the actual output growth in period t not explained by input growth in period[37]. In addition, it determines the presence of biased technical change by testing the following hypotheses:

$H_0\!: \gamma_i - \gamma_j \geq 0$ Technical change is augmenting input i relative to input j.

$H_a\!: \gamma_i - \gamma_j < 0$ Technical change is augmenting input j relative to input i.

This study follows a similar procedure for the measurement of crop and livestock productivity. However, it considers a nested CES production function with only one nest and an extra input, because it is assumed that crop and livestock production depends strongly on three inputs only in both cases. For crops, it assumes that these inputs are capital, labor and fertilizer. Thus, it considers two possible forms for this nested CES production function: i) primary inputs (labor and capital) in the nest and fertilizer as an extra output (see equation 15); and ii) capital related inputs (capital and fertilizer) in the

[37] Input growth is estimated as the growth of the predicted output, keeping inactive the time trend component (in this case the technical change component).

nest, and labor as an extra input (see equation 16). For livestock, the establish inputs are capital, labor and animal feed. Hence, it also considered two possible forms for this nested CES production function: i) primary inputs (labor and capital) in the nest and animal feed as an extra output (see equation 17); and ii) capital-related inputs (capital and animal feed) in the nest, and labor as an extra input (see equation 18)[38].

$$Q_t^{CP} = \left\{ \left[(E_{Kt}K_t)^{\frac{\eta-1}{\eta}} + (E_{Lt}L_t)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}\frac{\sigma-1}{\sigma}} + E_{Ft}F_t \right\}^{\frac{\sigma}{\sigma-1}} \quad (15)$$

$$Q_t^{CP} = \left\{ \left[(E_{Kt}K_t)^{\frac{\eta-1}{\eta}} + (E_{Ft}F_t)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}\frac{\sigma-1}{\sigma}} + E_{Lt}L_t \right\}^{\frac{\sigma}{\sigma-1}} \quad (16)$$

$$Q_t^{LS} = \left\{ \left[(E_{Kt}K_t)^{\frac{\eta-1}{\eta}} + (E_{Lt}L_t)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}\frac{\sigma-1}{\sigma}} + E_{St}S_t \right\}^{\frac{\sigma}{\sigma-1}} \quad (17)$$

$$Q_t^{LS} = \left\{ \left[(E_{Kt}K_t)^{\frac{\eta-1}{\eta}} + (E_{St}S_t)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}\frac{\sigma-1}{\sigma}} + E_{Lt}L_t \right\}^{\frac{\sigma}{\sigma-1}} \quad (18)$$

This implied that the measurement of crop and livestock productivity in Colombia involves a slightly different profit maximization problem. The main changes involve a different form for the initial linearized and normalized production function (equation 10), three first order condition equations only, and a different form for the first order condition estimated for the input considered as extra in each case. For instance, the following is the system of equations estimated to measure crop productivity in the

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[38] Animal feed is excluded from the crops production function, and fertilizers are excluded from the livestock production function.

scenario for which primary inputs (labor and capital) are included in the nest and fertilizer is considered as an extra output. The system of equations is equivalent in structure for the others cases.

$$\ln\left(\frac{Q_t^{CP}}{Q_0^{CP}}\right) = \frac{\sigma}{\sigma-1} ln\left\{\alpha\left[(1-\beta)\left(e^{\gamma_K(t-t_0)}\frac{K_t}{K_0}\right)^{\frac{\eta-1}{\eta}} + \beta\left(e^{\gamma_L(t-t_0)}\frac{L_t}{L_0}\right)^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}\frac{\sigma-1}{\sigma}} + \right.$$

$$\left. + (1-\alpha)\left[e^{\gamma_F(t-t_0)}\frac{F_t}{F_0}\right]^{\frac{\sigma-1}{\sigma}}\right\} \tag{19}$$

$$\ln(R_t) = ln\left[\frac{\alpha(1-\beta)}{1+\mu}\frac{Q_0}{K_o}\right] + \frac{(\eta-1)}{\eta}\gamma_K(t-t_0) + \frac{1}{\sigma} ln\left(\frac{Q_t}{Q_o}\right) - \frac{1}{\eta} ln\left(\frac{K_t}{K_o}\right) +$$

$$+ \frac{\sigma-\eta}{\sigma(\eta-1)} ln\left[(1-\beta)\left(e^{\gamma_K(t-t_0)}\frac{K_t}{K_0}\right)^{\frac{\eta-1}{\eta}} + \beta\left(e^{\gamma_L(t-t_0)}\frac{L_t}{L_0}\right)^{\frac{\eta-1}{\eta}}\right] \tag{20}$$

$$\ln(W_t) = ln\left[\frac{\alpha\beta}{1+\mu}\frac{Q_0}{L_o}\right] + \frac{(\eta-1)}{\eta}\gamma_L(t-t_0) + \frac{1}{\sigma} ln\left(\frac{Q_t}{Q_o}\right) - \frac{1}{\eta} ln\left(\frac{L_t}{L_o}\right) +$$

$$+ \frac{\sigma-\eta}{\sigma(\eta-1)} ln\left[(1-\beta)\left(e^{\gamma_K(t-t_0)}\frac{K_t}{K_0}\right)^{\frac{\eta-1}{\eta}} + \beta\left(e^{\gamma_L(t-t_0)}\frac{L_t}{L_0}\right)^{\frac{\eta-1}{\eta}}\right] \tag{21}$$

$$\ln(fP_t) = ln\left[\frac{(1-\alpha)}{1+\mu}\frac{Q_0}{F_o}\right] + \frac{(\sigma-1)}{\sigma}\gamma_F(t-t_0) + \frac{1}{\sigma} ln\left(\frac{Q_t}{Q_o}\right) - \frac{1}{\sigma} ln\left(\frac{F_t}{F_o}\right) \tag{22}$$

4.3.2 Dual techniques

In some respects, the measurement of agricultural productivity through dual techniques is simpler than using primal methods[39]. Antle & Capalbo (1988) indicate that dual functions, such as a cost or profit function, are valid alternatives to represent the

[39] The measurement of productivity depends on prices, which are usually easier to collect than quantities and more accurate.

multi-product function and to define technical change. The effects of technical change can then be perceived and quantified through a reduction in cost or an increase in profits, given an output and a set of input prices.

Capalbo (1988) explains the intuition behind the usage of cost functions to estimate technical change by starting with a general form of the cost function, such as the following:

$$C = g(w_1, w_2, \dots, w_n, Q, t) \tag{23}$$

where C is the total cost in agriculture, n are inputs demanded, w_i is the price of input i, Q is the output of agriculture, and t is a time trend variable.

Differentiating this expression with respect to time and dividing by total cost yields:

$$\frac{dC/dt}{C} = \sum_i^n \frac{1}{C}\frac{\partial g}{\partial w_i}\frac{dw_i}{dt} + \frac{1}{C}\frac{\partial g}{\partial Q}\frac{dQ}{dt} + \frac{1}{C}\frac{\partial g}{\partial t} \tag{24}$$

By employing Shephard's Lemma $\left(\frac{\partial g}{\partial w_i} = x_i\right)$, multiplying and dividing the first term by input prices (w_i) and the second by output (Q), and by defining for all variables $\dot{a} = \frac{\partial a/\partial t}{a}$, this expression can be written as:

$$\dot{C} = \sum_i^n s_i \dot{w}_i + \epsilon_{CQ}\dot{Q} + \dot{B} \tag{25}$$

where $\dot{B} = \frac{\partial g/\partial t}{C}$, $\epsilon_{CQ} = \frac{Q}{C}\frac{\partial g}{\partial Q}$, and $s_i = \frac{w_i x_i}{C}$.

Now, by rearranging the terms, this expression is equal to:

$$-\dot{B} = \sum_i^n s_i \dot{w}_i + \epsilon_{CQ}\dot{Q} - \dot{C} \tag{26}$$

Capalbo (1988) explains that this expression defines the rate of technical change ($-\dot{B}$) as an index of the rate of change exhibited by input prices ($\sum_i^n s_i \dot{w}_i$) plus a scale effect $\left(\epsilon_{CQ}\dot{Q}\right)$ minus the rate change of total cost. It also explains that the rate of technical change ($-\dot{B}$) is also related to productivity growth ($T\dot{F}P$), by using as starting point the following expression for the cost function:

$$C = \sum_i^n w_i x_i \tag{27}$$

Differentiating this expression with respect to time and dividing by the total cost yields:

$$\frac{dC/dt}{C} = \sum_i^n \frac{1}{C} w_i \frac{dx_i}{dt} + \sum_i^n \frac{1}{C} x_i \frac{dw_i}{dt} \tag{28}$$

By multiplying and dividing the first term by the demand for inputs (x_i) and the second by input prices (w_i), as well as assuming that s_i is equal to $\frac{w_i x_i}{C}$, this expression can be written as:

$$\dot{C} = \sum_i^n s_i \dot{x}_i + \sum_i^n s_i \dot{w}_i \tag{29}$$

Rearranging the terms of this expression yields:

$$-\sum_i^n s_i \dot{x}_i = \sum_i^n s_i \dot{w}_i - \dot{C} \tag{30}$$

Substituting this expression in equation 26 and rearranging terms yields:

$$-\dot{B} = \epsilon_{CQ} \dot{Q} - \dot{F} \tag{31}$$

where $\dot{F}$ is equal to $\sum_i^n s_i \dot{x}_i$.

For the multiple output-case, where agriculture minimizes the cost of producing j outputs using i inputs, Capalbo (1988) indicates this equivalent expression:

$$-\dot{B} = \sum_j \epsilon_{CQ} \dot{Q}_j - \dot{F} \tag{32}$$

Thus, by using the conventional definition of productivity growth, which establishes that is the growth not explained by input growth ($T\dot{F}P = \dot{Q} - \dot{F}$), and substituting this expression into equation (32), productivity growth ($T\dot{F}P$) is equal to:

$$T\dot{F}P = -\dot{B} + \left(1 - \sum_j \epsilon_{CQ}\right)\dot{Q}, \qquad \text{where } \sum_j \epsilon_{CQ} \neq 1 \tag{33}$$

Hence, productivity growth $\left(T\dot{F}P\right)$ exhibits a negative relation with shifts in the cost function and scale effects, but also a positive relation to output growth. Also, the measurement of productivity growth relies on the quantification of shifts in production and cost-output elasticities (ϵ_{CQ}) (Capalbo, 1988).

This study measures agricultural, crop, and livestock productivity in Colombia by estimating these components assuming a trans-log form for the cost function. This functional form is a second-order approximation of an arbitrary twice-continuously differentiable cost function, which exhibits three main strengths: i) it is a flexible functional form; ii) it does not established restrictions on the substitution possibilities among inputs, and iii) it allows that scale economies can vary based on the output level (Kant & Nautiyal, 1997; Varian, 1978). Also, it has been used successfully by other studies in which the cost generating dynamic structure was unknown (Binswanger, 1974b; Christensen & Greene, 1976; Clark & Youngblood, 1992; Kant & Nautiyal, 1997; Sun et al., 2009).

The trans-log functional form assumed in this study for the cost production function can be written as:

$$\begin{aligned}\ln C_t = {} & \alpha_0 + \alpha_Q \ln Q_t + \textstyle\sum_i \alpha_i \ln w_{it} + \frac{1}{2}\sum_i \beta_{ii}(\ln w_{it})^2 + \sum_i \beta_{ij} \ln w_{it} \ln w_{jt} + \\ & + \textstyle\sum_i \beta_{iQ} \ln w_{it} \ln Q_t + \frac{1}{2}\alpha_{QQ}(\ln Q_t)^2 + \alpha_t T + \frac{1}{2}\alpha_{tt} T^2 + \sum_i \beta_{it} \ln w_{it} T + \\ & + \beta_{Qt} \ln Q_t T + u_{it}\end{aligned} \tag{34}$$

where C_t are the production costs in Colombia's agriculture in period t, Q_t is the agricultural output in period t, w_{it} is the price of input i in period t, T is a time trend variable that captures technology change, and inputs i for estimating agricultural productivity are capital (K_t), labor (L_t), fertilizer (F_t) and animal feed (S_t), for crops productivity K_t, L_t and F_t, and for livestock productivity K_t, L_t and S_t.

Cost share functions for input i, which correspond to its optimal demand, are derived from the following expressions using Shepard's Lemma:

$$S_{it} = \frac{\partial \ln C_t}{\partial lnw_{it}} = \alpha_i + \beta_{ii}\ln w_{it} + \sum_{ij} \beta_{ij}\ln w_{jt} + \beta_{iQ}\ln Q_t + \beta_{it}T + \varepsilon_{it} \quad (35)$$

since Shepard's Lemma establishes that $\frac{\partial C}{\partial w_i} = x_i$. This implies that the cost share functions can be derived by differentiating the cost function by the inputs prices such as: $\frac{\partial \ln C}{\partial lnw_i} = \frac{\partial C/C}{\partial w_i/w_i} = \frac{\partial C}{\partial w_i}\frac{w_i}{C} = x_i\frac{w_i}{C} = S_i$.

The estimation of equation (34) and equations (35) becomes a system of $i + 1$ equations, for which there exists an implied truncation error due to the fact that the cost function is a second order approximation (Christensen & Greene, 1976). This implies that this error is transmitted across the residuals of each cost share function, which formed clearly a system of a seemingly unrelated regressions (SUR). However, this study estimates this system of equations including only 3 of the 4 cost share equations in each run, since the sum of all cost share functions is 1 and estimating all four cost share equation can result in a singular covariance matrix. Also, this system of equations was estimated by using Iterative Feasible Generalized Non-Linear Least Squares (IFGNLS), because this estimator is equivalent to a Maximum Likelihood estimator, and results are invariant regardless which equation is dropped (Greene, 2012). In addition, prices and quantities are normalized to 1 in 1995, which is the mid-point year of the sample, as economic literature suggested (Capalbo, 1988).

The following restrictions were included in the estimation to ensure that the corresponding production function is well behaved (Antle & Capalbo, 1988; Kant & Nautiyal, 1997): i) coefficients are the same in the cost function and cost share equations; ii) coefficients are symmetric among equations; iii) $\sum_i \alpha_i = 1$; $\sum_i \beta_{iQ} = 0$; and iv) $\sum_i \beta_{ij} = \sum_j \beta_{ji} = \sum_i \sum_j \beta_{ij} = \sum_i \beta_{it} = 0$. Also, own price elasticities are calculated for all inputs in order to evaluate the cost function estimated, by using the following expression. This is equivalent to calculating these elasticities using the Allen partial elasticities of substitution (AES) using equation (34) and equation (35) (Binswanger, 1974a)[40]:

$$\epsilon_{WX} = S_{it} - 1 + \frac{\beta_{ii}}{S_{it}} \tag{36}$$

Now, a general expression for technichal change, equivalent to $-\dot{B}$ in equation 32, is:

$$-\frac{\partial g/\partial t}{C} = -\dot{B} = -\left(\alpha_t + \alpha_{tt}T + \sum_i \beta_{it}\ln W_i + \beta_{Qt}\ln Q\right) \tag{37}$$

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40 The derivation of this expression begins by stating that $\frac{\partial lnS_{it}}{\partial lnw_{it}} = \frac{\partial ln\left(\frac{w_{it}x_{it}}{C_t}\right)}{\partial lnw_{it}} = \frac{\partial lnw_{it}}{\partial lnw_{it}} + \frac{\partial lnx_{it}}{\partial lnw_{it}} - \frac{\partial lnC_t}{\partial lnw_{it}}$. Then, using that $\frac{\partial lnx_{it}}{\partial lnw_{it}} = \epsilon_{WX}$ and $\frac{\partial lnC_t}{\partial lnw_{it}} = \widehat{S_{it}}$, this expression is equal to $\frac{\partial S_{it}}{\partial lnw_{it}} \cdot \frac{1}{S_{it}} = 1 + \epsilon_{WX} - \widehat{S_{it}}$, and it is equal to $\beta_{ii} \cdot \frac{1}{S_{it}} = 1 + \epsilon_{WX} - S_{it}$. Therefore, rearranging all terms yields this expression for the own price elasticity.

where the basic assumption is that costs decrease due to technology improvements. α_t is the constant technical change, $\alpha_{tt}T$ is the acceleration rate of the technical change, $\sum_i \beta_{it} \ln W_i$ is the input bias and $\beta_{Qt} \ln Q$ is the scale bias. Therefore, pure technical change is equal to $-(\alpha_t + \alpha_{tt}T)$, which corresponds to the rate of reduction in overall costs due to a technical innovation holding constant the scale production effect. Also, scale augmenting technical change is measured by -$\beta_{Qt} \ln Q$, which is the rate of reduction in costs due to a technical innovation that is exhibited along with changes in output.

Technical change should be calculated using the following expression when the production function behind a trans-log cost function is non homothetic (Antle & Capalbo, 1988):

$$-\dot{B} = \beta_{it} - \left(\frac{\partial LnS_i}{\partial LnQ}\right)\left(\frac{\partial LnC}{\partial LnQ}\right)^{-1}\left(\frac{LnC}{\partial t}\right) \quad (38)$$

where β_{it} capture the pure 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.

In addition, the hypotheses to test for biased technical change are the following, which are in terms of input-saving, since these test the rate of change in cost shares due to technical change $\left(\frac{\partial Si}{\partial T} = \beta_{ti}\right)$.

H_0: $\beta_{it} < \beta_{jt}$ Technical change is input i–saving and input j-using.

H_a: $\beta_{it} \geq \beta_{jt}$ Technical change is input j-saving and input i-using.

The cost-output elasticity, crucial in the decomposition of productivity growth derived by Capalbo (1988) (see equation 33), can be derived as:

$$\epsilon_{CQ} = \frac{\partial \ln C}{\partial lnQ} = \alpha_Q + \sum_i \beta_{iQ} \ln w_i + \alpha_{QQ} \ln Q + \beta_{Qt} \mathrm{T} \qquad (39)$$

Thus, an estimable expression for productivity growth ($T\dot{F}P$), based on equation 33, is:

$$T\dot{F}P = \widehat{-\dot{B}} + \left(1 - \widehat{\epsilon_{CQ}}\right)\dot{Q} + \varepsilon \qquad (40)$$

where $\widehat{-\dot{B}}$ is the shift estimated for the cost function due to technical change (see equation 37), $\widehat{\epsilon_{CQ}}$ is the cost-output elasticity estimated (see equation 39) and ε are the residuals.

CHAPTER 5. DATA

The underlying data used in this study primarily come from FAOSTAT, World Bank and USDA (FAO, 2015; USDA, 2015; World Bank, 2016). In order to expand the dataset for Colombia's agriculture, this study uses data from the National Department of Statistics of Colombia (DANE), the Central Bank of Colombia (BANREP), and the International Fertilizer Industry Association (IFA) (BANREP, 2015; DANE, 2015; IFA, 2016). This allowed us to build a historical database for Colombia's' agriculture from 1975-2013 based on existing data availability. This database includes the value of Colombia's agricultural output (aggregated and disaggregated by crops and livestock), and quantities and prices of inputs such as labor, capital, fertilizer, and animal feed. The construction of each variable included in this database is explained in detail below.

5.1 Output

The value of agricultural production corresponds to the total gross production value released yearly by FAOSTAT (FAO, 2015). FAO compiles these data by multiplying the gross production in physical terms by output prices at the farm gate (FAO, 2015)[41]. In the case of Colombia, this figure encompasses the value of production for 85 crops and

[41] This study uses the value of Colombia's agricultural production, because prices are needed to add quantities of different goods.

livestock commodities. Also, this ensures the usage of accurate data for the value of aggregate agriculture production, as well as for value of production of crops and livestock. These data are used as they are released: annually (per calendar year) and in 2005 international dollars. FAOSTAT releases these data in this currency unit in order to facilitate comparisons across analysis about productivity at the country level. The aim is to avoid the need to use exchange rates by assigning a single price to each commodity. Accordingly, one metric ton of any commodity has a unique price worldwide regardless where is produced (FAO, 2015).

For crops, the data correspond to crop category reported by FAOSTAT. This includes data for all harvested production in Colombia, sold in the market and consumed by the producers, multiplied by their producer prices (FAO, 2015). This also includes data for 74 crop products. For livestock, the data source is FAOSTAT as well, and corresponds to its livestock category, including production of eleven animal products, such as cattle meat, poultry meat, pork meat, milk, etc., multiplied by their producer prices.

5.2 Inputs

5.2.1 Capital Stock

Capital stock used in this study corresponds to Colombia’s gross capital stock released yearly by FAOSTAT (FAO, 2015). This is calculated as the sum of individual physical assets held by Colombian farmers (FAO, 2015). Also, this dataset includes 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 structures for livestock. This allows for the present study to disaggregate the capital stock for crops and for livestock.

Crops capital stock compiles the value of gross capital in plantation crops[42] and land development (FAO, 2015). Livestock capital stock encompasses the value of livestock fixed assets, livestock inventory, and in structures for livestock. FAO also releases figures for capital stock in machinery and equipment (FAO, 2015). However, this includes assets that can be owned by either activity, such as tractors. Accordingly, this study divides this stock for crops and livestock--using their respective shares in the total value of agricultural production--in order to consider this capital stock in both cases.

