THE CASE FOR INCLUDING ADDITIONAL LONG-TERM ORIENTED ENVIRONMENTAL DATA IN COFFEE AND
COCOA FUTURES FORECASTING MODELS: AN EXPLORATION

By

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Abstract

Price discovery is a key function of the futures markets yet limited public information exists about the price-building models used by market participants. To fill a gap in the literature, interviews were conducted with the largest coffee and cocoa traders, investors, and organizations to provide insight into the models they use to forecast supply and futures prices, with an emphasis on the environmental factors considered to have a significant impact on yield. Despite concerns in the academic literature about soil degradation and climate change affecting the future viability of these crops, market participants primarily based their forecasts on short-term weather patterns that deviated from the norm, as per historical data. Participants' near-unanimous acknowledgement that low coffee and cocoa prices pose a threat to the sustainability of the industry suggests that there is room to price in long-term factors into short-term futures models.

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Table of Contents

Author's Declaration for Electronic Submission of a Thesis.....	ii
Abstract.....	iii
Acknowledgements.....	iv
List of Tables.....	vi
List of Figures.....	vi
List of Appendices.....	vi
1. Introduction	1
2. Commodity trading: An Introductory Primer.....	6
3. Structure of the coffee and cocoa markets	8
3.1 History of coffee and cocoa to the present day.....	8
3.2 International crop reference prices	20
4. Plant Phenology and Environmental Conditions for Coffee and Cocoa Production.....	25
4.1 Cocoa.....	25
4.2 Coffee	27
5. Methodology.....	29
6. Qualitative Review of Models Used in the Literature.....	32
6.1 Econometric	32
6.2 Agricultural Sciences	35
Rainfall	35
Temperature	37
Atmospheric Carbon	40
El Niño/La Niña	41
Shade and Soil.....	41
6.3 Bioeconomic Models.....	44
6.4 Models used by market participants	47
7. Synthesis and Discussion	55
8. Conclusions	58
8.1 Recommendations	61
8.2 Opportunities for future study.....	62
8.3 Contribution to the Academic Literature.....	64
Appendix A: Interview Questionnaire.....	66
Appendix B: Variables Considered in Market Participants' Models	67
Appendix C: Variables Considered in Models in the Literature	68
Reference List.....	71

List of Tables

Table 1: Coffee “C” (Arabica) price discounts and premiums by country.....	21
Table 2: U.S. Cocoa Futures price premiums by country.....	21
Table 3: London Cocoa Futures price discounts by country.....	22
Table 4: Summary of optimal growing conditions for both cocoa and coffee.....	29
Table 5: Forecasted change in climate suitable areas for coffee production (excluding protected areas) by 2050.....	38

List of Figures

Figure 1: Worldwide coffee production by country, 2013.....	13
Figure 2: Volume of coffee processed (as % of global trade).....	14
Figure 3: Worldwide cocoa production by country, 2013.....	19
Figure 4: Volume of cocoa processed (as % of global trade).....	19
Figure 5: Cocoa Market Actors.....	23
Figure 6: Coffee Market Actors.....	24
Figure 7: Timing of Harvest Season and Rainy Season in Large Cocoa-Producing Countries.....	27
Figure 8: Timing of Harvest Season and Rainy Season in Large Coffee-Producing Countries.....	28
Figure 9: Summary of coffee market participant responses.....	51
Figure 10: Summary of cocoa market participant responses.....	54

Appendices

Appendix A: Interview Questions for Market Participants.....	65
Appendix B: Variables Considered in Market Participants’ Models.....	66
Appendix C: Variables Considered in Models in the Literature.....	67

Concerns expressed by the scientific community do not always prompt action by coffee stakeholders and policy makers, as there is often a greater perceived need to address short term production and profitability challenges. However, the resource-constrained public and private sectors do not seem to invest seriously in climate change adaptation, as long as 'hard evidence' in immediate export losses (USD) and livelihood impacts are lacking.

- Craparo et al., 2015

1. Introduction

The main objective of this thesis is to understand the potential to better incorporate environmental factors into the forecasting models that are currently used by key players in the coffee and cocoa markets. The expectation is that by doing so, long-term environmental cost constraints associated with coffee and cocoa production will be factored into supply and futures forecasting models, and in this way, more attention will be paid to the importance of addressing the underlying environmental factors associated with these two commodities beyond those that simply affect the next harvest season. It is worth mentioning that there are also social factors that affect coffee and cocoa production (e.g. adequacy of wages, child labour); however, given that the focus of this Master's program is the environmental sciences and researching the contribution of these social factors would enlarge the scope of research substantially, the social factors are not a focus of this work. The author's motivation for pursuing this subject was her previous experience working with coffee farmers in Peru and cocoa farmers in Côte d'Ivoire and seeing vast discrepancies between the economic, social, and environmental conditions which farmers face on the ground and the prices which they are paid.