Capital stock data is only available from 1961-2007. Accordingly, this study updated it for more recent years based on net investment flows to Colombia's agriculture (DANE, 2015). This allowed for an estimation of capital stock for Colombia's agriculture in terms of aggregate, crops, and livestock figures for the period covered by this study (1975-2013). This study used the data as they are released: annually (per calendar year) and in 2005 international dollars.

This study also estimates the cost (input price) of capital. To this end, we relied on the definition from cost benefit analysis, which considers the cost of capital as the opportunity cost for investing in a particular asset (Campbell & Brown, 2003). Therefore, its measurement is the sum of the real interest rate plus the depreciation rate for agricultural assets. The real interest rate is calculated as the difference between the

[42] Plantation crops correspond to trees yielding repeated products, such as fruits or nuts (FAO, 2015).

nominal interest rate and inflation. This nominal interest rate corresponds to a traditional passive interest rate in Colombia, also known as DTF[43], since there is not an official interest rate for agriculture credit in Colombia, and these 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 study and other research) corresponds to a deduction of 5 percentage points from this interest rate (Illera, 2009; C. Jaramillo & Jimenez, 2008)[44]. Finally, the depreciation rate for agriculture is taken from Pombo (Pombo, 1999). Pombo calculated the average depreciation rates exhibited by capital for all economic activity in Colombia.

5.2.2 Farm Labor and Wages

Farm labor data used in this study correspond to the total number of people (male and female) economically active in Colombia's agriculture, as released by the USDA for the years 1961-2012 (USDA, 2015). This study updated these data for the last decade (2001-2013) using available, more accurate data from national sources (DANE, 2015). Basically, it used the USDA data as a starting point, and then, using the farm labor growth reported by these sources, predicts the farm labor for the last decade. This study uses these data as they are released: annually (per calendar year).

[43] DTF corresponds to a Fixed Term Deposit Rate in Colombia.

[44] Corresponds to a weighted average of percentage points commonly deducted for small farmers credits (-8pp) and for 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%. These percentage points deducted are the ones that Colombian bank have usually deducted to farm credits by farmer type (Illera, 2009; C. Jaramillo & Jimenez, 2008)

For crops and livestock, labor data are primarily estimated in this study based on data reported by Barrientos & Castrillón (2007). This study reveals these data disaggregated for Colombia. However, it does so for the period 1993-2005 only. Accordingly, this study uses the data of that study as a starting point to estimate the labor data for crops and livestock before and after its scope (i.e. for periods 1975-1993 and 2006-2013). To this end, the present study uses their average trend within the sample. This trend exhibited a good fit, and enables this study to make a robust prediction. In crops its R^2 was 0.98, and in livestock it was 0.72. Thus, this study used these average trends to estimate labor data for crops and livestock. However, these estimations yield labor data slightly different from the USDA. Therefore, this study calculates labor shares for crops and livestock based on the predicted data, and then multiplied these shares by the USDA data. This allowed this study to predict the labor data for crops and livestock coherent with the USDA data[45].

Farm labor wages are derived implicitly from annual national accounts (DANE, 2015). These data reveal the total payroll paid by each sector in Colombia to generate sectoral GDP. Thus, this study takes the value paid by agriculture in current pesos, and estimates the average wage paid per employee by dividing this value by total farm labor. Then, this amount is converted into 2005 American dollars, by: i) dividing this value by the annual average Colombian exchange rate of peso-US American dollars (BANREP,

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[45] I'm aware that this procedure implies imposing exactly the same volatility of aggregated agricultural labor on labor in crops and livestock. However, this is considered one of the most straightforward ways to estimate labor data for crops and livestock in Colombia and make both series coherent with the actual data, given the lack of disaggregate data for Colombia.

2015); and ii) dividing this value by the GDP deflator for US$ prices with the base year 2005 (FAO, 2015).

It is worth indicating that these wages may be underestimated. These values only represent half of the official minimum wage for rural areas in Colombia, and it does not include non-monetary payments (i.e. food, housing, etc.) commonly received by farmers in developing countries. This figure also does not differentiate labor by skills, since it is only an average wage, as indicated above. In addition, it is assumed that this wage is received by all farmers regardless the activity on which they work (i.e. crop production or livestock production).

5.2.3 Fertilizers

Fertilizer quantities correspond to the total amount of major nutrients ($N+P_2O_5+K_2O$) demanded and applied to land by farmers in Colombia, released yearly by IFA (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. This study uses these data as these were released: annually (per calendar year) and in metric tons.

Fertilizer prices are estimated by this study based on FAOSTAT, DANE and BANREP (BANREP, 2015; DANE, 2015; FAO, 2015). The reason for this is that there is no historical database that compiles these prices in Colombia for the period covered by this study (1975-2013). Available data is for recent years (AGRONET, 2014). Thus, this study estimates fertilizers prices using the urea price paid in Colombia by farmers as a leaderindicator[46]. This price is reported annually (per calendar year) by FAOSTAT in current Colombian pesos and per metric ton for the period 1961-2002. However, the data exhibit some missing values for the 1990's, which are approximated in this study using the annual average Producer Price Index (PPI) of fertilizers, released monthly by BANREP since the early 1990's and by DANE in recent years (BANREP, 2015; DANE, 2015). Also, this price was estimated up to 2013 following the same procedure. Then, this current price is converted to 2005 American dollars by: i) dividing this value by the annual average Colombian exchange rate of peso-US American dollars (BANREP, 2015); and ii) dividing this value by the GDP deflator for US$ prices with the base year 2005 (FAO, 2015).

5.2.4 Animal Feed

Animal feed quantities used in this study come from FAOSTAT (FAO, 2015). These correspond to the total crop and animal products used for feeding animals. FAOSTAT reports these quantities in the Commodities Balance Sheet. This study uses these data as they are released: annually (per calendar year) and in metric tons.

Animal feed price is derived from FAOSTAT (FAO, 2015). This study estimates this price implicitly and as a weighted average. It takes the producer prices of crop and animal fish products used for feeding animals reported by FAOSTAT, and calculates the value of each feed using their quantities. Then, it estimates the total value of these products for each year. Finally, this total value is divided by the total product quantity to calculate an

[46] Urea represents about a third of all fertilizer used by farmers in Colombia (IFA, 2016).

average price per metric ton of animal feed for each year. Since this figure is in current Colombian pesos, it is the converted to American dollars, by: i) dividing this value by the annual average Colombian exchange rate peso-US American dollar (BANREP, 2015); and ii) dividing this value by the GDP deflator for US$ prices with the base year 2005 (FAO, 2015).

CHAPTER 6. RESULTS AND DISCUSSION

6.1 Introduction

This study uses primal and dual econometric techniques for the measurement of agricultural productivity in Colombia. The objective is to use a variety of methodologies from the economics literature as strategy to look for more consistent results. For primal techniques, this study experiments by assuming the following functional forms of the production function: i) Cobb-Douglas; and ii) Constant Elasticity of Substitution – CES. For dual techniques, this study uses a trans-log cost function. In addition, this study estimates the productivity of Colombia's agriculture in aggregate, and also disaggregated for crops and livestock.

This chapter presents the results obtained by this study in two sections. In the first, it reports in detail the results obtained for agricultural productivity in Colombia, using each econometric method. In the second, it compares these results across techniques by focusing on the decomposition of agricultural output growth between input accumulation and productivity growth during the period 1975-2013. In parallel, it also analyzes changes in agricultural productivity over time, and how they relate to agricultural policy and economic circumstances exhibited by Colombia's agriculture during this period.

6.2 Results

6.2.1 Primal Techniques

6.2.1.1 Cobb-Douglas Production Function

6.2.1.1.1 Total Agriculture

The model based on assuming a Cobb-Douglas production function with constant returns to scale for Colombia's agriculture as an aggregate shows an excellent fit. Its R^2 is 0.984, and its Root Mean Square Error (Root MSE) is 0.034 (see Table 14, column 1). Also, this model does not show heteroskedasticity, since it is estimated assuming robust standard errors, as for all models in this chapter. In addition, it does not show serial autocorrelation, since its Durbin Watson statistic (DW) is 1.65[47]. This model is not robust, however. Its estimates change significantly when technical change, for instance, is calculated for specific periods (see Table 14, column 2 and column 3). Also, specification changes lead to different coefficient estimates.

The results of this model indicate that Colombia's agriculture as an aggregate did not exhibit technical change during the period 1975-2013, when it is assumed constant over time (see Table 14, column 1). Agricultural productivity measured as TFP did not grow over this period. These results contradict USDA's productivity estimates for Colombia's agriculture, which predict that Colombia's agricultural productivity grew on average by 1.4% over this period (USDA, 2015). There are two possible reasons for this

[47] The rule of thumb for testing serial autocorrelation establishes that if the Durbin Watson Index (DW) is lower (higher) than 2, then this indicates possible positive (negative) serial autocorrelation among residuals. Also, if the DW index is equal or close to 2, there is not serial autocorrelation (Wooldridge, 2009).

discrepancy. On the one hand, the USDA estimates agricultural TFP for Colombian agriculture as a residual variable using an accounting technique, including the cost shares from Brazil's agriculture, and assuming that these are similar in both countries (USDA, 2016). However, this study finds that these cost shares (or production function coefficient estimates) are very different[48] (see Table 14, column 1). The labor cost share in Colombia is on average 7%, whereas in Brazil it is 42% (USDA, 2015). The Colombian capital cost share is 21.5%, while in Brazil it is 40.7%. The fertilizer cost share in Colombia is 30.2%, while in Brazil it is 10.8%; Colombian animal feed cost share is 41.3%, while in Brazil it is 6.5%. These differences are due to the fact that agriculture in these countries is very different. In Colombia, the cost share of intermediate inputs (i.e. fertilizers and animal feed) is higher than the cost share of primary inputs (i.e. labor and capital) (72% and 28% of the total costs, respectively). In contrast, the cost of primary inputs in Brazil constitutes almost all agricultural costs (83% of the total). Moreover, since the USDA uses an accounting technique for measuring Colombia's agricultural TFP, this might be biased due to omitting important regressors unrelated to productivity.

This study also estimates this model considering that technical change might have varied across periods established in Chapter 2 (see Table 14, column 2). To this end, six dummy variables were included for each period in the initial specification, as well as another six time-trend variables interacted with these dummy variables. The aim was to

[48] It is worth noting that estimated coefficients are marginal cost shares, not average cost shares. Also, these coefficients are not equal to marginal cost shares if the strong assumptions listed in detail in Chapter 4 do not hold. In that case, these coefficient estimates just correspond to the marginal change of output when any input changes.

examine the conclusion that agricultural productivity in Colombia did not grow during the period 1975-2013, by estimating a more appropriate specification in which technical change varies over time. Also, this approach might sweep out potential serial autocorrelation issues, by estimating a period specification which might break the correlation across residuals.

This revised model also shows an excellent fit. Its R^2 is 0.994, and its Root MSE is 0.025, which is slightly better than the initial model (see Table 14, column 2). Also, this model does not show serial autocorrelation, since its Durbin Watson statistic (DW) is 2.33. In addition, this model is estimated with no constant in order to include a dummy variable for all periods.

This specification is considered the most appropriate to analyze technical change by periods. This allows the pace of technical change to have varied over time, and it might have exhibited a different starting point in each period. However, this presents a problem for this study. Almost all time trend variables are not statistically significant, except for the technical change exhibited in the period 1975-1983, when it grew on average by 1% per year, and the technical change in the period 1998-2002, when it rose on average by 2.5% per year. This might suggest that this specification could have removed important information, because the inclusion of 12 dummy variables in a sample of only 39 observations might have captured correlated effects. Therefore, this study uses an alternative specification, in which it includes only six time-trend variables by period in the model. This corrects the problem explained above and does not affect seriously the model, since coefficients on dummy variables for each period exhibit a similar magnitude.

This alternative model shows an excellent fit. Its R^2 is 0.992, and its Root MSE is 0.025 (see Table 14, column 3). Also, this model does not show any econometric problems, and its Durbin Watson statistic (DW) is 2.15. Its results show that Colombia's agriculture as an aggregate exhibited continuous technical change during the period 1975-2013 (see Table 14, column 3). This varied between 0.5% and 0.9% per year. Also, agricultural productivity measured as TFP grew on average 0.6% per year over this period. Thereby, this contradicts our initial conclusion, which shows that Colombia's agricultural productivity had not grown over this period. However, this model exhibits a problem with estimating the input cost shares. It estimates that the cost share of labor is negative (-8.1%), although it is not statistically significant. This might suggest that Colombia's agriculture exhibited labor surplus during this period. Also, this might explain the significant differences regarding all inputs cost shares when these are estimated assuming constant technical change over time. This model estimates that the capital cost share is 75.2%, whereas this figure was only 21.5% assuming constant technical change; this model also estimates that the fertilizer cost share is only 20% while it was 30.2% assuming constant technical change; and this also estimates that the animal feed cost share is only 13% while it was 41.3% assuming constant technical change.

Table 14: Cobb-Douglas Production Function of Colombia's Agriculture

VARIABLES	(1) $\text{Log}(\text{Output}_t)$	(2) $\text{Log}(\text{Output}_t)$	(3) $\text{Log}(\text{Output}_t)$
$\text{Log}(\text{Labor}_t)$	0.0700	-0.189	-0.0811
	(0.109)	(0.213)	(0.144)
$\text{Log}(\text{Capital}_t)$	0.215*	0.918***	0.752***
	(0.117)	(0.265)	(0.193)
$\text{Log}(\text{Fertilizer}_t)$	0.302***	0.114	0.199***
	(0.0471)	(0.0835)	(0.0400)
$\text{Log}(\text{Animal Feed}_t)$	0.413***	0.158	0.130
	(0.0522)	(0.102)	(0.0829)
Technical Change	-0.00224		
	(0.00236)		
Technical Change − (1975 − 1983)		0.0104**	0.00691*
		(0.00496)	(0.00354)
Technical Change − (1984 − 1989)		0.00925	0.00457*
		(0.00881)	(0.00233)
Technical Change − (1990 − 1997)		-0.00108	0.00694***
		(0.00619)	(0.00228)
Technical Change − (1998 − 2002)		0.0246**	0.00749***
		(0.00885)	(0.00237)
Technical Change − (2003 − 2009)		0.00202	0.00861***
		(0.00804)	(0.00259)
Technical Change − (2010 − 2013)		0.00996	0.00499**
		(0.00931)	(0.00204)
Intercept Technical Change − (1975 − 1983)		-1.445	
		(2.789)	
Intercept Technical Change − (1984 − 1989)		-1.445	
		(2.750)	
Intercept Technical Change − (1990 − 1997)		-1.239	
		(2.768)	
Intercept Technical Change − (1998 − 2002)		-1.830	
		(2.855)	
Intercept Technical Change − (2003 − 2009)		-1.171	
		(2.596)	
Intercept Technical Change − (2010 − 2013)		-1.577	
		(2.601)	
Constant	6.316***		0.484
	(1.243)		(2.006)
Observations	39	39	39
Root MSE	0.034	0.025	0.025
R-squared[1]	0.984	0.994	0992

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

[1]R^2 is estimated as the square of the correlation between the actual value and the predicted value, because STATA software does not report R^2 for constraint regressions like these. This study estimates these regressions imposing a constraint to ensure that Colombia's agriculture exhibits constant returns to scale.

6.2.1.1.2 Crops

The model for crop production, assuming constant returns to scale, also shows a good fit. Its R^2 is 0.897 and its Root MSE is 0.066 (see Table 15, column 1). This model does not exhibit econometric problems either, since an initial serial autocorrelation problem among residuals was solved by including the crop output lagged one year as another regressor[49]. In addition, this model is also not robust. All coefficients change when technical change is calculated for specific periods (see Table 15, column 2 and column 3).

The results of this model indicate that crop production exhibited a negative rate of technical change (-0.8% per year) during the period 1976-2013[50], when it is assumed constant over time (see Table 15, column 1). Crop productivity measured as TFP decreased on average about -0.8% per year during this period. This result is consistent with the null growth exhibited by Colombia's agricultural TFP as an aggregate, when I assume constant technical change over time. In addition, primary inputs explain on average about 91% of costs in crop production (i.e. labor costs are 43.6% and capital costs are 47.3%); whereas intermediate inputs (i.e. fertilizer costs) determine the remaining 9%.

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[49] The initial DW Index was 0.46, which indicated positive serial autocorrelation among residuals. Once the dependent variable is lagged and included in the model, this problem is solved according to the alternative DW test. This study uses this test, since the Durbin h test (i.e. the most appropriate for cases with lagged variables) cannot be calculated due to a negative value within the square root of its formula. Thus, the alternative DW test allows testing for serial autocorrelation in these cases, by regressing the current residuals on the lagged residuals, lagged dependent variable, and all independent variables. Thereby, serial autocorrelation is tested by assessing the statistical significance of the lagged residuals coefficient.

[50] The results are reported for the period 1976-2013, since the model lost one observation in the estimation in order to included lagged output.

This fertilizer cost share estimate is somewhat low given recent evidence, although it is not statistically significant[51].

This study also estimates this model considering that technical change might have varied across periods (see Table 15, column 2). To this end, six dummy variables were also included for each period in the initial specification, as well as another six time-trend variables interacted with these dummy variables. The objective is to examine the conclusion that crop productivity decreased during the period 1976-2013, as well as to sweep out the serial autocorrelation of the model.

This revised model shows an excellent fit. Its R^2 is 0.982 and its Root MSE is 0.032, which is slightly better than the initial model (see Table 15, column 2). Also, this model does not show any econometric problems, and its Durbin Watson statistic (DW) is 2.07. In addition, it is estimated with no constant in order to include a dummy variable for all periods. However, this specification could have also removed important information due to the inclusion of 12 dummy variables into the model, as in the aggregate model. This might have affected the estimation of the model, since it yields some implausible results. For instance, technical change growth is close to 5% per year in the period 1998-2002. Historical evidence explains that Colombia's economy experienced a serious economic crisis in this period: armed conflict worsened, many people in rural areas left their farms due to the violence, and economic policy encouraged very little the creation of an attractive environment for productivity growth and private investment during this period

[51] On average, based on crop budget data, the cost share of fertilizer in total production costs varied between 10% and 30%, according to the product cultivated in 2008 (DNP, 2009).

(Alban, 2011; DNP, 2002; FAO, 2000; Kalmanovitz & López, 2003; Montero & Casas, 2012). Thus, this study also uses an alternative specification for crop production, including only the six time-trend variables by period in the model.

This alternative model also exhibits an excellent fit. Its R^2 is 0.969, and its Root MSE is 0.039 (see Table 15, column 3). This model does not exhibit any econometric problems, and its Durbin Watson statistic (DW) is 1.94. Its results indicate that crop production did not exhibit technical change during the period 1976-2013 at a 10% level of statistical significance (see Table 15, column 3). Technical change might have decreased in crop production on average by -0.6% with a probability of 80%, which is consistent with the negative technical change estimated by the model assuming constant technical change. In addition, this model estimates a different cost structure for crop production. It estimates that the capital cost share is 72.2%, whereas it was only 47.3% assuming constant technical change; it estimates that the labor cost share is 9.1% and not statistically significant at 10%, while it in fact was 43.6% assuming constant technical change; and it also estimates that fertilizer cost share is 18.6%, while it was 9.2% assuming constant technical change and not statistically significant.

Table 15: Cobb-Douglas Production Function of Colombia's Crops

VARIABLES	(1) $\text{Log}(\text{Output}_t)$	(2) $\text{Log}(\text{Output}_t)$	(3) $\text{Log}(\text{Output}_t)$
$\text{Log}(\text{Output}_{t-1})$	0.483*		
	(0.251)		
$\text{Log}(\text{Labor}_t)$	0.436***	-0.114	0.0915
	(0.141)	(0.146)	(0.176)
$\text{Log}(\text{Capital}_t)$	0.473***	0.890***	0.722***
	(0.144)	(0.174)	(0.160)
$\text{Log}(\text{Fertilizer}_t)$	0.0916	0.224***	0.186***
	(0.0885)	(0.0714)	(0.0443)
Technical Change	-0.00841*		
	(0.00441)		
Technical Change $-$ (1975 $-$ 1983)		0.00649	0.000981
		(0.00922)	(0.00706)
Technical Change $-$ (1984 $-$ 1989)		-0.00714	-0.00613
		(0.00731)	(0.00477)
Technical Change $-$ (1990 $-$ 1997)		0.00338	-0.00264
		(0.00450)	(0.00306)
Technical Change $-$ (1998 $-$ 2002)		0.0471***	-0.000816
		(0.0128)	(0.00299)
Technical Change $-$ (2003 $-$ 2009)		0.00566	0.00415
		(0.00383)	(0.00336)
Technical Change $-$ (2010 $-$ 2013)		0.0109	0.000196
		(0.0171)	(0.00299)
Intercept Technical Change $-$ (1975 $-$ 1983)		0.324	
		(1.695)	
Intercept Technical Change $-$ (1984 $-$ 1989)		0.388	
		(1.657)	
Intercept Technical Change $-$ (1990 $-$ 1997)		0.253	
		(1.600)	
Intercept Technical Change $-$ (1998 $-$ 2002)		-0.858	
		(1.858)	
Intercept Technical Change $-$ (2003 $-$ 2009)		0.376	
		(1.503)	
Intercept Technical Change $-$ (2010 $-$ 2013)		0.0255	
		(1.623)	
Constant	-6.759		1.819
	(5.819)		(1.474)
Observations	38	39	39
Root MSE	0.066	0.032	0.039
R-squared[1]	0.897	0.982	0.969

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

[1] R^2 is estimated as the square of the correlation between the actual value and the predicted value, because STATA software does not report R^2 for constraint regressions like these. This study estimates these regressions imposing a constraint to ensure that Colombia's crop production exhibits constant returns to scale.

6.2.1.1.3 Livestock

The model for livestock production, assuming constant returns to scale, also presents an excellent fit. Its R^2 is 0.977 and its Root MSE is 0.052 (see Table 16, column 1). This model does not show econometric problems, and livestock output lagged one year is included as another regressor in the model in order to solve an initial serial autocorrelation problem[52]. In addition, this model is not robust. Its coefficients change sharply when technical change is calculated for specific periods (see Table 16, column 2 and column 3).

The results of this model indicate that livestock production shows better results in terms of technical innovation in comparison to crop production during the period 1976-2013 (see Table 16, column 1). Livestock production exhibits a statistically significant technical change of 1.1% per year over this period. Therefore, livestock productivity measured as TFP grew on average by 1.1% per year during this period, versus the null growth exhibited by overall agricultural productivity. In addition, primary inputs explain on average about 83% of cost in livestock production (i.e. capital costs 63.7% and labor costs 19.2%), while intermediates inputs (i.e. animal feed costs) determined the remaining 17.1%[53]. Thus, livestock production was intensive in primary inputs in Colombia, mainly in capital.

[52] Initial DW was 0.94, which indicated positive serial autocorrelation among residuals. Once the dependent variables is lagged and included in the model, this problem is solved according to the alternative DW test. The lagged residuals coefficient in that test is not statistically significant. This study also experienced problems calculating the Durbin h in this case.

[53] This low cost share of animal feed in the total livestock production reaffirms the fact that Colombia's livestock production is land extensive (DANE, 2015). This means that pastures are used mainly to feed livestock rather than animal feed.

This study also estimates this model considering that technical change might have varied across periods. To this end, six dummy variables were also included for each period in the initial specification, as well as another six time-trend variables interacted with these dummy variables. The objective is to confirm that livestock productivity increases over the period 1976-2013 and to determine their variation across certain periods defined above. Also, it may sweep out the serial autocorrelation of the model.

This model exhibits an excellent fit. Its R^2 is 0.993 and its Root MSE is 0.034 (see Table 16, column 2). Also, this model does not show any econometric problems, and its Durbin Watson (DW) is 2.38. In addition, it estimated with no constant in order to include a dummy variable for all periods.

The results of this model confirm that livestock production exhibited technical change during the period 1975-2003, but it indicates that it was not continuous over time. Technical change grew on average by 1.2% per year during the late 1970's, by 3.5% per year after the Latin America debt crisis in the 1980's, by 1.8% per year in the late 1990's, and by 2% annually in more recent years. Therefore, these results seem somewhat larger versus the 1.1% technical change estimated when this is assumed constant over time.

This study also estimates an alternative specification for livestock production, because this model might have been affected by the inclusion of 12 dummy variables, similar to the aggregate model. This alternative model shows an excellent fit. Its R^2 is 0.991, and its Root MSE is 0.036 (see Table 16, column 3). Also, this model does not exhibit any econometric problems, and its Durbin Watson statistic (DW) is 1.64. Its results indicate that livestock production exhibited continuous technical change during the period 1976-2013 (see Table 16, column 3). This varies between 1.2% and 2% per year, rather than 1.1% per year, when it is estimated assuming constant technical change. Thereby, livestock productivity measured as TFP grew on average 1.6% per year over this period. However, this model also exhibits a problem estimating the input cost shares. It estimates that the cost share of labor is negative (-3.1%), although it is not statistically significant. This might suggest that livestock production exhibited labor surplus during this period. Also, this might indicate an incorrect estimation of all cost shares, which can explain the significant differences relative to cost shares estimated by assuming constant technical change over time. This model estimates that the cost share of capital is 92.7%, whereas it was 63.7% assuming constant technical change over time; and this estimates that the cost share of animal feed is 10.4% and not statistically significant, while it was 17.1% assuming constant technical change.

Table 16: Cobb-Douglas Production Function of Colombia's Livestock

VARIABLES	(1) $\text{Log}(\text{Output}_t)$	(2) $\text{Log}(\text{Output}_t)$	(3) $\text{Log}(\text{Output}_t)$
$\text{Log}(\text{Output}_{t-1})$	0.469**		
	(0.215)		
$\text{Log}(\text{Labor}_t)$	0.192*	0.0413	-0.0311
	(0.106)	(0.137)	(0.117)
$\text{Log}(\text{Capital}_t)$	0.637***	0.771***	0.927***
	(0.163)	(0.156)	(0.168)
$\text{Log}(\text{Animal Feed}_t)$	0.171	0.188	0.104
	(0.113)	(0.146)	(0.153)
Technical Change	0.0112*		
	(0.00584)		
Technical Change $-$ (1975 $-$ 1983)		0.0124*	0.0119**
		(0.00619)	(0.00565)
Technical Change $-$ (1984 $-$ 1989)		0.0346***	0.0169***
		(0.00947)	(0.00361)
Technical Change $-$ (1990 $-$ 1997)		0.00900	0.0195***
		(0.00791)	(0.00552)
Technical Change $-$ (1998 $-$ 2002)		0.0177*	0.0201***
		(0.00957)	(0.00524)
Technical Change $-$ (2003 $-$ 2009)		0.0200	0.0195***
		(0.0162)	(0.00601)
Technical Change $-$ (2010 $-$ 2013)		0.0204**	0.0155**
		(0.00931)	(0.00564)
Intercept Technical Change $-$ (1975 $-$ 1983)		-1.009	
		(1.628)	
Intercept Technical Change $-$ (1984 $-$ 1989)		-1.216	
		(1.619)	
Intercept Technical Change $-$ (1990 $-$ 1997)		-0.789	
		(1.662)	
Intercept Technical Change $-$ (1998 $-$ 2002)		-0.938	
		(1.606)	
Intercept Technical Change $-$ (2003 $-$ 2009)		-1.017	
		(1.649)	
Intercept Technical Change $-$ (2010 $-$ 2013)		-1.165	
		(1.512)	
Constant	-9.726*		-2.639
	(5.502)		(1.747)
Observations	38	39	39
Root MSE	0.052	0.034	0.036
R-squared[1]	0.977	0.993	0.991

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

[1]R^2 is estimated as the square of the correlation between the actual value and the predicted value, because STATA software does not report R^2 for constraint regressions like these. This study estimates these regressions imposing a constraint to ensure that Colombia's livestock production exhibits constant returns to scale.

6.2.1.2 CES Production Function

6.2.1.2.1 Total Agriculture

The model based on assuming a CES production function with Hicks neutral technical change for Colombia's agriculture shows an excellent fit for the output equation, but a very poor fit for input inverse demands, with the exception of the capital inverse demand. The R^2 for the output equation is 0.95, and for capital inverse demand, it is 0.98. However, the R^2 is just 0.02 for labor inverse demand, 0.09 for fertilizer inverse demand, and 0.06 for animal feed inverse demand (see Table 17). This model also does not exhibit heteroscedasticity, but it does present serial autocorrelation across the residuals[54]. I 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, I 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. This model continued exhibiting serial autocorrelation. This study then employed the Cochrane-Orcutt procedure, which fixed the problem but severely impacted the model's estimation results. STATA software failed to estimate all elasticities of substitution, probably due to collinearity across variables. Therefore, this study reports the model without fixing serial autocorrelation, since: i) the technical change coefficient,

[54] The DW index is 1.39 for capital inverse demand, 0.70 for labor inverse demand, 0.88 for fertilizer inverse demand, 0.66 for animal feed inverse demand, and 0.41 for the output function. This indicated positive serial autocorrelation among residuals of each equation.

which is the most important result from this model, is robust, changing only marginally when the serial autocorrelation is corrected; and ii) STATA is able to estimate all elasticities of substitution without any problem.

The results of this model indicate that Colombia's agriculture exhibited technical change of almost 1.3% per year during 1976-2013 [55] (see Table 17). Agricultural productivity measured as TFP grew on average 1.3% per year over this period. This result contradicts the null growth estimated by assuming a Cobb-Douglas production function and constant technical change, and it is twice the productivity growth calculated by assuming a Cobb-Douglas production function but estimating a time-varying specification for technical change (0.6% per year). However, this result is close to the average Colombia's agricultural productivity estimated by the USDA (1.4% per year) (USDA, 2015).

This model also shows that Colombia's agriculture varies its usage between primary and intermediate inputs due to changes in prices. The overall elasticity of substitution between nests (σ) is 1.3. Also, Colombia's agriculture used apparently fixed proportions of capital and labor during this period, since the elasticity of substitution between primary inputs (η) is not statistically significant at 10%. However, this elasticity of substitution between capital and labor (η) is 2.8 and is statistically significant at 30% (see Table 17)[56]. In addition, fertilizer and animal feed usage were very sensitive to prices, since the elasticity of substitution between them (ζ) is 1.9 and statistically significant at 1%. Since

[55] The results are reported for the period 1976-2013, since the model lost one observation in the estimation.

[56] This elasticity of substitution may have been estimated imprecisely due to the serial autocorrelation issue, because it seems very large.

these intermediate inputs are generally used by different agricultural activities (i.e. fertilizers in crops and animal feed in livestock), this reaffirms the importance of disaggregating the measurement of agricultural productivity into crops and livestock, as is done in the next section.

Table 17: CES Production Function of Colombia's Agriculture Assuming Hicks Neutral Technical Change

VARIABLES	(1) Technical Change	(2) σ [1]	(3) η [2]	(4) ζ [3]
	0.0128***	1.259***	2.834	1.916***
	(0.000679)	(0.0795)	(2.661)	(0.609)
Observations	38	38	38	38

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Equations	Obs	Parms	R^{2*}
$\text{Log}(\text{Capital}_t)$	38	3	0.978
$\text{Log}(\text{Labor}_t)$	38	3	0.022
$\text{Log}(\text{Fertilizer}_t)$	38	3	0.091
$\text{Log}(\text{Animal Feed}_t)$	38	3	0.064
$\text{Log}(\text{Output}_t)$	38	4	0.954

$^*R^2$ is estimated as the square of the correlation between the actual value and the predicted value, because STATA software reports a wrong index for each equation. The reason is the form this software calculates the R-square index for NLSUR models.
[1] is the overall elasticity of substitution between nests.
[2] is the elasticity of substitution between primary inputs (i.e. capital and labor).
[3] is the elasticity of substitution between intermediate inputs (i.e. fertilizer and animal feed).

In order to test for the possible presence of biased technical change, this study relaxes the assumption that Colombia's agriculture exhibits Hicks-neutral technical change. This also yields a model with an excellent fit for Colombia's agricultural production and capital inverse demand, but a very poor for the other input inverse demands (see Table 18). The R^2 for the output equation and for capital inverse demand are still 0.96 and 0.98, respectively; whereas for labor inverse demand the R^2 increases slightly to 0.03, for fertilizer inverse demand it rises to 0.17, and for animal feed demand it falls to 0.02. Also, this model does not exhibit heteroscedasticity, but it presents serial autocorrelation across the residuals as in the previous model[57]. I followed the same procedure to fix it, which was also ineffective. I again tried the Cochrane-Orcutt procedure, which fixed the problem, but it severely impacted all model coefficient estimates. STATA software failed to estimate all elasticities of substitution, probably due to collinearity across variables. It yields implausible estimates for technical change. Therefore, this study reports the model without fixing serial autocorrelation, since: i) the technical change coefficients, which are the most important results from this model, are robust, changing only marginally when the serial autocorrelation is corrected; and ii) STATA is able to estimate all elasticities of substitution without experiencing any estimation problem.

The results of this model indicate that Colombia's agriculture exhibited biased technical change during the period 1976-2013. This was capital-augmenting relative to all inputs, since technical change exhibited by capital grew on average by 4.1% per year over this period. Technical change exhibited by the others inputs is not statistically significant (see Table 18). Also, these results show that Colombia's agricultural production tended to behave similarly to a Cobb-Douglas production function, since the overall elasticity of

[57] The DW index is 1.49 for capital inverse demand, 0.89 for labor inverse demand, 0.97 for fertilizer inverse demand, 0.70 for animal feed inverse demand, and 0.43 for output function. This indicated positive serial autocorrelation among residuals of each equation.

substitution (σ) is 0.94, the one between primary inputs (η) is 0.88, and the one between intermediate inputs is (ζ) is 0.97. Therefore, this reaffirms that Colombia's agriculture varies their input usage with changes in prices. Also, Colombia's agriculture exhibited biased technical change, which was capital-augmenting.

Table 18: CES Production Function of Colombia's Agriculture Assuming Biased Technical Change

VARIABLES	(1) Technical Change Capital	(2) Technical Change Labor	(3) Technical Change Fertilizer	(4) Technical Change Animal Feed	(5) σ [1]	(6) η [2]	(7) ζ [3]
	0.0408*	-0.0264	0.170	-0.252	0.942***	0.882***	0.969***
	(0.0247)	(0.143)	(1.147)	(0.241)	(0.0773)	(0.241)	(0.0926)
Observations	38	38	38	38	38	38	38

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Equations	Obs	Parms	R^{2*}
$\text{Log}(\text{Capital}_t)$	38	4	0.976
$\text{Log}(\text{Labor}_t)$	38	4	0.027
$\text{Log}(\text{Fertilizer}_t)$	38	4	0.169
$\text{Log}(\text{Animal Feed}_t)$	38	4	0.018
$\text{Log}(\text{Output}_t)$	38	7	0.963

*R^2 is estimated as the square of the correlation between the actual value and the predicted value, because STATA software reports a wrong index for each equation. The reason is the form this software calculates the R-square index for NLSUR models.

[1] is the overall elasticity of substitution between nests.

[2] is the elasticity of substitution between primary inputs (i.e. capital and labor).

[3] is the elasticity of substitution between intermediate inputs (i.e. fertilizer and animal feed).

In order to obtain more robust results, this study estimates crop and livestock productivity separately, as with the Cobb-Douglas case.

6.2.1.2.2 Crops

The model for crop production, assuming a CES production function, also begins by considering that crop production shows Hicks-neutral technical change, and also relaxes this assumption in the second part of this section to determine the possible presence of biased technical change. This model assumes that crop production is mainly explained by inputs, such as capital, labor, and fertilizer. In addition, this was estimated under two specifications: i) primary inputs (i.e. capital and labor) in the only nest of this function, and fertilizer as the extra input; and ii) capital-related inputs (i.e. capital and fertilizer) in the nest, and labor as the extra input. The second specification exhibited a better fit. Accordingly, this study only reports the results of that model.

This model shows an excellent fit for the crop production equation, but a very poor fit for input inverse demands (see Table 19). The R^2 for the output equation is 0.92, for capital inverse demand it is 0.60, for labor inverse demand it is 0.01, and for fertilizer inverse demand is 0.05. This model also exhibits serial autocorrelation across the residuals as in the aggregate agriculture model[58]. I followed the same strategy to address this as with the aggregate model, but it was ineffective. For instance, STATA software failed to estimate all parameters when I considered a specification on which technical change might have varied over time, and the serial autocorrelation was not swept out like is in Cobb-Douglas case. This was only possible by using the Cochrane-Orcutt procedure, which also severely impacted the estimation of coefficients in the model. Therefore, this

[58] The DW index is 0.81 for capital inverse demand, 0.57 for labor inverse demand, 0.74 for fertilizer inverse demand, and 0.66 for output function. This indicated positive serial autocorrelation among residuals of each equation.

study again reports the model without fixing the serial autocorrelation, because in this case: i) the technical change coefficient, which is the most important result from this model, is robust, changing only marginally when the serial autocorrelation is corrected; and ii) STATA software is able to estimate all elasticities of substitution without experiencing any estimation problem.

The results of this model indicate that crop production in Colombia exhibited technical change of 0.8% per year during 1976-2013 (see Table 19). Crop productivity measured as TFP grew on average by 0.8% over this period. Therefore, crop productivity largely explains the low technical change exhibited by Colombia’s agriculture as an aggregate during this period.

This model also shows that crop production sharply adjusted its usage among inputs due to changes in prices. The overall elasticity of substitution (σ) is 1.7 (see Table 19). However, this is less between capital and fertilizer, since the elasticity of substitution between these inputs (η) is 1.1. Therefore, input usage in Colombian crop production was sensitive to change in prices during the period 1976-2013.

Table 19: CES Production Function of Crop Production Assuming Hicks Neutral Technical Change

VARIABLES	(1) Technical Change	(2) σ [1]	(3) η [2]
	0.00808***	1.718***	1.126***
	(0.00298)	(0.319)	(0.101)
Observations	38	38	38

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

	Obs	Parms	$^*R^2$
$\text{Log}(\text{Capital}_t)$	38	3	0.598
$\text{Log}(\text{Labor}_t)$	38	2	0.008
$\text{Log}(\text{Fertilizer}_t)$	38	3	0.045
$\text{Log}(\text{Output}_t)$	38	3	0.923

$^*R^2$ is estimated as the square of the correlation between the actual value and the predicted value, because STATA software reports a wrong index for each equation. The reason is the form this software calculates the R-square index for NLSUR models.
[1] is the overall elasticity of substitution between inputs in the nest (i.e. capital and fertilizer) and labor.
[2] is the elasticity of substitution between inputs in the nest.

This study also relaxes the assumption of Hicks neutrality in technical change for crop production. This yields a model with better fit, although it is still poor for input inverse demands (see Table 21). The R^2 for the output equation decreases to 0.88, for capital inverse demand it increases to 0.79, for labor inverse demand it stays around 0.01, and for fertilizer inverse demand it rises to 0.32. This model also exhibits serial autocorrelation across the residuals as in the case of the aggregate agriculture model[59]. I followed the same strategy to fix it as with the aggregate model, but it was ineffective. Then I used the Cochrane-Orcutt procedure, which fixed the problem, but also severely

[59] The DW index is 1.04 for capital inverse demand, 0.75 for labor inverse demand, 0.84 for fertilizer inverse demand, and 0.43 for output function. This indicated positive serial autocorrelation among residuals of each equation.

impacted the model's estimation. Therefore, this study reports the model without fixing the serial autocorrelation.

The results of this model reaffirm that crop production experienced technical change during the period 1976-2013. This was capital-augmenting relative to all inputs, since technical change exhibited by capital grew on average by 3.9% per year, whereas technical change exhibited by labor decreased at an average rate of 4.2% per year and technical change exhibited by fertilizers is not statistically significant (see Table 21). This study tests statistically the difference among the technical change coefficients found for each input to confirm this conclusion, by using a Chi-Square test for testing this hypothesis. The results show that there is a statistically significant difference between technical change exhibited by capital and labor (see Table 20). Also, these indicate there is not a statistically difference between technical change coefficients found for capital and fertilizer; however, there is a statistically significant difference between technical change coefficients exhibited by fertilizer and labor. Therefore, this reaffirms that crop production exhibited biased technical change during the period 1976-2013, and this technical change was capital-augmenting. Also, this decreasing labor productivity might reaffirm that Colombia's agriculture exhibited a surplus of labor as indicate the results in the Cobb-Douglas case.

Table 20: Test of Differences among Technical Change Estimates Exhibited by Inputs in Crop Production

	Capital	Labor	Fertilizers
Capital			
Labor	12.23 0.0005***		
Fertilizers	0.29 0.5894	4.05 0.0442**	

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

This model also shows that crop production tended to behave similarly to a Cobb-Douglas production function. The overall elasticity of substitution (σ) is 0.79, and the elasticity of substitution between capital and fertilizer (η) is 0.85 (see Table 21).

Table 21: CES Production Function of Crops Production Assuming Biased Technical Change

VARIABLES	(1) Technical Change Capital	(2) Technical Change Labor	(3) Technical Change Fertilizer	(4) σ [1]	(5) η [2]
	0.0387***	-0.0417***	0.0677	0.792***	0.847***
	(0.0146)	(0.0104)	(0.0497)	(0.0635)	(0.0589)
Observations	38	38	38	38	38

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

	Obs	Parms	$^*R^2$
$\text{Log}(\text{Capital}_t)$	38	4	0.787
$\text{Log}(\text{Labor}_t)$	38	2	0.011
$\text{Log}(\text{Fertilizer}_t)$	38	4	0.324
$\text{Log}(\text{Output}_t)$	38	5	0.875

$^*R^2$ is estimated as the square of the correlation between the actual value and the predicted value, because STATA software reports a wrong index for each equation. The reason is the form this software calculates the R-square index for NLSUR models.
[1] is the overall elasticity of substitution between inputs in the nest (i.e. capital and fertilizer) and labor.
[2] is the elasticity of substitution between inputs in the nest.