At the outset, it should be noted that there is limited publicly available information concerning how commodity traders make their decisions, with the specific approaches used being considered carefully guarded commercial secrets. When the research for this thesis began, in the absence of information available to the researcher concerning commodity price-building models that suggested otherwise, the operating assumption for the research was that current commodity pricing models employed by market actors only took environmental factors into effect to a limited extent (e.g. taking

into consideration only major and self-evident environmental shocks like a seasonal drought and not incorporating gradual, long-term environmental changes, such as those associated with climate change, into their models). To develop a better understanding of the environmental factors that are currently being considered in coffee and cocoa forecasting models, interviews with important actors in the coffee and cocoa industries were conducted. The interviews revealed that the market actors collect substantial environmental data on an ongoing basis, both on the ground and through third-party sources, which allow them to estimate yield for the upcoming harvest season. To evaluate environmental factors that significantly affect coffee and cocoa production in the short- (<2 years), medium- (2-5 years), and long-term (>5 years), a review of important works in the scientific and economic literature was employed.

Concerns about the impending shortage of cocoa and coffee have been widely reported in the news (e.g. Sayid, 2013 and Collins, 2012) since 2011 and 2012, when the International Center for Tropical Agriculture (CIAT) and the [UK] Royal Botanic Gardens, Kew published articles that predicted climate change would lead to significant declines in land suitability in areas where coffee and cocoa are currently grown. Despite evidence that long-term, gradual changes are taking place that may significantly affect the production of these two crops, little evidence exists to suggest that these changes are being accounted for in pricing coffee and cocoa.

Coffee and cocoa prices are largely determined by futures markets (see Section 2.2), which bring together hedgers and speculators (defined below) who respectively offload and take on risk, in a regulated market where price discovery occurs in a public and transparent setting. Players in these markets have developed models to forecast supply and demand of these commodities, which in turn are used to estimate futures prices for given delivery dates. Because the nature of these models is proprietary, it is unclear to the public what factors are considered in determining futures prices. The United Nations Principles for Responsible Investment (UNPRI), in its *Responsible Investor's Guide to Commodities* (2011), expressed surprise “by the relative lack of academic research going beyond simple

regression analysis to actually model and understand the complex mechanisms behind price building in futures and spot markets. This is particularly true for certain types of commodities and for behavioural phenomena and herding effects. There certainly is a need for more and better research in this area” (UNPRI, 2011, pg. 14).

Several news articles located by the author that discuss the subject of commodity pricing seem to imply that only environmental “shocks” such as droughts, frost, pests, and disease are considered. For example, Bloomberg reported on October 26, 2014 (Javier, 2014) that increased rainfall in Brazil was driving Arabica coffee futures prices down after months of drought resulting in crop damage had driven up prices by 72% since January 2014. No mention is made of any longer-term environmental factors being taken into account. In a similar vein, on February 18, 2014, The Wall Street Journal published an article entitled “ICE Cocoa Futures Edge Up as Dry Weather Fans Supply Worries” (Wexler, 2014) which detailed the effect of drought in Côte d’Ivoire on futures prices, which rose in anticipation of lower supply. As these articles suggest, extreme weather events in Brazil and Côte d’Ivoire – the largest producers of these commodities – have a significant impact on futures prices and therefore it is not surprising that these visible and easily quantifiable weather effects are given prominence in light of the short-term nature of futures trading. However, is it also reasonable to expect that gradual environmental changes that take place over the long-term (e.g. climate change) would also have an influence on yields, such as an increase frequency of extreme weather events or deteriorating soil conditions (as discussed in greater detail in Section 5.2)? While the interviews conducted for this study revealed that market actors are considering certain environmental data beyond shocks in their models, they have not fully adjusted their models to account for climate change.

As climate change is increasingly accepted as a business risk (Mercer and LGT Capital Partners, 2015), there is a movement in the broader investment community to incorporate environmental, social, and governance (ESG) factors into investment decisions. The world’s leading initiative for responsible

investment, the aforementioned UNPRI, has grown from 100 signatories, primarily institutional investors and asset managers, with USD 6.5 trillion in assets under management (AUM) in 2006 to 1380 signatories with USD 59 trillion AUM in 2015 (UNPRI, 2015a). Signatories of the UNPRI agree to incorporate environmental, social, and governance (ESG) concerns into their investment analyses and decisions. While the initiative was started as a way to promote institutional investors to take on a more active and long-term investment approach in their equity holdings, the incorporation of ESG factors into other asset classes is now also seen as a logical next step, not just for institutional investors but also for the other investment service providers with which they work (UNPRI, 2015b). In 2011, the UNPRI issued a document for commodity investors on how to adopt responsible investment practices, signaling the market's appetite for guidance on best practice in this area (UNPRI, 2011). A study conducted by Mercer and LGT Capital Partners (2015) found that 76% of institutional investors integrate ESG factors in their decisions to invest in alternative asset classes. While the study excluded commodities, what is notable is that 54% of survey respondents only started to incorporate ESG factors in their alternative asset investment decisions in the past 3 years (Mercer and LGT Capital Partners, 2015). Given that commodities are part of the alternative asset class, we may see a push for this kind of analysis being done for commodity trading in the near future.