6.2.1.2.3 Livestock

The model for livestock production, assuming a CES production function, also initially considers that livestock production exhibits Hicks-neutral technical change, and also relaxes this assumption in the second part of this section. This model assumes that livestock production mainly depends on capital, labor, and animal feed. It was also estimated under two specifications: i) primary inputs (i.e. capital and labor) in the only nest of this function, and animal feed as the extra input; and ii) capital-related inputs (i.e. capital and animal feed) in the nest and labor as the extra input. The second specification exhibited a better fit. Therefore, this study only reports the results of that second model.

This model shows good fit (see Table 22). The R^2 for the output equation is 0.98, for capital inverse demand it is 0.97, and for labor inverse demand it is 0.63. This fit is poor for animal feed inverse demand, which exhibits an R^2 of 0.19. This model also exhibited the same problem of serial autocorrelation experienced by the model estimated for aggregate agriculture and for crops. However, it was possible to fix it using the Cochrane-Orcutt procedure without affecting the coefficients estimation. Therefore, this study reports the model with the serial autocorrelation problem corrected in this case[60].

[60] The initial DW was 1.44 for capital inverse demand, 0.89 for labor inverse demand, 0.85 for animal feed inverse demand, and 0.56 for output function. This indicated a positive serial autocorrelation problem among residuals of each equation. Since the DW index cannot be used in a model when lagged variables are included, as in this case due to the Cochrane-Orcutt procedure, this study uses a more general test, the Breusch-Godfrey Test (BG-Test), to confirm that the serial autocorrelation was removed. Its null hypothesis established that there is no evidence of serial autocorrelation, whereas its alternative hypothesis indicates that there is. This study estimates the BG-Test for each equation once the Cochane-Orcutt procedure was applied, and in all cases there was no evidence of serial autocorrelation. These are the p-values of the BG-Test for each equation: 0.75 for the capital inverse demand equation, 0.34 for the labor inverse demand equation, 0.54 for the animal feed inverse demand equation, and 0.36 for the output equation.

The results of this model indicate that livestock production exhibited technical change of 2.2% per year during 1978-2013[61] (see Table 22). Livestock productivity measured as TFP grew on average by 2.2% over this period. Therefore, livestock productivity was the stronger driver of agricultural productivity in Colombia, since crop productivity only grew on average by 0.8% per year in recent decades, as found in the previous section.

The overall elasticity of substitution (σ) is 3.9 (see Table 22). Also, the elasticity of substitution between capital and animal feed (η) is also 3.9, which implies that livestock farmers in Colombia strongly substituted pastures for animal feed based on price variations. Therefore, input usage in livestock production was very sensitive to change in prices.

[61] The results are reported for the period 1978-2013, since the model lost 3 observations in estimation, mainly due to the serial autocorrelation correction.

Table 22: CES Production Function of Livestock Production Assuming Hicks Neutral Technical Change

VARIABLES	(1) Technical Change	(2) σ [1]	(3) η [2]
	0.0223***	3.906***	3.860***
	(0.00123)	(0.729)	(0.820)
Observations	36	36	36

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

VARIABLES	(4) $\rho 1$ [3]	(5) $\rho 2$ [3]	(6) $\rho 3$ [3]	(7) $\rho 4$ [3]
	0.000729	0.467***	0.805***	0.362***
	(0.00973)	(0.0379)	(0.0299)	(0.0575)
Observations	36	36	36	36

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

	Obs	Parms	$^*R^2$
$\text{Log}(\text{Capital}_t)$	36	4	0.972
$\text{Log}(\text{Labor}_t)$	36	3	0.625
$\text{Log}(\text{Animal Feed}_t)$	36	4	0.186
$\text{Log}(\text{Output}_t)$	36	4	0.976

$^*R^2$ is estimated as the square of the correlation between the actual value and the predicted value, because STATA software reports a wrong index for each equation. The reason is the form this software calculates the R-square index for NLSUR models.
[1] is the overall elasticity of substitution between inputs in the nest (i.e. capital and animal feed) and labor.
[2] is the elasticity of substitution between inputs in the nest.
[3] each ρ corresponds to the specific first order autocorrelations coefficients.

Once this study relaxes the assumption of Hicks neutrality in technical change for livestock production, it estimates a model with a somewhat worse fit than the initial model. The R^2 for the output equation and capital inverse demand are still 0.98, but for labor inverse demand it decreases to 0.56, and for animal feed inverse demand it falls to 0.04 (see Table 24). This model does not show serial autocorrelation across the residuals, since an initial problem was solved by using the Cochrane-Orcutt procedure without affecting the estimated coefficients. Therefore, this study reports this model with the serial autocorrelation problem corrected[62].

The results of this model indicate that livestock production in Colombia exhibited biased technical change during the period 1978-2013. This is animal feed-augmenting relative to labor and capital, since technical change exhibited by animal feed grew on average by 5.8% per year over this period, technical change of labor increased on average by 3.3% per year, and technical change of capital rose on average by 1.8% per year. This study tests statistically the difference among these technical change coefficients estimated for each input using also a Chi-Square test. The results reaffirm this conclusion, showing that there is a statistically significant difference between the technical change exhibited by animal feed relative to technical change exhibited by capital and labor. Also, it shows that there is no statistically significant difference between the technical change exhibited by capital and labor (see Table 23). Therefore, this reaffirms that livestock production exhibited biased technical change during the period 1978-2013, and this was animal-feed augmenting.

[62] The initial DW was 1.68 for capital inverse demand, 1.07 for labor inverse demand, 0.75 for animal feed inverse demand, and 0.55 for output function. Since the DW index cannot be used in a model when there are lagged variables included, as in this case due to the Cochrane-Orcutt procedure, this study uses the BG-Test. This indicates that there is no evidence of serial autocorrelation in any equations. These are the p-values of the BG-Test for each equation: 0.43 for the capital inverse demand equation, 0.29 for the labor inverse demand equation, 0.68 for the animal feed inverse demand equation, and 0.39 for the output equation.

Table 23: Test of Differences among Technical Change Estimates Exhibited by Inputs in Livestock Production

	Capital	Labor	Animal Feed
Capital			
Labor	1.88		
	0.1708		
Animal Feed	8.25	4.52	
	0.0041***	0.0336**	

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

The overall elasticity of substitution (σ) is 2.2 (see Table 24). Also, the elasticity of substitution between capital and animal feed (η) is also 2.1, which confirms that livestock farmers in Colombia strongly substituted pastures for animal feed in response to price changes.

Table 24: CES Production Function of Livestock Production Assuming Biased Technical Change

VARIABLES	(1) Technical Change Capital	(2) Technical Change Labor	(3) Technical Change Animal Feed	(4) σ [1]	(5) η [2]
	0.0181***	0.0327***	0.0585***	2.253***	2.128***
	(0.00215)	(0.00970)	(0.0126)	(0.344)	(0.327)
Observations	36	36	36	36	36

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

VARIABLES	(6) $\rho 1$ [3]	(7) $\rho 2$ [3]	(8) $\rho 3$ [3]	(9) $\rho 4$ [3]
	-0.00761	0.426***	0.727***	0.507***
	(0.00896)	(0.0372)	(0.0331)	(0.0747)
Observations	36	36	36	36

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

	Obs	Parms	$^*R^2$
$\text{Log}(\text{Capital}_t)$	36	5	0.971
$\text{Log}(\text{Labor}_t)$	36	3	0.558
$\text{Log}(\text{Animal Feed}_t)$	36	5	0.043
$\text{Log}(\text{Output}_t)$	36	6	0.979

$^*R^2$ is estimated as the square of the correlation between the actual value and the predicted value, because STATA software reports a wrong index for each equation. The reason is the form this software calculates the R-square index for NLSUR models.

[1] is the overall elasticity of substitution between inputs in the nest (i.e. capital and animal feed) and labor.

[2] is the elasticity of substitution between inputs in the nest.

[3] each ρ corresponds to the specific first order autocorrelation coefficients.

6.2.2 Dual Techniques

6.2.2.1 Cost function – Trans-Log

6.2.2.1.1 Total Agriculture

The dual cost model for Colombia's agriculture as an aggregate, estimated assuming linear homogeneity in prices and symmetry among parameters, exhibits an excellent fit in all equations (see Table 26). The R^2 exhibited by all equations are in the range 0.80-0.99. This model does not present heteroscedasticity, because it is estimated assuming robust errors. Also, an initial serial autocorrelation problem was corrected using a version of the Cochrane-Orcutt procedure for a system of equations with invariant parameters (E. R. Berndt & Savin, 1975)[63]. In addition, this model initially predicted positive price elasticities for certain inputs. This was corrected by imposing curvature restrictions at the point of the approximation of this cost function[64] (Diewert & Wales, 1987; Ryan & Wales, 2000)[65]. However, this model exhibits multicollinearity problems, since: i) it is very demanding to estimate 16 parameters at a time only using 38 observations[66]; ii) crucial variables such as the value of production and the time trend exhibit correlation of approximately 98%, and iii) all variables were included lagged one period to solve the

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[63] This method basically assumes that the correlation term included in the Cochrane Orcutt procedure (ρ) is the same across equations, maintaining all such parameters invariant.

[64] It refers to the year in which input prices and output are equal to one once normalized. In this study, this year is 1995, the mid-point of the sample.

[65] This required imposing the following constraints: $\beta_{ii} = \alpha_i - \alpha_i^2$, and $\beta_{ij} = -\alpha_i\alpha_j$.

[66] The model estimates 29 parameters in total but only 16 at a time, because the cost share variables sum to one, and the residuals across equations add to zero. This means that the estimation of the complete system of equations at once will result in a singular error covariance matrix. Therefore, one should omit one equation of the system for its estimation, and the parameters of that equation are calculated based on the restrictions imposed on this system of equations. The methodology chapter explains this in detail.

serial autocorrelation problem. Accordingly, all standard errors are large and may be overestimated. In any case, this study uses all these parameters for estimating Colombia' agricultural productivity, since multicollinearity does not affect the statistical properties of parameters. This problem primarily yields large standard errors, which might incorrectly determine that a parameter is not statistically different from zero.

This study calculates the own price elasticities for all inputs in order to evaluate the estimated cost function. All elasticities in the constrained model are negative (as they must be), showing that this cost function is well behaved (see Table 25). Also, capital is the least sensitive input to changes in prices, whereas fertilizer is the most sensitive. However, it is important to emphasize that these elasticities are highly sensitive to the variability in the cost share of each input. Accordingly, this study estimates these elasticities using the mean of the cost share of each input.

Table 25: Price Elasticities of Input Demand on the Cost Function for Overall Agriculture

	ε_{kk}	ε_{ll}	ε_{ff}	ε_{ss}
Without Imposing Curvature Restrictions	0.0124	-0.1435***	-0.3507***	-0.2457***
	(0.00954)	(0.05121)	(0.0684)	(0.1014)
Imposing Curvature Restrictions	-0.0409***	-0.1428***	-0.8840***	-0.2136***
	(0.00991)	(0.01887)	(0.06202)	(0.04964)

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The results of this model indicate that agricultural productivity in Colombia, measured as TFP, grew on average by 1.4% per year during 1975-2013. These results coincide with the estimates by assuming a CES production function (+1.3%), and with the USDA estimates (+1.4%) (USDA, 2015). In particular, this growth was due to large scale effects rather than by a large reduction in production cost due to technical change. The scale effects contributed to this TFP estimation with an average growth of 2.4% per year. However, the overall technical change component (i.e. pure technical change, scale production technical change, and biased technical change) subtracted 1% per year from this TFP, mainly due to a decrease exhibited by pure technical change (-1%).

This model also shows that Colombia's agriculture exhibited slightly biased technical change in recent decades. This was labor-saving and fertilizer-saving, relative to capital and animal feed, since the cost shares of both inputs decreased by 0.01% per year due to technical change. Also, this was capital-using and animal feed using, since their cost shares increased by 0.01% annually due to technical change (see Table 26, column 25 to column 28). Therefore, technical change in Colombia's agriculture tended to improve slightly more the marginal productivity of labor and fertilizers relative to productivity exhibited by the other inputs.

This study was unable to test statistically the difference between technical change coefficients exhibited across all inputs since the standard errors of all parameters are large, as explained above. Also, it was not possible to test the homotheticity of the dual production function related to this cost function due to this problem. Accordingly, I assumed that this production function is homothetic to estimate the technical change exhibited by all inputs. However, those estimates should be corrected by a scale effect in the case that this production function was not homothetic as explained in Chapter 4. This implies larger technical change exhibited by all agricultural inputs. Colombia's agriculture continued being considered fertilizer-saving and will become animal-feed saving, since their cost shares decreased on average by 2.4% and 3.4% per year, respectively, due to technical change. Also, Colombia's agriculture was capital and labor using, since their cost shares increased on average by 0.3%, and 0.7% per year, respectively.

This model also estimates that, at the point of approximation of this cost function, the cost share of capital is almost 80%, the cost share of labor is 12.8%, the cost share of fertilizer cost is 1.6%, and the cost share of animal feed is 5.9% (see Table 26, column 2 to column 5). This also predicts that the cost share of capital will increase by 1.6%, the cost share of labor will rise by 1.1%, the cost share of fertilizer will expand by 0.2%, and the cost share of animal feed will increase by 0.6%, if their own prices increase by 10% (see Table 26, column 7, column 11, column 14, and column 16). Moreover, this model estimates that the cost share of capital is mainly sensitive to variations in the price of labor, decreasing on average by 1.0% if the price of labor increases by 10% (see Table 26, column 8 to column 10). Also, the cost share of labor will also decrease by 1.0% if the price of capital increases by 10%. In addition, the cost share of fertilizer and the cost share of animal feed will vary marginally due to changes in the prices of other inputs. Finally, this model estimates that the cost share of capital will decrease by 0.5% and the cost share of labor will diminished by 0.3% if Colombia's agricultural production increases by 10% (see Table 26, column 17 to column 20). In, contrast, the cost share of fertilizer will increase by 0.1%, and the cost share of animal feed by 0.7% if this occurs.

Table 26: Trans-Log Cost Function of Colombia's Agriculture (1975-2013)

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	α_0	α_k	α_l	α_f	α_s	ρ [1]
	23.88***	0.798***	0.128***	0.0156***	0.0589***	0.666***
	(0.0109)	(0.00699)	(0.00295)	(0.00126)	(0.00386)	(0.0622)

Elasticities: Price to Input Shares [2]

	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
VARIABLES	β_{kk}	β_{kl}	β_{kf}	β_{ks}	β_{ll}	β_{lf}	β_{ls}	β_{ff}	β_{fs}	β_{ss}
	0.1612***	-0.1021***	-0.0124***	-0.0470***	0.1116***	-0.0020***	-0.0075***	0.01536***	-0.0009***	0.05543***
	(0.00734)	(0.00252)	(0.00101)	(0.00311)	(0.00302)	(0.00017)	(0.00052)	(0.00126)	(0.00001)	(0.00388)

Elasticities: Output to Total Cost & Input Shares

	(17)	(18)	(19)	(20)	(21)	(22)
VARIABLES	β_{kQ}	β_{lQ}	β_{fQ}	β_{sQ}	α_Q	α_{QQ}
	-0.0493	-0.0291	0.0122	0.0662*	-0.210	-1.962
	(0.0634)	(0.0323)	(0.0135)	(0.0343)	(0.184)	(2.385)

Elasticities: Technical Change to Total Cost & Input Shares

	(23)	(24)	(25)	(26)	(27)	(28)	(29)
VARIABLES	α_t	α_{tt}	β_{kt}	β_{lt}	β_{ft}	β_{st}	β_{Qt}
	0.0110***	0.000241	0.000102	-0.000112	-0.0001	0.0001	0.0237
	(0.00414)	(0.00122)	(0.00129)	(0.000684)	(0.000268)	(0.000760)	(0.0535)

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Equation	Obs	Parms	R^{2*}
Log(Total Cost(t))	38	16	0.997
Cost Share of Capital (t)	38	6	0.951
Cost Share of Labor (t)	38	6	0.966
Cost Share of Fertilizer(t)	38	6	0.793
Cost Share of Animal Feed(t)	38	6	0.920

*R^2 is estimated as the square of the correlation between the actual value and the predicted value, because STATA software reports a wrong index for each equation. The reason is the form this software calculates the R-square index for NLSUR models.

[1] corresponds to the specific first-order autocorrelation coefficient.

[2] these coefficients were calculated based on the restrictions required for imposing curvature on a trans-log cost function.

6.2.2.1.2 Crops

The dual cost model for crop production shows an excellent fit in all equations (see Table 28). The R^2 exhibited by all equations range from 0.93-0.99. This model does not present econometric problems. Also, this model was estimated by imposing curvature restrictions at the point of approximation to ensure that it is concave in inputs prices, and thereby all input price elasticities are negative (Diewert & Wales, 1987; Ryan & Wales, 2000). However, this model predicted implausible figures for crop productivity. It yields that crop productivity had grown on average by 9.2% per year during the period 1975-2013. Therefore, this study reports the model without imposing these restrictions, because that model yields more plausible results, and all input price elasticities are negative. However, this model also exhibits multicollinearity problems, which means that all standard errors are large and may be overestimated. In any case, this study uses all these parameters to estimate crop productivity, since multicollinearity does not affect their statistical properties, as explained above.

As in the aggregate case, this study also calculates the own price elasticities for all input demands used in crop production to evaluate the cost function estimated. These are negative for all inputs (as they must be), regardless if curvature restrictions are imposed on the cost function (see Table 27). Therefore, these elasticities indicate that this cost function is well behaved. In addition, these elasticities show that capital is the least sensitive input to changes in prices, whereas labor is the most sensitive input without imposing the curvature restriction, and fertilizer is the most sensitive when that restriction is imposed. In this case, it is also important to mention that these elasticities are also highly sensitive to the variability in the cost share of each input.

Table 27: Price Elasticities of Input Demand on the Cost Function for Crops Production

	ε_{kk}	ε_{ll}	ε_{ff}
Without Imposing Curvature Restrictions	-0.0289***	-0.1663***	-0.1074
	(0.00777)	(0.03053)	(0.09521)
Imposing Curvature Restrictions	-0.021	-0.0823**	-0.7273***
	(0.02690)	(0.04387)	(0.12288)

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The results of this model indicate that crop productivity, measured as TFP, exhibited marginal growth (+0.1% per year) during the period 1975-2013. These results reaffirm the TFP estimated by the Cobb-Douglas function for crops, which indicates that crop productivity did not grow over this period. However, this contradicts the TFP estimated by assuming a CES production function for crops, which indicates that crop productivity increased on average by 0.8% per year. A large scale effect was crucial in this growth rather than a strong reduction in the costs of production due to technical change**.** This scale effect contributed to expanding crop TFP with an average growth of 1.9% per year, whereas the overall technical change component subtracted 1.8% per year from this TFP, due again to a decrease exhibited by the pure technical change term (-1.5% per year) over this period.

This model also shows that crop production exhibited biased technical change in recent decades. This was capital-saving relative to all inputs, since the cost share of capital decreased by 0.5% per year due to technical change. Also, this was labor-using and fertilizer-using, since the cost share of labor increased on average by 0.4% per year due to technical change and the one of fertilizer rose on average by 0.1% per year for this reason (see Table 28, column 19 to column 21). Therefore, technical change in crop production improved more the marginal productivity of capital than the productivity exhibited by labor and fertilizer. Hence, technical change in crop production tended to be biased toward capital relative to labor and fertilizer.

This study also assumed that the dual production function related to this cost function is homothetic to estimate the technical change exhibited by all inputs. However, those estimates should be corrected by a scale effect in case this production function is not homothetic, as explained in the aggregate model. Thereby, crop production continued being capital-saving, and also became fertilizer-saving, because their cost shares decreased by 0.4% per year, respectively, due to technical change. In addition, crop production continued being labor-using, since the cost share of labor increased by 0.9% per year due to technical change.

This model also estimates that, at the point of approximation of this cost function, the cost share of capital is 57.3%, the cost share of labor is 37.6%, and the cost share of fertilizer is 5.1% (see Table 28, column 2 to column 4). This also predicts that the cost share of capital will increase by 2.4%, the cost share of labor will increase by 1.8%, and the cost share of fertilizer will rise by 0.7% if their own prices increase by 10% (see Table 28, column 6, column 9, and column 11). Furthermore, it estimates that the cost share of capital is also mainly sensitive to variations in the price of labor, decreasing on average by 1.7% if the price of labor increases by 10% (see Table 28, column 7 to column 8). Also, the cost share of labor will also decrease by 1.7% if the price of capital increases by 10%.

In addition, the cost share of fertilizer will vary marginally due to changes in the prices of capital and labor. Finally, this model shows that the cost share of capital and the cost share of labor will increase by 0.3% per year if crop production increases by 10%, while the cost share of fertilizer will decrease by 0.6% per year if this happens (see Table 28, column 12 to column 14).

Table 28: Trans-Log Cost Function of Colombia's Crop Production (1975-2013)

	(1)	(2)	(3)	(4)	(5)
VARIABLES	α_0	α_k	α_l	α_f	ρ [1]
	22.36***	0.573***	0.376***	0.0510***	0.684***
	(0.0200)	(0.00553)	(0.00784)	(0.00645)	(0.0667)

Elasticities: Price to Input Shares

	(6)	(7)	(8)	(9)	(10)	(11)
VARIABLES	β_{kk}	β_{kl}	β_{kf}	β_{ll}	β_{lf}	β_{ff}
	0.236***	-0.169***	-0.0664***	0.174***	-0.00418	0.0705***
	(0.00375)	(0.00808)	(0.00637)	(0.0131)	(0.00792)	(0.00834)

Elasticities: Output to Total Cost & Input Shares

	(12)	(13)	(14)	(15)	(16)
VARIABLES	β_{kQ}	β_{lQ}	β_{fQ}	α_Q	α_{QQ}
	0.0300	0.0325	-0.0625	-0.0437	0.355
	(0.0377)	(0.0662)	(0.0587)	(0.225)	(4.320)

Elasticities: Technical Change to Total Cost & Input Shares

	(17)	(18)	(19)	(20)	(21)	(22)
VARIABLES	α_t	α_{tt}	β_{kt}	β_{lt}	β_{ft}	β_{Qt}
Constant	0.0149***	0.00001	-0.00505***	0.00401***	0.00104	-0.0224
	(0.00384)	(0.00125)	(0.000658)	(0.00141)	(0.00126)	(0.0701)

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

	Obs	Parms	R^{2*}
Log(Total Cost(t))	38	16	0.992
Cost Share of Capital(t)	38	6	0.994
Cost Share of Labor(t)	38	6	0.987
Cost Share of Fertilizer(t)	38	6	0.925

$^*R^2$ is estimated as the square of the correlation between the actual value and the predicted value, because STATA software reports a wrong index for each equation. The reason is the form this software calculates the R-square index for NLSUR models.

[1] corresponds to the specific first order autocorrelation coefficient.

[2] these coefficients were calculated based on the restrictions required for imposing curvature to a trans-log cost function.

6.2.2.1.3 Livestock

The dual cost model for livestock production shows an excellent fit as well (see Table 30). The R^2 exhibited by all equations ranges from 0.83-0.99. This model does not present econometric problems. Also, it initially predicted positive price elasticities for certain inputs, which was corrected by imposing curvature restrictions on this cost function at their point of approximation, as in the aggregate model (Diewert & Wales, 1987; Ryan & Wales, 2000). However, this model also exhibits multicollinearity problems, which implies that all standard errors in the model are large and possibly overestimated. In any case, all parameters were used for making inferences regarding livestock production, since the multicollinearity problem does not affect their statistical properties.

This study also calculates the own price elasticities for all inputs used by livestock production to evaluate the estimated cost function. All elasticities in the constrained model are negative (as they must be), showing that this function is well behaved (see Table 29). Also, capital is the least sensitive input to changes in prices, while animal feed is the most sensitive input. In addition, these elasticities are also highly sensitive to the variability in the cost share of each input.

Table 29: Price Elasticities of Input Demand on the Cost Function for Livestock Production

	ε_{kk}	ε_{ll}	ε_{ss}
Without Imposing Curvature Restrictions	0.0328***	-0.0899	-0.2697***
	(0.01367)	(0.11691)	(0.06972)
Imposing Curvature Restrictions	-0.0257**	-0.0635	-0.2038***
	(0.01197)	(0.07269)	(0.04681)

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The results of this model indicate that livestock productivity, measured as TFP, grew on average by 2.0% per year during 1975-2013. These results are close to those obtained by assuming a CES production function (+2.2%), and are somewhat higher than those yielded by assuming a Cobb-Douglas production function (+1.6%). A large scale effect was also crucial, rather than a strong reduction in the costs of production due to technical change. The scale effect contributed to livestock TFP with an average growth of 2.3% per year, whereas the technical change component deducted on average 0.3% per year from this TFP, due to a reduction in the scale-augmenting of technical change.

This model also shows that livestock production exhibited biased technical change. This was labor-saving, as well as capital-using and animal feed-using, since the cost share of labor decreased by 0.5% per year due to technical change, whereas the cost share of capital increased by 0.4% per year, and the cost of share of animal feed rose by 0.1% per year. Thus, technical change in livestock production tended to improve more the marginal productivity of labor. Hence, technical change in livestock production has been biased toward labor relative to capital and animal feed.

As in the crops model, this study assumed that the dual production function related to this cost function is homothetic to estimate the technical change exhibited by all inputs. However, those estimates should be corrected by a scale effect in case this function is not homotethic. This implied that livestock production was capital-using, labor-using, and animal feed-using, since their cost shares increased by 0.1%, 2.1%, and 0.7% respectively per year due to technical change.

This model also estimates that, at the point of approximation of this cost function, the cost share of capital is 85.4%, the cost share of labor is 6.9%, and the cost share of animal feed is 7.8% (see Table 30, column 2 to column 4). This also predicts that the cost share of capital will increase by 1.3%, the cost share of labor will rise by 0.6% and the cost share of animal feed will increase by 0.7% if their own prices increase by 10% (see Table 30, column 6, column 9, and column 11). Besides, it estimates that the cost share of capital is sensitive to variations in the price of labor and animal feed, decreasing on average by 0.6%-0.7% if the price of any of these inputs increases by 10% (see Table 30, column 7 to column 8). Also, the cost share of labor will also decrease by 0.6% if the price of capital increases by 10%. In addition, the cost share of animal feed will also decline by 0.7% if the price of capital increases by 10%. Finally, this model shows that the cost share of capital will decrease by 1.1% per year, the cost share labor will increase by 0.6% per year, and the cost share of fertilizer will rise by 0.4% per year if Colombia's livestock production increases by 10% (see Table 30, column 12 to column 14).

Table 30: Trans-Log Cost Production Function of Colombia's Livestock Production (1975-2013)

	(1)	(2)	(3)	(4)	(5)
VARIABLES	α_0	α_k	α_l	α_s	ρ [1]
	23.64***	0.854***	0.0687***	0.0777***	0.692***
	(0.0140)	(0.00955)	(0.00535)	(0.00479)	(0.0743)

Elasticities: Price to Input Shares [2]

	(6)	(7)	(8)	(9)	(10)	(11)
VARIABLES	β_{kk}	β_{kl}	β_{ks}	β_{ll}	β_{ls}	β_{ss}
	0.127***	-0.059***	-0.066***	0.064***	-0.005***	0.0717***
	(0.00984)	(0.00462)	(0.00081)	(0.00539)	(0.00053)	(0.00484)

Elasticities: Output to Total Cost & Input Shares

	(12)	(13)	(14)	(15)	(16)
VARIABLES	β_{kQ}	β_{lQ}	β_{sQ}	α_Q	α_{QQ}
	-0.111	0.0667	0.0448	0.118	0.973
	(0.0856)	(0.0551)	(0.0381)	(0.148)	(1.939)

Elasticities: Technical Change to Total Cost & Input Shares

	(17)	(18)	(19)	(20)	(21)	(22)
VARIABLES	α_t	α_{tt}	β_{kt}	β_{lt}	β_{st}	β_{Qt}
	0.00166	0.00178	0.00395*	-0.00494***	0.000992	-0.0327
	(0.00447)	(0.00176)	(0.00221)	(0.00146)	(0.00101)	(0.0575)

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Equation	Obs	Parms	R^{2*}
Log(Total Cost(t))	38	13	0.997
Cost Share of Capital(t)	38	5	0.869
Cost Share of Labor(t)	38	5	0.825
Cost Share of Animal Feed(t)	38	5	0.923

$^*R^2$ is estimated as the square of the correlation between the actual value and the predicted value, because STATA software reports a wrong index for each equation. The reason is the form this software calculates the R-square index for NLSUR models.

[1] corresponds to the specific first order autocorrelation coefficient.

6.3 Discussion

6.3.1 Comparison across Results

In the previous section I described the main results obtained while estimating agricultural productivity in Colombia during the period 1975-2013. Overall, these results give special emphasis to four aspects: i) what was agricultural productivity growth in Colombia, measured as TFP and assuming Hicks-Neutral technical change, in aggregate and also disaggregated for crops and livestock during this period; ii) whether or not Colombia's agriculture exhibited biased technical change during this period; iii) whether Colombia's agricultural productivity growth varied over time across periods established in Chapter 2; and iv) the contribution of scale effects to Colombia's agricultural productivity. This section aims to analyze these results by comparing the results across techniques. This analysis begins by comparing agricultural productivity estimated by all techniques to evaluate the consistency of the results. Then, it focuses on the decomposition of agricultural output growth between input accumulation and productivity growth during the period 1975-2013. In parallel, it also analyzes changes in agricultural productivity over time, and how those fluctuations relate to the economic circumstances exhibited by Colombia's agriculture during this period. It is worth remembering that agricultural productivity, measured as TFP, is estimated by assuming a Cobb-Douglas production function and as CES production function as the output growth not explained by input accumulation growth[67]. Furthermore, under the dual-cost

[67] For the Cobb-Douglas, in Chapter 6 I calculate agricultural productivity using the alternative specification for which it includes six time-trend variables for periods.

approach, agricultural productivity is measured as the sum of shifts in the cost function due to technical change plus a scale effect, as Chapter 4 explains in detail.

6.3.1.1 Agricultural Productivity

A comparison of all results across techniques show high consistency among them (see Table 31). Overall, this allows one to draw the conclusion that aggregate agricultural productivity in Colombia grew on average between 0.6% and 1.4% per year during the period 1975-2013. In particular, the CES and dual-cost techniques predict that it grew on average by 1.3 and 1.4% per year, respectively, aligned with the USDA's prediction (1.4%). The Cobb-Douglas technique predicts agricultural productivity in Colombia only grew on average by 0.6% per year. Also, this comparison shows that these aggregate estimates of agricultural productivity might be biased upwards/downwards, since these are calculated as an aggregate and without linking these changes to crop productivity and livestock productivity differences. Accordingly, this study calculates agricultural productivity as a weighted average, using the estimates for crop productivity and livestock productivity and as weights the shares of crop and livestock production value in total agricultural production value. This exercise suggests that aggregate agricultural productivity estimated by the Cobb-Douglas technique is downward biased, because it predicts an average growth close to 0.6% per year versus the 0.8% per year when it is estimated as a weighted average. Likewise, this calculation indicates that aggregate agricultural productivity estimated using the dual-cost approach is upward biased, because it predicts an average growth of about 1.4% per year versus the 0.9% per year when it is estimated as a weighted average. Therefore, this suggests that agricultural productivity grew between 0.8% and 1.3% per year in Colombia during 1975-2013. Also, it indicates that it is more appropriate to use this weighted average for agricultural productivity, since it more closely represents different dynamics exhibited by crop productivity and livestock productivity. Hence, this study uses this estimated weighted average for Colombia's agricultural productivity growth for the rest of this analysis.

Table 31: Average Agricultural Productivity in Colombia from 1975-2013

	Cobb-Douglas	CES	Dual 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%

All techniques also predict that agricultural productivity in Colombia was mainly driven by livestock productivity. This grew on average at a rate between 1.6% and 2.2% during the period 1975-2013, probably due to: i) more efficient production practices in the poultry sector; ii) higher investments in new herds and technology (mainly in dual-purpose cattle) in the late 1990's; and iii) introduction of innovations for feeding and management of livestock, genetic improvements, and the purchase of highly productive species in the milk sector (Kalmanovitz & López, 2003; MADR, 2005b; Mojica & Paredes, 2005). In contrast, crop productivity expansion is unclear over this period. By assuming a Cobb-Douglas production function and using the dual-cost approach, it is predicted that average crop productivity growth was zero. However, by assuming a CES production function, crop productivity grew on average by 0.8% per year, which is still low.

Historical evidence suggests crop productivity would have been low during the period 1975-2013, because farmers experienced difficult conditions: i) agricultural budget cuts during the 1980's Latin American debt crisis; ii) a profitability crisis after Colombia executed the second package of reforms of its Structural Adjustment in the early 1990's; 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 agriculture competitiveness, and vii) the segmented and restricted funding for Colombian farmers (Cuevas et al., 2003; C. F. Jaramillo, 1998; Junguito et al., 2014; Junguito, 1994; Kalmanovitz & López, 2003; Reina et al., 2011). However, some crops are exceptions and seemingly exhibited higher levels of productivity during this period, for example: i) sugar cane, due to the introduction of mechanized harvesting practices, the modernization of production processes and equipment and machinery; ii) flowers, due to a reallocation of the varieties according to climate conditions; iii) banana, due to cultivating more productive varieties; and iv) recently cereals and vegetables due to better farming practices, higher investment in research and development of genetically modified seeds (Arbeláez, 1993; Becerra, 2009; COMPITE, 2008; C. F. Jaramillo, 1998; La Republica, 2012; Montero & Casas, 2012; Ramirez & Garcia, 2006; SIC, 2012).

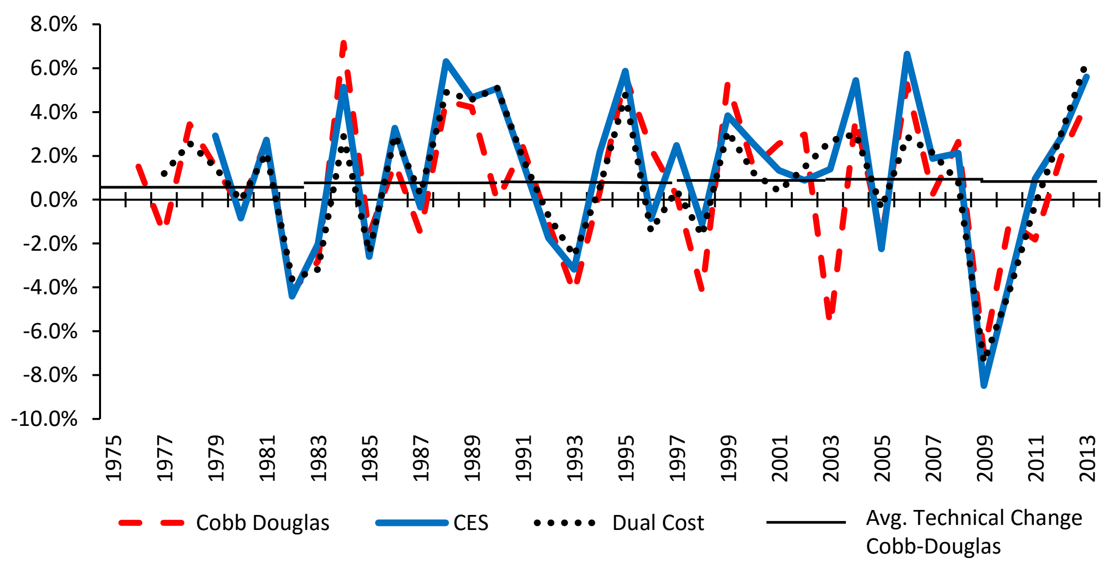
A correlation matrix across the results when estimating agricultural productivity over time also shows high consistency among these estimates (see Table 32). This correlation matrix is calculated by taking the annual predictions of agricultural productivity from all techniques for the period 1975-2013, and then calculating the correlation among them. Overall, this correlation across predictions varies between 70% to 95%. The highest is between the agricultural productivity predicted by assuming a CES production function and the dual-cost approach (+94%), whereas the lowest is between the agricultural productivity predicted by assuming a Cobb-Douglas production function and the dual-cost approach (73%). Also, the range of agricultural productivity estimates is small. All techniques predict that agricultural productivity grew on average between 0.8% and 1.3% between 1975 and 2013, crop productivity increased between 0% and 0.8%, and livestock productivity rose between 1.6% and 2.2% (see Table 31). Therefore, these results indicate that all techniques broadly predict similar estimates of agricultural productivity. Also, these reaffirm that there is high consistency across agricultural productivity estimates from all techniques.

Table 32: Correlation Matrix among Agricultural Productivity Estimates by Technique

	Cobb-Douglas	**CES**	**Dual-Cost**
Cobb-Douglas	1.000		
CES	0.818	1.000	
Dual-Cost	0.734	0.943	1.000

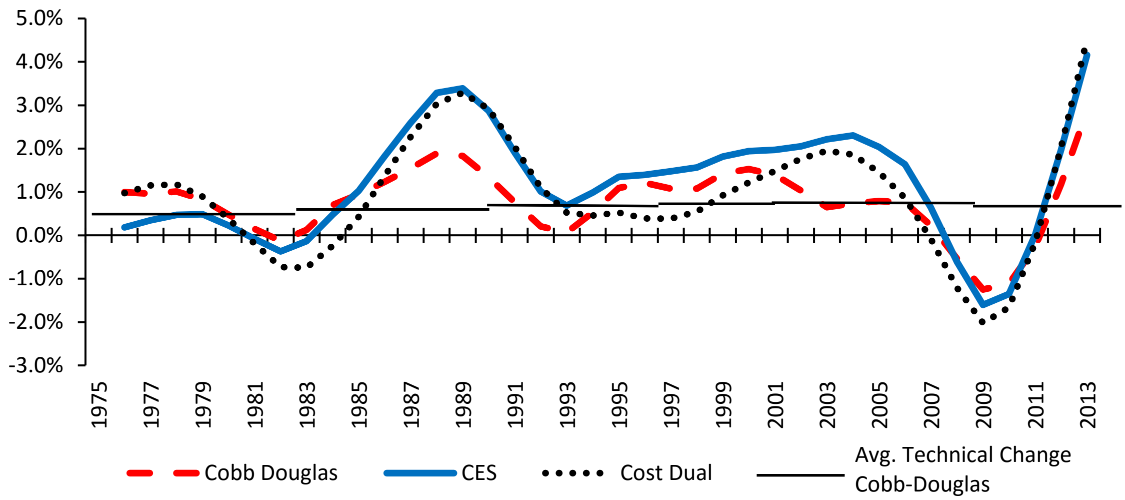
A simple graphical analysis across agricultural productivity estimates reaffirms this conclusion (see Figure 35). This shows that all techniques predict similar estimates for Colombia's agricultural productivity for the period 1975-2013. However, these estimates exhibit slightly different smoothed trends (see Figure 36). This study removed the cyclical component from each annual TFP estimate by using the Hodrick-Prescott filter[68] to estimate their smoothed trend, and found that: i) not all estimates of agricultural productivity exhibit exactly the same turning points (mainly the Cobb-Douglas prediction), and ii) each estimate shows a different magnitude in growth peaks and falling periods. Accordingly, each technique predicts that agricultural productivity grew on average at a somewhat different pace per year, as explained above (see Table 31).

Figure 35: Agricultural Productivity Growth in Colombia Predicted by Technique



[68] This study estimated this smoothed trend for all agricultural productivity estimates using the Hodrick-Prescott filter, by assuming a parameter λ= 6.25, recommended in the literature for yearly series and used by the USDA to calculate agricultural productivity (Ravn & Uhlig, 2002; USDA, 2016).

Figure 36: Smoothed Trend of Agricultural Productivity in Colombia Predicted by Technique



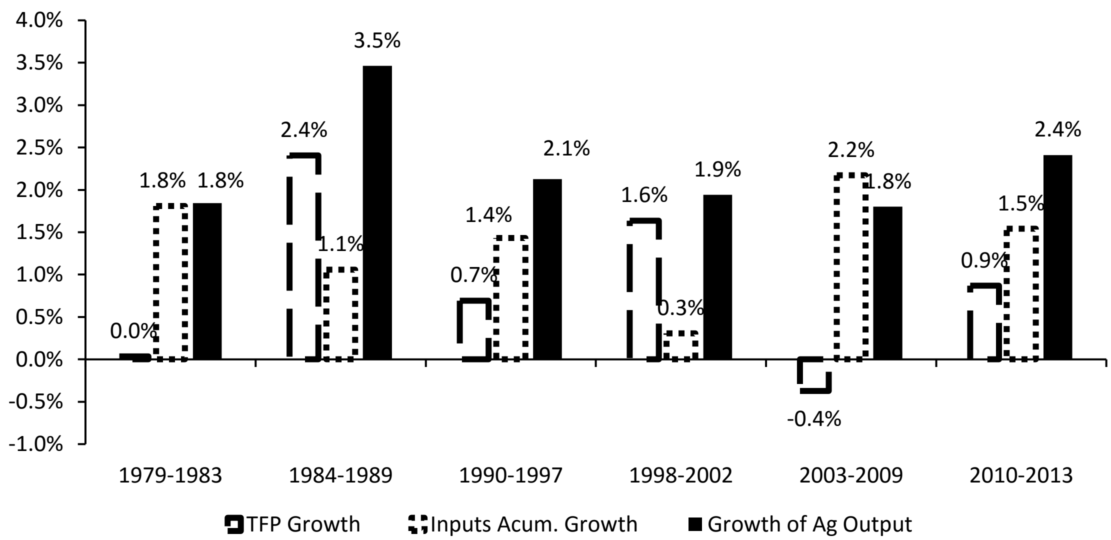
*This figure uses smoothed data obtained from the Hodrick-Prescott filter

This evidence suggests that estimates of agricultural productivity predicted in this study are consistent across techniques. Also, these estimates do not exhibit large differences among them. Therefore, this study uses these estimates to analyze the drivers of Colombia's agricultural growth during the period 1979-2013: agricultural productivity growth or input accumulation growth. To this end, this study carries out analysis for the periods established in Chapter 2, for which: i) Colombia's agriculture exhibited similar economic conditions; and ii) agricultural policy regimens did not sharply change (see Table 12).