One major deterrent to progress in the commodity trading space to date has been the financial community's focus on short-term gains. The UNPRI was successful in rallying large asset owners around the cause of responsible investment given that they are long-term investors by nature and therefore should logically be considering long-term ESG risks such as climate change if they are to perform their fiduciary duty. This push for long-termism in the investment community has been renewed over the past few years as a result of a survey conducted by McKinsey and the Canada Pension Plan Investment Board (CPPIB) in 2013 (Barton and Wiseman, 2014) that found pressure for companies to perform in the short-term had actually increased over time, despite 73% of the stock being held by supposedly-long term

asset owners. However, in contrast to the evolving ESG practices of institutional investors, commodity trading by nature is short-term, as futures contracts can only be purchased for fixed delivery dates up to 2 years in advance and often are traded many times prior to the contract closing (UNCTAD, 2012). Nonetheless, given that perennial crops such as coffee and cocoa are inherently affected by longer-term environmental and social factors that extend beyond the length of the futures contracts, this short-term mentality could hinder the growth of the industry. The suggestion made here is that market participants would find it to be in their best interests to incorporate these factors into their models or run the risk of failing to price in an important consideration.

One theoretical framework that supports this hypothesis is that of institutionalization. March and Olsen (1999) define an institution as “a relatively stable collection of practices and rules defining appropriate behavior for specific groups of actors in specific situations.” Institutionalization is therefore the theory that organizations must adhere to certain behavioural norms in the environments in which they operate (DiMaggio and Powell, 1983). Given that commodity traders operate within a broader business context that is beginning to internalize long-term environmental and social costs, it is likely they will also follow. A key objective of this thesis is to determine *which* additional environmental factors could be usefully incorporated into current models to more accurately forecast coffee and cocoa yields in the context of climate change, and better understand the market dynamics that have tended to discourage factoring longer-term variables into the models, and possible pathways to better integration.

The thesis is organized as follows: first, an overview of agricultural commodity trading is provided in Section 2 to establish the market context in which coffee and cocoa operate. This section is followed by a history of the coffee and cocoa markets in Section 3.1, and subsequently, by an explanation of the role of the futures market in determining the international reference prices for coffee and cocoa in Section 3.2. Section 4 details the environmental conditions necessary to produce coffee

and cocoa. With this background information articulated, an overview of the methodology is provided in Section 5, followed by a review of the various crop forecasting models in Section 6. By comparing the models developed in different disciplines in Section 7, an analysis of the key yield determinants is undertaken. Conclusions, recommendations for improving the forecasting tools currently used by the key industry players, and suggestions for further study are elaborated in Section 8. The thesis concludes with an overview on its contribution to the academic literature.

2. Commodity trading: An Introductory Primer

For the purposes of this thesis, before providing discussing the details of the coffee and cocoa markets, it is useful to have a rudimentary understanding of how various agricultural commodities (e.g. wheat, rice, corn, coffee, cocoa) are traded in the global marketplace. Agricultural commodities are traded on two markets: the physical market and the financial market. The physical market involves commercial actors (e.g. producers, traders, exporters, and end users) who buy and sell the commodity, while the financial market trades derivative products – i.e. products that derive their value from the underlying commodity – which provide commercial actors and investors a means of price discovery and risk management. The critical derivative instrument in global agricultural commodities trading on public exchanges is a “futures” contract. “Futures” are financial contracts in which two parties agree on the delivery of a specified amount of a physical commodity at a future date at a particular delivery point that is licensed by the exchange. While only about 3% of futures contracts actually result in the physical delivery of coffee and cocoa (CME Group, 2006), futures prices are used as reference prices for commodities in the physical markets. However, even when the futures contract does not result in physical delivery, it is often linked to the physical trade of a commodity by commercial players who wish to hedge their physical trade. Hedging is a strategy whereby a commercial actor offsets his risk in the physical market by taking an opposite position in the futures market. For example, a coffee farmer that anticipates future coffee prices to fall as a result of an abundant harvest may enter a futures contract to

receive a higher price for his crop than he would receive if he were to sell his coffee on the cash market. For this reason, in the futures market, commercial players are called hedgers, while non-commercial actors (e.g. hedge funds) are called speculators, as they take on the risk of the hedgers with the expectation that they will capitalize on favourable price movements (CME Group, 2013). These players determine their participation in the market by developing models to predict what global demand or supply will be at a given point in time and therefore whether or not the futures contract price works to their benefit.