During the period 1979-1983, Colombia's agricultural output grew on average by 1.8% per year. This low growth was due to low agricultural productivity, which did not grow at all when it is measured assuming a Cobb-Douglas production function (see Figure 37, Figure 38 and Figure 39), fell on average by 0.3% per year when it is measured with a

CES production function, and grew marginally (+0.1% per year) using the dual-cost technique. Therefore, this indicates that Colombia's agriculture exhibited low growth in this period, due to very low productivity and the negative impact of the Latin American Debt crisis on Colombian agriculture[69] (Kalmanovitz & López, 2003). Also, this shows that agricultural output was mainly supported by input accumulation growth, which grew on average around 2% per year during this period.

Figure 37: Decomposition of Growth Exhibited by the Value of Agricultural Production, When TFP growth is Measured Using a Cobb-Douglas Production Function



[69] Due this crisis, Colombia's agriculture did not receive much attention and promotion for its development in this period; for instance, Colombia exhibited a reduction of about 14% in the R&D investment received in the early 1980's.

Figure 38: Decomposition of Growth Exhibited by the Value of Agricultural Production, When TFP growth is Measured Using a CES Production Function

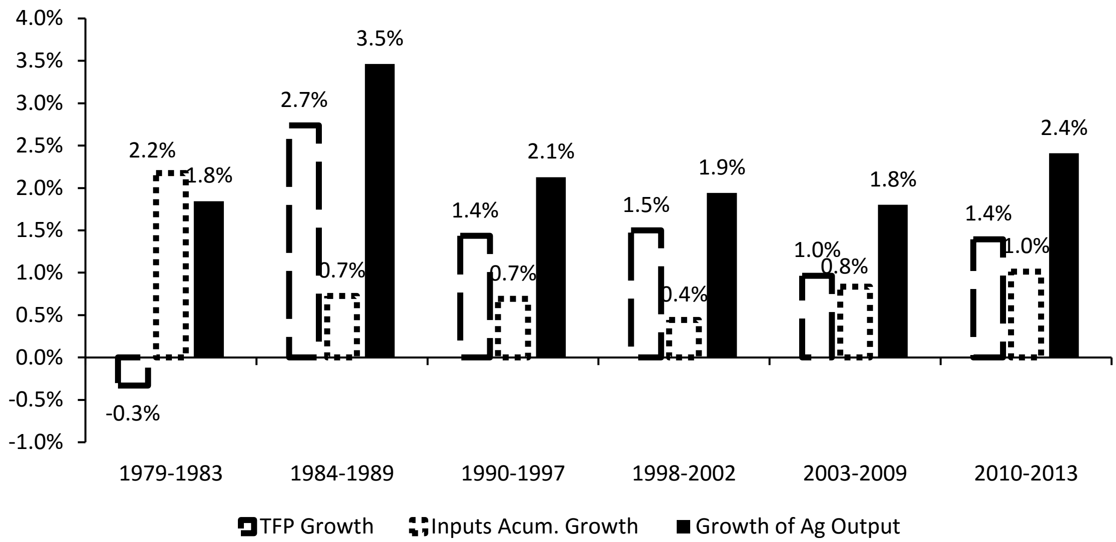
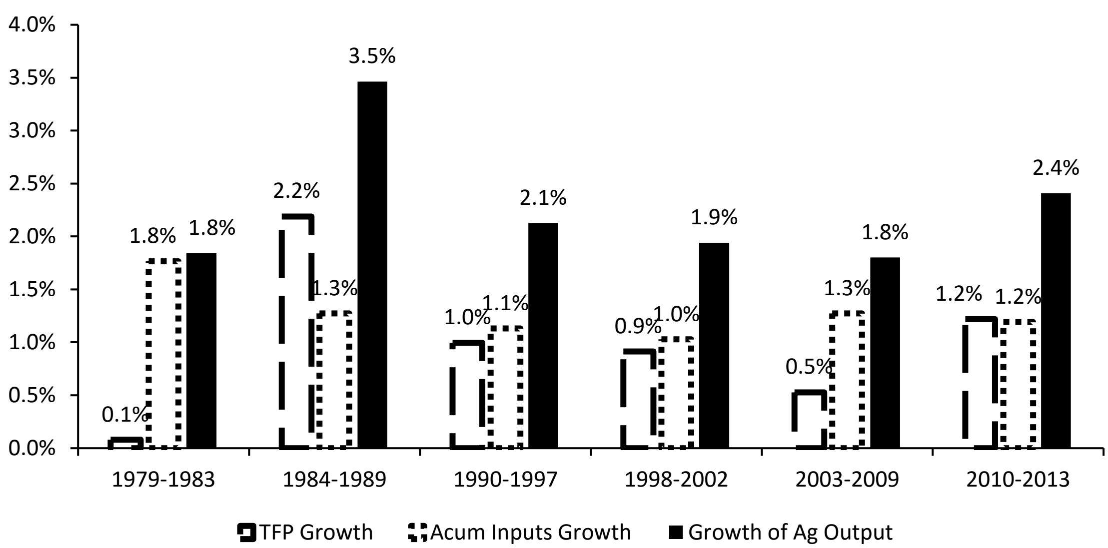


Figure 39: Decomposition of Growth Exhibited by the Value of Agricultural Production, When TFP Growth is Measured Using the Dual-Cost method



In the period 1984-1989, agricultural output increased its average growth to 3.5% per year in Colombia. All techniques indicate that agricultural productivity was crucial for this higher growth, since they predict that agricultural productivity grew on average between 2.2% and 2.7% per year during this period. This shows that Colombia's agriculture increased its growing pace in the late 1980's, due to: i) agricultural policy executed during the Barco administration, which focused on promoting private investment, adjusting the price system, raising farmer's margins, limiting agricultural imports, etc., ii) higher commodity prices; iii) a mini-boom exhibited by coffee production; and iv) probably all productivity innovations carried out by farmers to overcome the early 1980's crisis (Guterman, 2007; IMF, 2015; Kalmanovitz & López, 2003; Reina et al., 2011). Also, this shows that input accumulation growth reduced its contribution to agricultural growth during this period, and productivity growth became its main driver.

By the period 1990-1997, agricultural output exhibited a slowdown in Colombia. It only grew on average by 2.1% per year, mainly due to lower productivity growth (see Figure 37, Figure 38 and Figure 39). All techniques predict that agricultural productivity growth diminished its pace during this period. By assuming a Cobb-Douglas production function, it is estimated that productivity reduced its average growth from 2.4% per year in the late 1980's to 0.7% per year from 1990-1997. By assuming a CES production function, productivity reduced its growth from 2.7% per year to 1.4% per year, and by using the dual-cost approach, this rate fell from 2.2% per year to 1.0% per year. Also, all techniques indicate that input accumulation growth did not exhibit a significant change, and continued growing at the same pace of the late 1980's. This means that the severe crisis exhibited by Colombia's agriculture during the early 1990's directly impacted productivity. Thereby, Colombia's agricultural growth decreased during this period, mainly due to lower productivity growth rather than by a lower input accumulation growth.

During the period 1998-2002, agricultural output growth slightly reduced to 1.9% per year (see Figure 37, Figure 38 and Figure 39). Less input accumulation growth explains this slowdown. By assuming a Cobb-Douglas production function for the measurement of agricultural productivity, input accumulation growth decreased from 1.4% per year during 1990-1997 to 0.3% per year, although this was partially offset by an increase in agricultural productivity from 0.7% to 1.6% per year. By assuming a CES production function, input accumulation growth diminished from 0.7% to 0.4% per year, whereas agricultural productivity continued growing around 1.4%-1.5% per year. In addition, using the dual-cost approach, this slower growth was due to a slight decrease in agricultural productivity from 1.0% to 0.9% per year, and another decrease in the input accumulation growth from 1.1% to 1.0% per year. Therefore, all techniques indicate that agricultural productivity stagnated during this period and farmers diminished input accumulation, probably due to the macroeconomic crisis and worsening armed conflict experienced by Colombia during this period. As explained in Chapter 2, these factors impeded the Pastrana administration (1998-2002) from executing its agricultural policy, which had been designed with a great emphasis on promotion of agricultural productivity (Kalmanovitz & López, 2003; Villalba, 2002).

During 2003-2009, agricultural output grew on average around 1.8% per year (see Figure 37, Figure 38 and Figure 39). Colombia's agriculture continued stagnating during this period, growing at the same pace of the 1990's. All techniques indicate that slower agricultural productivity growth during this period is what explains the lower growth exhibited by Colombia's agricultural output. By assuming a Cobb-Douglas production function, agricultural productivity fell on average by -0.4% per year during this period, and therefore agricultural growth was supported by higher input accumulation growth (2.2% per year). According to the dual-cost approach, agricultural productivity decreased its average growth to 0.5% per year during this period, reaffirming that agricultural growth was driven by higher input accumulation growth (+1.3%). In addition, using a CES production function, agricultural productivity decreased slightly to 1.0% per year, whereas input accumulation growth increased to 0.8%. Therefore, these results show that the agricultural policy implemented by Uribe-I administration (2002-2006) and Uribe-II administration (2006-2010) promoted more input accumulation growth among farmers rather than agricultural productivity. This could have been the result of the administration's misallocation of resources for promoting the agriculture, poor transportation infrastructure, and a lack of innovation and technological development to improve agricultural productivity (Reina et al., 2011). In addition, these administrations executed an agricultural policy for which the priority was to give direct subsidies to farmers rather than use these resources as investments for promoting agricultural productivity (Reina et al., 2011).

Finally, agricultural output has rallied in Colombia in recent years. Over 2010-2013, agricultural output grew on average by 2.4% per year (see Figure 37, Figure 38 and Figure 39). All techniques indicate that this was due to an increase in agricultural productivity growth. Using a Cobb-Douglas production function, agricultural productivity growth increased sharply from -0.4% per year in the period 2003-2009 to 0.9% per year in 2010-2013. Using a CES production function, agricultural productivity increased from 1.0% to 1.4% per year during this period. Using the dual-cost approach, agricultural productivity rose from 0.5% to 1.2% per year. This indicates that Colombia's agriculture expanded recently, due to improvements in productivity. Also, it seems that the Santos administration's (2010-2014) distinct approach to agricultural policy was crucial for this outcome.

This analysis shows that estimates of agricultural productivity predicted in this study are consistent across techniques. Also, it indicates that agricultural productivity has been a crucial factor in determining agricultural output growth in Colombia in recent decades, especially during periods of stronger growth. Therefore, agricultural policy in Colombia must give priority to boosting productivity, since this is a crucial factor in promoting agricultural growth. To this end, this study identifies certain elements that Colombian agricultural policy should consider to promote agricultural productivity in the next chapter. The objective is to determine the factors that best explain agricultural productivity in Colombia.

CHAPTER 7. DETERMINANTS OF COLOMBIA'S AGRICULTURAL PRODUCTIVITY

7.1 Introduction

Many studies have analyzed the main determinants of worldwide agricultural productivity growth, as explained in Chapter 3 (Avila et al., 2010; Desai & Namboodiri, 1998; Ekbom, 1998; Evenson & Fuglie, 2010; Evenson et al., 1999; Fan, 1991; Fuglie & Rada, 2011, 2013; Jin et al., 2002; Kumar et al., 2008; Rada & Valdes, 2012; Sun et al., 2009; Thirtle et al., 2008). Overall, these studies have found that agricultural productivity is largely explained by four determinant types: i) investment in agricultural research and agricultural extension programs; ii) efficiency gains through the use of high quality factors, as well as more human capital; iii) scale economies via trade openness and higher competence in the domestic market; and iv) miscellaneous factors, such as weather and commodity prices (Suphannachart & Warr, 2012). Thus, there is an overall consensus in economics literature on the determinant types that explain worldwide agricultural productivity growth.

A common issue in this literature is that some studies consider determinants that are more related to factor (capital) accumulation than to technical change (see Chapter 3). It is common to find determinants in these studies such as labor availability, land use, credit availability, total length of road network and farm size, as well as input reallocation across sectors, as candidates for explaining agricultural productivity (Atkinson, 1970; Ekbom, 1998; Rada & Valdes, 2012; Sun et al., 2009; Suphannachart & Warr, 2012; Thirtle et al., 2008). Therefore, agricultural productivity has been sometimes analyzed considering determinants that are not directly related to technical change. Consequently, these studies have likely drawn misguided conclusions about determinants that could have explained agricultural productivity but instead explain investment, and haven't determined the factors that really explain it.

Recent research continues to focus on designing better instruments to explain agricultural productivity (Wang et al., 2013). Also, it has become important to analyze the relations between these determinants and agricultural productivity over time. The objective has been to identify the factors that exhibit short-term effects on agricultural productivity and those with more long-term effects (Ali et al., 2012; Suphannachart & Warr, 2012). These studies emphasize that agricultural development boosts economic growth and improves social conditions (Johnson & Mellor, 1961). Accordingly, the identification of determinants that better explain agricultural productivity is crucial for better design of agricultural policy that boosts agricultural development.

This chapter aims to identify the elements that Colombia's agricultural policy should consider to boost agricultural productivity. It uses agricultural productivity estimates from the previous chapter, assuming a Cobb-Douglas production function[70], to test whether those determinants suggested by economics literature, such as the typical drivers of

[70] It presents similar results from to other methods and exhibits the fewest econometric issues.

agricultural productivity, exhibit a direct impact on Colombia's agricultural productivity. It worth highlighting that this analysis could not evaluate many key determinants, due to lacking data for the entire sample period (1975-2013).

7.2 Methodology

Economics literature indicates that there are two possible approaches to analyze the determinants that explain agricultural productivity (Evenson & Fuglie, 2010; Evenson, Landau, & Ballou, 1987; Schimmelpfennig, Thirtle, van Zyl, Arnade, & Khatri, 2000). On the one hand, there is an integrated approach, in which conventional inputs (i.e. labor, capital, land, etc.) and non-conventional factors (i.e. investment in R&D, human capital, patent development, etc.) are directly inputted in a single specification of a production function, cost function, or profit function. On the other hand, there is a "two-stage" approach, in which agricultural productivity is initially estimated, considering only conventional inputs in a first stage. Then, results are used to analyze the impact of non-conventional factors on agricultural productivity in a second stage.

The integrated approach is the most direct way to identify the main determinants of agricultural productivity, since all parameters are estimated simultaneously (Evenson et al., 1987; Schimmelpfennig et al., 2000). However, this approach exhibits certain problems that make the "two-stage" approach an appropriate alternative. For instance, collinearity problems are very common in the integrated approach because all factors, conventional and non-conventional, are included in a single specification and these factors usually exhibit common trends (Evenson & Fuglie, 2010). Also, the results derived from using this approach are usually not robust, because high correlations among conventional and non-conventional factors cause these results to exhibit high sensitivity to changes in model specification (Evenson & Fuglie, 2010). In addition, the sample size is not always sufficient to ensure robust results using an integrated approach, because the loss of degrees of freedom is significant given the number of variables included in the model (Schimmelpfennig et al., 2000). Therefore, some studies suggest that the "two-stage" approach most appropriately manages these difficulties (Evenson & Fuglie, 2010; Schimmelpfennig et al., 2000).

This study uses the "two-stage" approach to identify the main determinants of Colombia's agricultural productivity. This allows us to concentrate our analysis on the relation between non-conventional factors and agricultural productivity, since the relation between conventional factors and agricultural productivity is analyzed in the previous chapter. Also, this enables us to avoid the typical econometric problems associated with an integrated approach. In addition, many studies have successfully followed this approach to determine the relation among these non-conventional factors and agricultural productivity for countries such as Mexico, Brazil, India, South Africa, and the UK (Evenson & Fuglie, 2010; Fernandez-Cornejo & Shumway, 1997; Rada & Valdes, 2012; Schimmelpfennig et al., 2000; Sun et al., 2009; Thirtle et al., 2008).

This study also acknowledges that all determinants that might explain Colombia's agricultural productivity could, in fact, exhibit a cumulative effect over time. The presumption is that their returns in terms of productivity are perceived after a maturity period, and then start to decline thereafter. Accordingly, it is assumed that current agricultural productivity is explained by the cumulative effect of changes exhibited by these determinants in prior years rather than a particular change at a specific (short) time in one of these factors. This is a common approach used to analyze the impact of R&D investment in productivity. The idea here is to use this approach to analyze the impact of other determinants of Colombia's agricultural productivity (Alston, Chan-Kang, Marra, Pardey Philip, & Wyatt, 2000; Huffman & Evenson, 2006; Thirtle et al., 2008).

Three common methods exist to estimate these model types, commonly known in economics literature as distributed-lag models (Alston et al., 2000; Thirtle et al., 2008). One method is the Polynomial Distributed Lag (PDL) approach, in which a set of constraints are imposed to ensure that model's lagged coefficients follow a polynomial of degree P. From this, a weights structure is derived for each independent variable x_t that is lagged in a model (e.g. in this case, all determinants that explain agricultural productivity). Thereby, any shock exhibited by a lagged variable x_{t-i} on a dependent variable y_t (e.g. Colombia's agricultural productivity) can be modeled using the PDL approach, because this allows one to assign different weight structures to all lagged variables according to the degree P chosen for the polynomial (Almon, 1965; Fair & Jaffee, 1975). Also, it avoids the collinearity issue that often arises when this type of model is estimated by only considering lags of variables x_t in the model specification. However, this approach's main issue is that it requires a careful and accurate selection of the model's lag-length and the degree of the polynomial P. Otherwise, all coefficients in the model may be biased or inefficient (Berry & Wei, 2013).

Another method is the Trapezoidal Lag Distribution approach, which is a specific functional form of distributed-lag models. This is often used to analyze the impact of research on agricultural productivity (Huffman & Evenson, 2006). Basically, this is a predetermined lag structure used to model the impact of investment in agricultural research on agricultural productivity, which establishes the following weight structure: i) there is no impact on agricultural productivity during the first two years; ii) the weight of impact for each lagged variable increases linearly during the following seven years; iii) these weights then remain constant for 6 years; and iv) these weights decrease linearly to zero over 20 years. One problem with this approach is that its lag structure is designed specifically to model the impact of investing in research on agricultural productivity. Accordingly, it might not show a good fit for the weight structures of other determinants and in this study might also not fit Colombia's patterns, which could vary from those of other countries. Another issue is that this approach demands a large sample size. This requires an extensive data history for all determinants (35 periods), which poses a serious problem when used with a small sample, as in this study.

Finally, a third method is to calculate a simple moving average for all lagged variables over a specific period of time P. Then, these moving averages of all variables x_t are regressed on a dependent variable y_t to measure their cumulative impact. This is the approach used in this study, because: i) it is a simple method to implement and evaluate the effects of all lagged determinants on Colombia's agricultural productivity without the need to include all x_t variables lagged for many periods, which would imply a significant loss of degrees of freedom; ii) it avoids econometric problems, such as multicollinearity;

iii) it is appropriate for small and/or large samples; and iv) it allows for conducting sensitivity analyses to determine the potential effect of changing the lag length of factors on agricultural productivity.

7.2.1 Model

The model used in this study for identifying the main determinants of agricultural productivity in Colombia assumes that it is mainly impacted by four determinant types: i) investment in agricultural research and agricultural extension programs; ii) efficiency gains through the use of high quality factors, as well as more human capital; iii) scale economies via trade openness and higher competence in the domestic market; and iv) miscellaneous factors, such as weather and commodity prices. Thereby, this model assumes that Colombia's agricultural productivity (TFP_t) is a function of these four types of determinants (w_{it}), and each is proxied by a set of j variables $(\overrightarrow{z_{ijt}})$:

$$TFP_t = f\left(w_{1t}\left(\overrightarrow{z_{1jt}}\right), w_{2t}\left(\overrightarrow{z_{2jt}}\right), w_{3t}\left(\overrightarrow{z_{3jt}}\right), w_{4t}\left(\overrightarrow{z_{4jt}}\right)\right) + \varepsilon_t \quad (41)$$

where TFP_t is an index of Colombia's agricultural productivity with base year 1975=100, calculated using the agricultural productivity growth estimates from the previous chapter, assuming a Cobb-Douglas production function and a time-varying specification, as well as estimated as a weighted average between crop productivity and livestock during the period 1975-2013. Also, each determinant type (w_{it}) is identified with at least one variable $(z_{ijt,})$ in order to ensure good model identification. In addition, this model is estimated using moving averages for all variables $(MA\left(\overrightarrow{z_{ijt}}\right)_p)$ with lag length p, in order to model the cumulative effect of each on Colombia's agricultural productivity.

An extended structure of this model can be written as:

$$TFP_t = f\left(w_{1t}\left(MA(\overrightarrow{z_{1jt}})_p\right), w_{2t}\left(MA(\overrightarrow{z_{2jt}})_p\right), w_{3t}\left(MA(\overrightarrow{z_{3jt}})_p\right), w_{4t}\left(MA(\overrightarrow{z_{1jt}})_p\right)\right) + \varepsilon_t \quad (42)$$

where the moving average for each variable j and each determinant type i, denoted by $(MA(\overrightarrow{z_{ijt}})_p)$, is:

$$MA(\overrightarrow{z_{ijt}})_{t-p} = \sum_{k=1}^{p} \frac{(\overrightarrow{z_{ij}})_{t-k}}{p} \quad (43)$$

This study estimates equation 42 using Ordinary Least Squares (OLS), since this method allows us to estimate the marginal effect of the moving average calculated for each variable with lag length p on Colombia's agricultural productivity (TFP_t). It is worth noting that this study conducted a sensitivity analysis to determine the optimal lag length to be considered in the estimation of the moving average calculated for each determinant. This sensitivity analysis involves regressing the moving average several times for each variable $(MA(\overrightarrow{z_{ijt}})_p)$ on Colombia's agricultural productivity (TFP), changing the lag-length considered each time. This exercise is carried out separately for each variable. The lag-length for all moving averages are integers between 1 and 10 years, given the sample size. The criterion for selecting the optimal lag-length p for the moving average of each variable is the lag for which: i) the model exhibits the highest R^2; ii) the coefficient of the moving average variable is statistically significant, and; iii) the coefficient magnitude (i.e. its returns in terms of agricultural productivity) is the highest. The Durbin-Watson index was estimated in all models to test for the possible presence of serial autocorrelation. When this problem was detected, this study used the Prais-Winsten estimation procedure to address it. This procedure is the most efficient to correct for serial autocorrelation in small samples (Rao & Griliches, 1969).

The variables considered by this study are explained below in detail.

7.2.2 Variables

Many variables have been considered by the economics literature to identify the main determinates of worldwide agricultural productivity. The interest in designing better instruments, as well as data availability, undoubtedly explains this wide portfolio of variables. Data availability was a strong limitation to selecting and ruling out many variables in this study. In any case, based on this literature, which is reviewed in detail in Chapter 3, this study uses the following variables to identify the four determinant types that may have impacted Colombia's agricultural productivity during the period of 1975-2013.

1. Research investment: investment in agricultural R&D and agricultural extension programs are the most common variables used in economics literature to identify this determinant type (Desai & Namboodiri, 1998; Evenson & Fuglie, 2010; Evenson et al., 1999; Fernandez-Cornejo & Shumway, 1997; Fuglie & Rada, 2011; Sun et al., 2009). Studies show that a direct, positive, and strong causal relation exists between these variables and agricultural productivity. All such studies have found that higher investment in agricultural R&D and/or agricultural extension programs increases agricultural productivity. Therefore, investment in these two areas often explains differences in agricultural productivity worldwide.

This study only includes agricultural R&D investment in the model, because there is no available data on Colombian investment in agricultural extension programs. Data on agricultural R&D investment corresponds to the public agricultural R&D expenditure released by Beintema, Romano, and Pardey (2006) for the period 1970-1996 and by the DNP (2015) for the period 1997-2013. Beintema, Romano, and Pardey (2006) compiled these data by collecting this R&D expenditure from Colombia's federal governmental agencies, non-profit institutions, and higher education agencies. That study releases these data as a ratio of Colombia's agricultural GDP. The DNP (2015) does some data compilation from recent decades, reporting yearly public expenditure for improving Colombia's agriculture competitiveness. The DNP (2015) releases these data in nominal Colombian Pesos.

This study built the variable of total investment in Colombian agricultural R&D for the period 1975-2013, by using Colombia's agricultural GDP in current pesos to implicitly derive investment in agricultural R&D compiled by Beintema, Romano, and Pardey (2006) for the period 1970-1996. Then, I appended these data to the series released by the DNP (2015) for the period 1997-2013. Finally, these data are converted into 2005 Colombian pesos, by dividing this value by the Consumer Price Index of Colombia with the base year of 2005 (World Bank, 2016).

2. Efficiency gains: human capital, total length of the road network, and area equipped with irrigation are the most frequently-used variables to identify this type of determinant (Ali et al., 2012; Desai & Namboodiri, 1998; Ekbom, 1998; Sun

et al., 2009; Suphannachart & Warr, 2012). These studies show that agricultural productivity exhibits a positive relation to these three factors. Productivity improves when a country increases the length of their road networks, exhibits more area equipped with irrigation, and increases human capital. However, this study considers that human capital is the only variable directly related to technical change. The total length of the road network and area equipped with irrigation are variables more related to physical capital accumulation, even if that is by public investment. Therefore, this study only considers human capital in the model.

This study measures human capital as the number of people graduated from secondary schools. This variable allows us to capture the impact of people with the highest level of education in rural areas on Colombia's agricultural productivity. Recent figures suggest that only about half of students enrolled in rural schools finish secondary schooling (MINEDUCACION, 2012). Given that Colombia is a developing country, this figure was probably lower in previous decades. This study uses the number of people enrolled in tertiary education in Colombia in all programs released by UNESCO as a proxy for this variable, because data for the number of secondary school graduates is not available for Colombia. Accordingly, it is expected that the number of people enrolled in tertiary education is closely related to the number of people that previously completed secondary education.

3. Economies to scale: economic openness indices are the most common variables used in economics literature to identify this determinant type (Ali et al., 2012; Suphannachart & Warr, 2012). These studies show that there is a positive

relation between economic openness and agricultural productivity, since greater openness allows farmers to increase their market size. Economics literature also shows that there is a positive relation between foreign competence and manufacturing productivity in the medium term, and this might have the same impact on agricultural productivity (Fernandes, 2007; Muendler, 2004; Olley & Pakes, 1996). This study considers economic openness indicators in the model as the ratio of agricultural exports to agricultural output and the ratio of agricultural imports to agricultural output. However, I include the ratio of agricultural imports to agricultural output only, because Colombia's agricultural exports have historically been concentrated in a few products (e.g. coffee, flowers and banana), as is mentioned in Chapter 2. Thus, it is unlikely that Colombia's agriculture has experienced any significant broadly-based gains in productivity from agricultural exporting. These gains might have been concentrated on these few products.

The foreign competence variable corresponds with the ratio of Colombian agricultural imports to agricultural GDP. The numerator includes the value of all agricultural imports, which FAOSTAT reports annually as a CIF value (FAO, 2015). Agricultural GDP is the value added of Colombia's agriculture, released annually by the World Bank (World Bank, 2016).

4. Miscellaneous factors: many other variables, such as commodities prices and weather, are frequently considered when agricultural productivity is analyzed and segmented into its main determinants. Empirical evidence shows that good weather conditions (i.e. more rainfall and less droughts and floods) and higher

commodity prices tend to increase agricultural productivity (Evenson, 2001; Henderson et al., 2011; Suphannachart & Warr, 2012). However, this study did not include these factors, since: i) the impact of weather on agricultural productivity varies for each crop; and ii) commodity prices are disaggregated by product and this study analyzes aggregate agricultural productivity in Colombia.

7.3 Results and Discussion

In order to identify the main determinants of agricultural productivity in Colombia, this study begins by corroborating those factors suggested by economics literature as exhibiting a direct and positive relationship with Colombia's agricultural productivity during the period 1975-2013. To this end, this study calculated a simple correlation between these factors and Colombia's agricultural productivity. The results of this exercise show that all factors exhibited a reasonably high and positive correlation with Colombia's agricultural productivity during the period 1975-2013 (see Table 33). Human capital is the variable that displays the highest correlation (93%), followed by the correlation exhibited by foreign competence (86%), and last by the correlation shown by agricultural R&D investment (62%).

Table 33: Correlation between Agricultural Productivity in Colombia and Key Explanatory Factors Suggested by Economics Literature during the Period (1975-2013)

	$\text{Log}(TFP_t)$
$\text{Log}(\text{InvR}\&D_t)$	0.62
$\left(\frac{\text{Ag. Imports}}{\text{Ag. GDP}}\right)_t$	0.86
$\text{Log}(\text{Human Capital}_t)$	0.93

As explained above, this study considers that all factors exhibited a cumulative impact on Colombia's agricultural productivity during the period 1975-2013. Next, I used a moving average to estimate their impact. This study conducted sensitivity analysis to determine the optimal lag length to calculate the moving average for each variable, considering a maximum lag of 10 years.

This sensitivity analysis shows an excellent fit for all factors. In the case of human capital, the R^2 for all models is approximately 0.99, and the Root MSE ranges from 0.030-0.032 (see Table 34). No model shows heteroscedasticity, because all sensitivity analyses were estimated assuming robust standard errors. Also, an initial serial autocorrelation problem in all models was corrected by estimating each using the Prais-Winsten estimation procedure. In addition, all coefficients are statistically significant at 1% and vary between 0.12-0.14. The largest coefficient is estimated for the moving average of lag 8 (0.137) and the smallest for lag 1 (0.121). Therefore, the difference between the maximum returns in terms of agricultural productivity when human capital increases on average by 1% during the last year versus when this increase happens on average during the last 10 years under similar conditions is insignificant. Agricultural productivity increases between 0.12% and 0.14% per year when average human capital increases by 1% in the last year, last two years, three years, etc. This study selects the moving average calculated for human capital considering 8 years as the optimal lag, because that model exhibits an R^2 of 0.99, the coefficient of this moving average is statistically significant at 1%, and the returns of human capital in terms of productivity are the highest at this lag.

Table 34: Sensitivity Analysis for Determining Optimal Lag-Length for Human Capital

	Coef	Robust Std. Err.	Root MSE	R^2	DW – Index
$\text{Log}(\text{Human Capital}_t) - \text{MA}(1)$	0.1210***	0.013	0.0308	0.988	1.95
$\text{Log}(\text{Human Capital}_t) - \text{MA}(2)$	0.1259***	0.014	0.0302	0.989	1.95
$\text{Log}(\text{Human Capital}_t) - \text{MA}(3)$	0.1243***	0.015	0.0302	0.990	1.96
$\text{Log}(\text{Human Capital}_t) - \text{MA}(4)$	0.1249***	0.016	0.0307	0.990	1.96
$\text{Log}(\text{Human Capital}_t) - \text{MA}(5)$	0.1272***	0.017	0.0311	0.989	1.93
$\text{Log}(\text{Human Capital}_t) - \text{MA}(6)$	0.1255***	0.019	0.0317	0.989	1.91
$\text{Log}(\text{Human Capital}_t) - \text{MA}(7)$	0.1338***	0.020	0.0311	0.990	1.97
$\text{Log}(\text{Human Capital}_t) - \text{MA}(8)$	0.1371***	0.024	0.0313	0.990	1.92
$\text{Log}(\text{Human Capital}_t) - \text{MA}(9)$	0.1240***	0.019	0.0298	0.992	1.90
$\text{Log}(\text{Human Capital}_t) - \text{MA}(10)$	0.1268***	0.022	0.0302	0.992	1.88

*** p<0.01, ** p<0.05, * p<0.1

*In all models, the natural logarithm of Colombia's agricultural productivity for period t ($\text{Log}(TFP_t)$) is the dependent variable.

In the case of foreign competence, the R^2 for all models is 0.98-0.99 as well, and the Root MSE varies from 0.032-0.036 (see Table 35). Also, all coefficients are statistically significant at 1%, except for the moving average estimate for lag 1 (year). In addition, all coefficients vary from 0.009 to 0.013. The largest coefficient is estimated when the moving average is calculated for lag 8 (0.0130) and the smallest when it is only calculated for lag 2 (0.0089). This indicates that agricultural productivity increases by 0.89% per year when foreign competence in the domestic market increases on average by 1% of GDP during the last two years. Also, agricultural productivity increases somewhat more, by 1.3% per year, if average foreign competence increases on average by 1% of GDP during the last 8 years. This study selects the moving average calculated for foreign competence considering also 8 years as the optimal lag, because that model exhibits an R^2 of 0.99, the coefficient of this moving average is statistically significant at 1%, and the returns of foreign competence in Colombia's domestic market in terms of agricultural productivity are the highest at this lag.

Table 35: Sensitivity Analysis for Determining Optimal Lag-Length for Foreign Competence in Colombia's Agricultural Market

	Coef	Robust Std. Err.	Root MSE	R^2	DW – Index
$\left(\frac{\text{Ag. Imports}}{\text{Ag. GDP}}\right)_t - \text{MA}(1)$	0.0041	0.003	0.0349	0.984	2.05
$\left(\frac{\text{Ag. Imports}}{\text{Ag. GDP}}\right)_t - \text{MA}(2)$	0.0089***	0.003	0.0362	0.987	1.87
$\left(\frac{\text{Ag. Imports}}{\text{Ag. GDP}}\right)_t - \text{MA}(3)$	0.0100***	0.003	0.0352	0.988	1.92
$\left(\frac{\text{Ag. Imports}}{\text{Ag. GDP}}\right)_t - \text{MA}(4)$	0.0117***	0.003	0.0336	0.989	1.91
$\left(\frac{\text{Ag. Imports}}{\text{Ag. GDP}}\right)_t - \text{MA}(5)$	0.0119***	0.003	0.0340	0.989	2.03
$\left(\frac{\text{Ag. Imports}}{\text{Ag. GDP}}\right)_t - \text{MA}(6)$	0.0119***	0.003	0.0337	0.990	1.96
$\left(\frac{\text{Ag. Imports}}{\text{Ag. GDP}}\right)_t - \text{MA}(7)$	0.0127***	0.003	0.0341	0.990	1.95
$\left(\frac{\text{Ag. Imports}}{\text{Ag. GDP}}\right)_t - \text{MA}(8)$	0.0130***	0.004	0.0352	0.989	1.91
$\left(\frac{\text{Ag. Imports}}{\text{Ag. GDP}}\right)_t - \text{MA}(9)$	0.0116***	0.003	0.0323	0.992	1.85
$\left(\frac{\text{Ag. Imports}}{\text{Ag. GDP}}\right)_t - \text{MA}(10)$	0.0116***	0.004	0.0332	0.991	1.81

*** p<0.01, ** p<0.05, * p<0.1

*In all models, the natural logarithm of Colombia's agricultural productivity for period t ($\text{Log}(TFP_t)$) is the dependent variable.

Finally, in the case of agricultural R&D investment, the R^2 for all models also ranges from 0.98-0.99, and the Root MSE is around 0.035-0.037 (see Table 36). Unlike the sensitivity analysis carried out for human capital and foreign competence in Colombia's agricultural market, this only shows two statistically significant coefficients. These are the coefficients calculated for the moving averages of agricultural R&D investment, considering the lags of 6 and 7 (years). However, only the coefficient for the moving average lagged 7 (0.1458) is statistically significant at 1%, since the coefficient for the moving average lagged 6 (0.0845) is statistically significant only at 10%. This suggests a weak relation between agricultural R&D and agricultural productivity in Colombia during the last several decades, likely due to: i) lack of public resources for promoting Colombia's agriculture competitiveness; ii) misallocation of resources for agricultural promotion; and iii) segmented and restricted funding for Colombian farmers (Cuevas et al., 2003; Junguito et al., 2014; Reina et al., 2011). This study selects the moving average calculated for agricultural R&D investment considering 7 years as the optimal lag, because that model exhibits an R^2 of 0.99 and the coefficient of this moving average is statistically significant at 1%.

Table 36: Sensitivity Analysis for Determining Optimal Lag-Length for Agricultural R&D Investment

	Coef	Robust Std. Err.	Root MSE	R^2	DW − Index
$\text{Log}(\text{InvR\&}D_t) - \text{MA}(1)$	-0.0121	0.024	0.0347	0.977	2.02
$\text{Log}(\text{InvR\&}D_t) - \text{MA}(2)$	0.0052	0.033	0.0356	0.980	2.13
$\text{Log}(\text{InvR\&}D_t) - \text{MA}(3)$	-0.0207	0.039	0.0350	0.979	2.15
$\text{Log}(\text{InvR\&}D_t) - \text{MA}(4)$	-0.0303	0.045	0.0352	0.979	2.09
$\text{Log}(\text{InvR\&}D_t) - \text{MA}(5)$	0.0511	0.055	0.0360	0.984	2.16
$\text{Log}(\text{InvR\&}D_t) - \text{MA}(6)$	0.0845*	0.046	0.0356	0.986	2.14
$\text{Log}(\text{InvR\&}D_t) - \text{MA}(7)$	0.1458***	0.055	0.0350	0.988	2.15
$\text{Log}(\text{InvR\&}D_t) - \text{MA}(8)$	0.1442	0.086	0.0367	0.988	2.11
$\text{Log}(\text{InvR\&}D_t) - \text{MA}(9)$	0.0628	0.087	0.0346	0.989	1.94
$\text{Log}(\text{InvR\&}D_t) - \text{MA}(10)$	0.1008	0.102	0.0354	0.989	1.91

*** p<0.01, ** p<0.05, * p<0.1

*In all models, the natural logarithm of Colombia's agricultural productivity for period t ($\text{Log}(TFP_t)$) is the dependent variable.

Next, I searched for the model that best explains Colombia's agricultural productivity during the period 1975-2013, by using the optimal lags identified above in the sensitivity analysis for each factor. This allowed identifying that the optimal specification for this model involves the moving average lagged 8 years for human capital and foreign competence, as well as lagged 7 years for agricultural R&D investment.

This model shows an excellent fit. Its R^2 is 0.99, and its Root MSE is around 0.031 (see Table 37). Also, this model indicates that human capital is apparently the only variable that exhibits a positive and statistically significant relation with agricultural productivity (see Table 37). An increase of 1% in their average exhibited during the last 8 years explains an increase of almost 0.31% in Colombia's agricultural productivity. In contrast, foreign competence exhibits the wrong sign, because its coefficient is negative and economics literature suggests that it should be positive, as did in the earlier sensitivity analysis to determine its optimal lag. In addition, agricultural R&D investment is not statistically significant at 10%, despite the positive relation shown by this variable in the sensitivity analysis. Evidently, the human capital variable has captured the effects seen earlier for foreign competence and investment in agricultural R&D, and dominates these other effects. Also, this reaffirms the weak relation between agricultural R&D in Colombia, due to the factors above mentioned, and agricultural productivity

Table 37: Model of Agricultural Productivity Regressed using the Moving Averages of Main Determinants

VARIABLES	$\text{Log}(TFP_{\text{t}})$
$\text{Log}(\text{Human Capital}_{\text{t}}) - \text{MA}(8)$	0.306***
	(0.0818)
$\left(\frac{\text{Ag. Imports}}{\text{Ag. GDP}}\right)_t - \text{MA}(8)$	-0.0161**
	(0.00760)
$\text{Log}(\text{InvR\&}D_{\text{t}}) - \text{MA}(7)$	-0.0756
	(0.0605)
Constant	3.673***
	(0.248)
Observations	31
Root MSE	0.031
R-squared	0.99

Robust Standard errors in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

This study evaluates whether this model exhibits collinearity issues among its variables, and this explains why human capital is the only variable that is statistically significant and shows the expected sign. To this end, I calculate a correlation matrix to determine if the correlation among pairs of these variables is equal or higher than 80%, since the rule of thumb recognizes this as evidence of collinearity problems (Montgomery, Peck, & Vining, 2001). This allows to us confirm this hypothesis (see Table 38). The model exhibits collinearity problems, because the correlation between the moving averages calculated for human capital and foreign competence is 95%. Also, the correlation between the moving averages calculated for human capital and investment in agricultural R&D is 72%, which is also close to this threshold. Therefore, this study estimates this model again, but it drops out the moving average of human capital to address this collinearity. The idea is to determine the marginal effect of agricultural R&D investment and agricultural import penetration on Colombia's agricultural productivity, abstracting from the potential impact of human capital. In addition, it also estimates this model, considering human capital as the only factor to explain Colombia's agricultural productivity (see Table 39).

Table 38: Correlation Matrix among Factors that Explain Agricultural Productivity in Colombia from 1975-2013

	$\text{Log}(\text{InvR\&}D_t) - \text{MA}(7)$	$\text{Log}(\text{Human Capital}_t) - \text{MA}(8)$	$\left(\frac{\text{Ag. Imports}}{\text{Ag. GDP}}\right)_t - \text{MA}(8)$
$\text{Log}(\text{InvR\&}D_t) - \text{MA}(7)$	1.00		
$\text{Log}(\text{Human Capital}_t) - \text{MA}(8)$	0.72	1.00	
$\left(\frac{\text{Ag. Imports}}{\text{Ag. GDP}}\right)_t - \text{MA}(8)$	0.53	0.95	1.00

These models show excellent fits. Both exhibit an R^2 of 0.99 and Root MSEs from 0.031-0.034 (see Table 39). The model, for which human capital was not included, indicates that agricultural R&D investment and foreign competence are important drivers of Colombia's agricultural productivity (see Table 39, column 1). These show that if the average agricultural R&D investment increases by 1% over the last 7 years, agricultural productivity increases by 0.11% per year. Also, if foreign competence in Colombia's agricultural market increases by 1% of agricultural GDP over the last 8 years, agricultural productivity increases by 0.9% per year. Moreover, the results of the model in which human capital is the only determinant of Colombia's agricultural productivity show that if the average human capital increases by 1% over the last 8 years, Colombia's agricultural productivity increases by almost 0.14% per year (see Table 39, column 2).

Table 39: Adjusted Model for Agricultural Productivity Regressed using the Moving Averages of Main Determinants

VARIABLES	(1) $\text{Log}(TFP_t)$	(2) $\text{Log}(TFP_t)$
$\text{Log}(\text{Human Capital}_t) - \text{MA}(8)$		0.137*** (0.02411)
$\left(\frac{\text{Ag. Imports}}{\text{Ag. GDP}}\right)_t - \text{MA}(8)$	0.00944*** (0.00327)	
$\text{Log}(\text{InvR\&}D_t) - \text{MA}(7)$	0.110* (0.0634)	
Constant	4.101*** (0.326)	4.028*** (0.1330)
Observations	31	31
Root MSE	0.034	0.031
R-squared	0.99	0.99

Robust Standard errors in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

In brief, this study finds evidence that agricultural R&D investment, human capital, and foreign competence in the domestic market are important drivers of Colombia's agricultural productivity. Also, it finds that agricultural policy should be designed with a long-term perspective, because agricultural productivity will increase in Colombia if: i) average investment in R&D increases steadily during the previous 7 years; and ii) foreign competence increases over the last 2 to 7 years, since this determinant exhibits increasing returns in terms of productivity over this period and might lead productivity improvements in Colombia's agriculture in order to face this increasing foreign competence. In addition, agricultural productivity might be boosted in the short term by increasing human capital, since its returns in terms of productivity in the short and long term are quite similar.

This suggests that agricultural policy in Colombia should consider mainly three elements for increasing agricultural productivity. First, it should promote a steady increase in agricultural R&D investment for developing new farming technologies and technical improvements. This increased investment should also consider funding agricultural extension programs, since these programs are possibly the most efficient way to ensure an effective dissemination of the technical knowledge developed for all Colombian farms. Second, Colombia's agricultural policy should consider a gradual removal of all trade distortions, which have been very strong during last several decades, as explained in Chapter 2. This would imply a reduction of agricultural tariffs, which would raise foreign competence in the domestic market and might encourage Colombian farmers to adopt the new technical knowledge developed in the field. Finally, this agricultural policy should promote higher education levels in rural areas. This would ensure a good transmission of technical knowledge, since Colombian farmers will be able to comprehend the importance of these new farming technologies in improving the productivity of their farms.

This study finds that Colombia will be able to raise its agricultural productivity in the next decades if it includes these elements in its agricultural policy. Also, success will depend on implementing a comprehensive policy that incorporate all three elements and is designed with a long term perspective. Otherwise, efforts to increase Colombia's agricultural productivity will be in vain, and Colombia will continue exhibiting low agricultural productivity, similar to the period 1975-2013.

CHAPTER 8. CONCLUSIONS

8.1 Structural Issues of Colombia's Agriculture

Colombia's agriculture exhibited only a moderate expansion during the agricultural commodity price booms from 2006 to 2011, and it has mainly encountered serious difficulties in recent decades (see Chapter 2). For instance, Colombia's agriculture has remained stagnant since the 1990's, growing just 1.5% on average in the 1990's, and 1.9% in the 2000's (World Bank, 2016). Many factors explain this weak performance, but economics literature explains that the following are the most important: i) the type of policies implemented in Colombia to boost its economic development, mainly promoting other sectors, such as finance, mining, and utilities (Junguito et al., 2014); ii) a misallocation of resources within the agricultural sector, despite the fact that Colombia's government increased its investment during the 2000's (Reina et al., 2011); iii) the accelerated and abrupt implementation of the second package of reforms associated with Colombia's Structural Adjustment (SA) program during the 1990's (Ocampo, 2000); and iv) a significant structural transformation of Colombia's economy toward the services sector due to effects known as the Dutch Disease (Clavijo et al., 2013). Therefore, agriculture did not continue as a main driver of Colombia's economy in recent decades.

Furthermore, its share in Colombia's total GDP decreased steadily from an average of 24% in the 1970's to 6%-8% in the 2000's.

Colombia's agricultural policy has been historically designed to face short-term problems, instead of being a long-term strategy for sectoral development (SAC, 2014). Colombia has executed a wide variety of policies to promote its agricultural performance, but most have in common the central role assigned to the government for carrying out constant market interventions (Guterman, 2007). Consequently, Colombia's agriculture has been subject to many distortions during the last several decades, which have considerably limited its competitiveness (Anderson & Valdés, 2008).

Finally, Colombia's agriculture has exhibited a serious lack of public resources for improving its competitiveness. Public expenditure on agriculture has represented just 0.2%-0.4% of overall GDP since the late 1990's, while this figure has reached 1% in other emerging markets, and 4% in developed countries (Junguito et al., 2014). Also, Colombia has shown two types of bottlenecks that have discouraged agricultural investment in recent years (COMPITE, 2008). On the one hand, projects developed in this sector usually have low expected returns, due to the lack of human capital in the sector, land misallocation, limited exploitation of economies of scale, etc. On the other hand, Colombia's agriculture has exhibited funding problems, because credit to this sector is segmented and restricted (Cuevas et al., 2003). These structural issues have surely had an impact on agricultural productivity growth in Colombia.

A key issue in this weak performance exhibited by Colombia's agriculture is stagnant productivity growth. In order to estimate its significance, this study estimates Colombia's agricultural productivity growth and analyses which are the most important factors that explain it. This study identifies those elements that Colombia's government should consider in their agricultural policy to: i) boost productivity growth in this sector; ii) reach faster growth and development of its agriculture; and iii) take advantage of all available opportunities for Colombia's agriculture in the following decades.

8.2 Measuring Colombia's Agricultural Productivity

The principal objective of this research was to measure agricultural productivity and to analyze if it changed over time, due to changes in agricultural policy regimes and/or economic circumstances. This study estimates Colombia's agricultural productivity using econometric techniques, with special emphasis on four aspects: i) agricultural productivity growth in Colombia, measured as TFP and assuming Hicks-Neutral technical change, in aggregate and also disaggregated for crops and livestock during this period; ii) whether or not Colombia's agriculture exhibited biased technical change during this period; iii) whether Colombia's agricultural productivity growth varied over time across periods established in Chapter 2; and iv) the contribution of scale effects to Colombia's agricultural productivity.

This study finds evidence that aggregate Colombia's agricultural productivity grew on average between 0.6% and 1.4% during the period 1975-2013 (see Table 40). Also, it estimates that productivity growth varied between 0.8% and 1.3% per year during this period, when Colombia's agricultural productivity is calculated as a weighted average using crop productivity and livestock productivity, using as weights the shares of crop and livestock production value in total agricultural production value. I consider this weighted average estimate a more reliable indicator for Colombia's agricultural productivity, since it represents more closely the different dynamics exhibited by crop productivity versus livestock productivity. Also, I find that agricultural TFP varied across the six periods established in Chapter 2. Accordingly, Colombia's agricultural productivity is sensitive to significant changes in policy regimes and economic circumstances.

Table 40: Average Agricultural Productivity in Colombia from 1975-2013

	Cobb-Douglas	CES	Dual 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%

All methods used in this study – Cobb-Douglas and CES production function and Dual cost function -- estimate that Colombia's agricultural productivity was mainly driven by livestock productivity. This grew on average at a rate between 1.6% and 2.2% during this period, probably due to: i) more efficient production practices in poultry sector; ii) higher investments in new herds and technology (mainly in dual-purpose cattle) in the late 1990's; and iii) introduction of innovations for feeding and management of livestock, genetic improvements, and the purchase of highly productive species in the milk sector (Kalmanovitz & López, 2003; MADR, 2005b; Mojica & Paredes, 2005). In contrast, crop productivity expansion is unclear over this period. By assuming a Cobb-Douglas production function and using the dual cost approach, it is predicted that average crop productivity growth was zero, whereas by assuming a CES production function, this grew on average by 0.8% per year.

Historical evidence suggests crop productivity would have been low during the period 1975-2013, because farmers experienced difficult conditions: i) agricultural budget cuts during the 1980's Latin American debt crisis; ii) a profitability crisis after Colombia executed the second package of reforms of its Structural Adjustment program in the early 1990's; 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 agriculture competitiveness, and vii) the segmented and restricted funding for Colombian farmers (Cuevas et al., 2003; C. F. Jaramillo, 1998; Junguito et al., 2014; Junguito, 1994; Kalmanovitz & López, 2003; Reina et al., 2011). However, some crops are exceptions and seemingly exhibited higher levels of productivity, for example: i) sugar cane, due to the introduction of mechanized harvesting practices, the modernization of production processes and equipment and machinery; ii) flowers, due to a reallocation of the varieties according to climate conditions; iii) banana, due to cultivating more productive varieties; and iv) recently cereals and vegetables, due to better farming practices, higher investment in research and development of genetically modified seeds (Arbeláez, 1993; Becerra, 2009; COMPITE, 2008; C. F. Jaramillo, 1998; La Republica, 2012; Montero & Casas, 2012; Ramirez & Garcia, 2006; SIC, 2012).

It worth noting that these agricultural productivity estimates are strongly consistent across techniques. The correlation of annual estimates across these agricultural productivity results, estimated using each technique, varies between 70% to 95%. Also, the range of agricultural productivity estimates is small. All techniques predict that agricultural productivity grew on average between 0.8% and 1.3% between 1975 and 2013, crop productivity increased between 0% and 0.8%, and livestock productivity rose between 1.6% and 2.2% (see Table 40).

This study also finds that agricultural productivity was a crucial factor in determining agricultural production value growth in Colombia in recent decades, and especially during periods of stronger growth. Agricultural production growth always accelerated to more than 2% per year when agricultural productivity growth increased its pace (e.g. in the late 1980's and in recent years). Moreover, it finds evidence that the pace of agricultural productivity was strongly dependent on policy regimes and economic circumstances. Thus, agricultural policy in Colombia must give priority to boosting productivity, because this is a crucial factor for promoting agricultural growth. However, this policy should be carefully designed in order to avoid any unexpected results and to boost Colombia's agricultural productivity growth in the proper way.

Finally, this study finds evidence that Colombia's agriculture exhibited biased technical change during the period 1975-2013 (see Table 41). Using a CES production function, it determines that technical change was capital augmenting in crop production, and animal feed augmenting in livestock production. However, using the dual-cost approach, technical change was capital saving in crop production, but unclear in livestock production. In this case in particular, there was an inconsistency between results when the livestock production function behind the cost function is assumed homothetic versus non-homothetic. Either way, these results indicate that changes in input efficiency in Colombia's agriculture was different across agricultural activities during 1975-2013. Also, technical change tended to improve more the marginal productivity of capital in crop production relative to other inputs, and the marginal productivity of animal feed in livestock production relative to other inputs.

Table 41: Biased Technical Change by Agricultural Activity in Colombia

	Crops	**Livestock**	**Aggregate**		**Assumed Prod. Fn. behind**
CES	Capital Augmenting	Animal Feed Augmenting	Capital Augmenting		
Dual Cost	Capital saving	Labor saving	Labor saving Fertilizer saving		Homothetic
	Capital saving Fertilizer saving	Using in all inputs	Animal Feed saving Fertilizer saving		Non-Homothetic

8.3 Comparison with Other Literature

The focus of this discussion so far has been the analysis of results obtained by the different econometric techniques for the measurement of agricultural productivity in Colombia. The objective of this section is to compare the results with other studies (Avila et al., 2010; USDA, 2015). For this purpose, I use the estimates of agricultural productivity derived assuming a Cobb-Douglas production function, since these exhibit the fewest econometric problems. This study also uses the smoothed trend exhibited by annual agricultural productivity growth estimates from all studies, since this allows one to more comprehensively analyze the predictive power of each approach[71].

By comparing agricultural productivity growth estimates from this study versus USDA calculations, I find that our estimates are on average lower than the USDA's (0.8% versus 1.4%) for the period 1975-2013. Also, there exists a large discrepancy between the smoothed trends (see Figure 40) (USDA, 2015). First, USDA estimates do not predict a sharp fall in agricultural productivity during the 1990's as our estimates indicate and historical evidence suggests. The USDA only predicts a moderate slowdown of Colombia's agricultural productivity growth during this decade, which bottomed out in 1998. Second, USDA estimates indicate that agricultural productivity remained stable until 2007, whereas our estimates predict that agricultural productivity started to decline in the 2000's and agricultural growth was mainly explained by higher input accumulation during this period. Finally, USDA estimates predict that agricultural productivity contracted in 2010-2011. In contrast, our estimates forecast that this occurred earlier during the period 2009-2010, which is more plausible since Colombia's agriculture plunged into a crisis in 2009 (see Chapter 2). Agricultural productivity estimated by the USDA has a low correlation with our estimates (only 50%).

This study finds two possible reasons for these discrepancies. On the one hand, the USDA estimates agricultural productivity as a residual variable using an accounting technique, including cost shares from Brazil's agriculture, and assuming that these figures

[71] I applied the Hodrick-Prescott filter to all estimates of Colombia's agricultural productivity in order to remove their cyclical component and to estimate the smoothed trend from each one.

are similar for both countries (USDA, 2016). However, as explained in Chapter 3, this is not true. This confirms the suspicions of this study: agriculture in Colombia and Brazil are very different. Brazil's agriculture is developed on large and flat lands, and it has been supported by a long-term agricultural policy. In contrast, Colombia's agriculture is developed on hillsides, and its agricultural policy has mainly been executed to solve short-term issues (see Chapter 2). Moreover, since the USDA uses an accounting technique for measuring Colombia's agricultural TFP, this might be biased due to omitting important regressors unrelated to productivity. For instance, the USDA does not include variables to control for the impact on changes in policy regimes and in economic circumstances on Colombia's agricultural productivity.

A comparison of our results and those estimated by Avila et al. (2010) also shows significant discrepancies (see Figure 40). On the one hand, Avila et al. (2010) predict that agricultural productivity in Colombia exhibits a different trend than the one estimated by this study in the 1980's. Avila et al. (2010) estimate that agricultural productivity fell during that decade, whereas our estimates predict that it increased. Avila et al. (2010) also estimate that Colombia's agricultural productivity fell in the late 1990's, while our estimates suggest that this occurred in the early 1990's. The correlation between their results and ours is -54%.

A possible reason for this discrepancy is the methodology used by Avila et al. (2010) to measure agricultural productivity. Avila et al. (2010) uses the Tornqvist-Theil Index, which also measures agricultural productivity as a residual variable[72]. This means that the agricultural productivity estimated by Avila et al. (2010) might include omitted but important regressors unrelated to productivity. In contrast, I estimate agricultural productivity assuming a Cobb-Douglas function, which is similar to Tornqvist- Theil Index, but I specified a model that allows for variation in technical change over time, which our results show to be important.

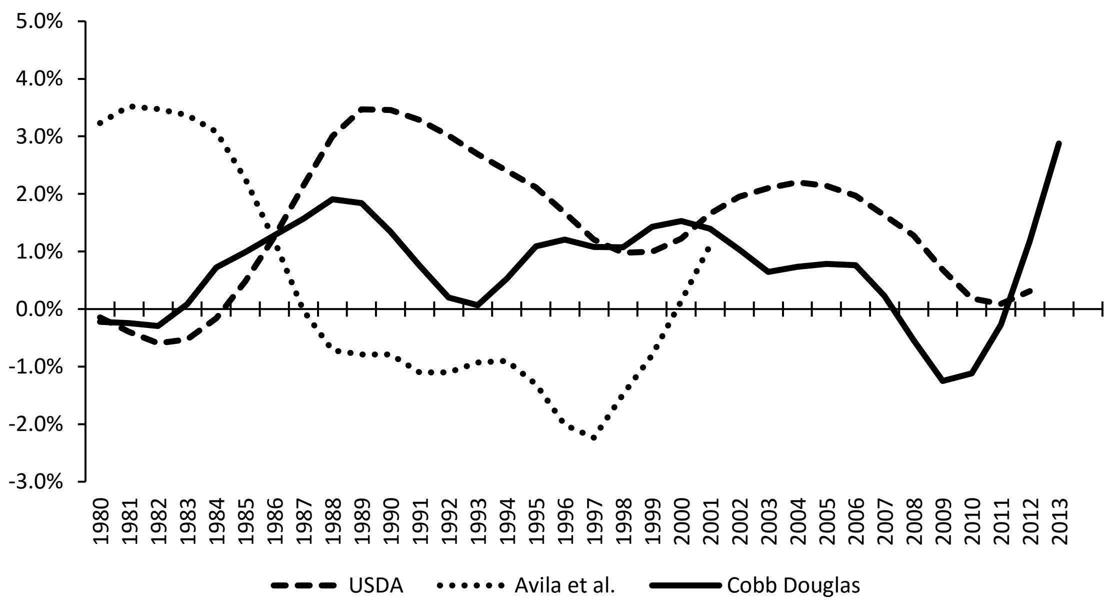
Finally, this study also finds a significant discrepancy regarding the results obtained by Ludena (2010). Although that study does not reveal details on their Colombian TFP estimates, it does indicate that agricultural productivity in Colombia grew on average by 2.4% during the 1980's, 2.5% during the 1990's, and only 0.2% between 2000-2007. In contrast, the present study finds that agricultural productivity grew by an average of 1.0% during the 1980's, 0.7% during the 1990's, and 1.1% from 2000-2007. Also, Ludena (2010) predicts that agricultural productivity exhibited a strong decline during the 2000's, which we do not find.

A possible reason for this discrepancy is that Ludena (2010) used the Malmquist index methodology for measuring agricultural productivity, which exhibits two serious problems: i) it requires a very accurate estimation of the frontier production function, as do other frontier techniques, which is not always possible due to gaps in data for certain sectors (Sena, 2003); and ii) its results are very sensitive to the chosen period, data quality, and outliers (Thirtle et al., 2008). Thus, it is believed that the measurement of this frontier

[72] This is a discrete approximation of the growth accounting technique, using the economic theory of index numbers (Caves et al., 1982; Diewert, 1976).

production function could have exhibited problems, since agriculture in Colombia (as in other countries) is a volatile activity constantly impacted by commodity price volatility, weather, and policy. In addition, it is possible that data availability, which this study found to be problematic for Colombia, could have also affected the measurement of this frontier production function.

Figure 40: Estimated TFP of Colombia's Agriculture using Econometric Techniques versus Estimates from Other Literature (Source: Estimates based on Avila et al., 2010; USDA, 2015).



In brief, this analysis suggests that agricultural productivity in Colombia estimated by this study is very consistent across econometric techniques. Also, our estimates of agricultural productivity seem to accurately reflect the performance exhibited by Colombia's agriculture during the sub-periods established in chapter 2 for the overall period 1975-2013. In addition, this study considers the case in which Colombia's agriculture might have exhibited biased technical change, something that other studies have not yet considered for Colombia. Likewise, it measures the contribution of scale effects on Colombia's agricultural productivity.

8.4 Determinants of Colombia's Agricultural Productivity

This study uses agricultural productivity estimates obtained by assuming a Cobb-Douglas production function and a time-varying trend specification to test whether those determinants suggested by economics literature, such as the typical drivers of agricultural productivity, exhibit a direct impact on Colombia's agricultural productivity. It finds that agricultural productivity will increase by 0.11% per year if the average agricultural R&D investment increases by 1% over the last 7 years; it will increase by 0.9 per year if foreign competence in Colombia's agricultural market increases by 1% of agricultural GDP over the last 8 years; or between 0.12% and 0.14% if human capital increases by 1%. Thus, it finds evidence that agricultural policy in Colombia should mainly consider three elements for increasing agricultural productivity. First, it should promote a steady increase in agricultural R&D investment for developing new farming technologies and technical improvements. This increased investment should also consider funding agricultural extension programs, since these programs are possibly the most efficient way to ensure an effective dissemination of the technical knowledge developed for all Colombian farms. This way, crop productivity might be boosted, since this study finds that it has been stagnant in recent decades. Second, Colombia's agricultural policy should consider a gradual removal of all trade distortions, which have been very strong during the last several decades. This would imply a reduction of agricultural tariffs, which would raise foreign competence in the domestic market and indirectly encourage Colombian farmers to adopt the new technical knowledge developed in the field. Finally, this agricultural policy should promote higher education levels in rural areas. This would ensure good transmission of technical knowledge, since Colombian farmers will be able to comprehend the importance of these new farming technologies in improving their farms' productivity.

Colombia will be able to raise its agricultural productivity in the next decades if it includes these elements in its agricultural policy. Success will depend on implementing a comprehensive policy that incorporates all three elements and is designed with a long-term perspective in mind. Otherwise, efforts to increase Colombia's agricultural productivity will be in vain, and Colombia will continue exhibiting low agricultural productivity similar to the period 1975-2013.

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