Trading agricultural commodities through futures markets is a practice that dates back to the first rice futures market in Dojima, Japan in 1722 and popularized by the Chicago Board of Trade (CBOT) between the 1840s and 1860s, when the telegraph and steamship drastically changed the flow of information about supply and demand between continents (Baffes, 2011). Regulated exchanges, such as CBOT, became the preferred avenue through which to trade commodities, as futures contracts guarantee the delivery of a standardized quantity of product at a given date, for a price arranged prior to delivery. Additionally, the exchanges set quality specifications to ensure standardization of the commodity delivered through futures contracts and to eliminate the need for potential buyers to physically assess product quality.

While the early players in the initial futures markets were those that had a commercial interest in the trade of agricultural commodities, like coffee and cocoa, non-commercial interests have increasingly played a role in price formation in recent history. The next two sections will provide an overview of the development of the coffee and cocoa markets the role of the futures markets in determining the price of these commodities.

3. Structure of the coffee and cocoa markets

Coffee and cocoa were selected as the commodities of focus for this study, given the author's previous experience of working with coffee farmers in Peru and cocoa farmers in Côte d'Ivoire. As commodities for study, when compared with other agricultural commodities, coffee and cocoa are of interest for two main reasons: the first being that they are perennial crops, which means that producers have less flexibility to respond to price signals than farmers of annual crops, e.g. corn and wheat. While some other traded soft commodities are also perennial crops – e.g. orange [juice] and cotton – coffee and cocoa are unique in that their production is largely concentrated in 3-4 countries with similar climatic conditions and are predicted to be highly affected by climate change (see Section 6.2). On a global scale, the trade of coffee and cocoa is significant: the global coffee market is estimated to be worth USD 81 billion (Sharf, 2014), while the global chocolate industry is estimated at USD 110 billion (Torre and Jones, 2014). An estimated 25 million farmers earn their living from coffee production (Fairtrade Foundation, n.d.), while 5.5 million farmers are involved in the production of cocoa (Fountain and Hütz-Adams, 2015), the vast majority of whom are shareholders on less than 3 hectares of land. Concerns about coffee sustainability are long-standing, as evidenced by the crop being the focus of some of the earliest voluntary standards addressing social and environmental concerns. Coffee's price drop in the late 1980s was the impetus for the development of the first Fairtrade standard, Max Havelaar; coffee was also the second agricultural crop to be certified by the Rainforest Alliance in 1995, followed shortly after by cocoa in 1997 (Rainforest Alliance, n.d.). Coffee and cocoa markets share a similar history in their efforts to fix prices in the 1960s-1980s through international agreements, instigated by the imbalance between the value captured by producer and consumer countries that persists today.

3.1 History of coffee and cocoa to the present day

To understand the current challenges facing the coffee and cocoa markets, it is useful to understand how these industries developed in the locations that they did and the institutions that were established

to support them. Given the nature of this study, particular attention will be paid to the trade relationships and pricing mechanisms in five of the world's most important coffee and cocoa producing countries: Brazil, Colombia, Vietnam, Côte d'Ivoire, and Ghana.

3.11 Coffee

While coffee cultivation originates from Ethiopia and Central Africa, its trade during Muslim hajj pilgrimages to Mecca resulted in its dispersion to Java, Indonesia, Persia, Turkey, Morocco, and Western Africa in the late 15th and early 16th century (Topik, 2004). Coffee became a popular drink in the Ottoman Empire in the 1550s, allowing it to be traded safely through roads and waterways within the region. At the time, coffee was grown on small garden plots in Yemen and traded not as a commodity, but rather, was treated as an additional source of income for farmers and therefore production levels were low and supply was inconsistent (Topik, 2004). Coffee was purchased by Indian merchants who exported it to the Middle East, Indian Ocean, North Africa, and Europe and controlled the price, which at the time was unaffected by world demand (Topik, 2004). After encountering the crop during trade with Muslim ports on the Persian Gulf and India, the Dutch introduced coffee to Java in the 1690s and forced Indonesian farmers to sell coffee to the Dutch East India Company at a fixed price. The coffee was then transported to the Netherlands, where it was auctioned off in Amsterdam and Rotterdam every six months, then later every 3 months and, as of 1864, every month (Topik, 2004).

In 1714, the Mayor of Amsterdam gifted a coffee plant to King Louis XIV, who then planted it in the Royal Botanical Garden of Paris (NCA USA). The French introduced coffee from Yemen to the colony of Reunion in 1715 and used slaves to grow coffee on large plantations, averaging 200 hectares (Topik, 2004). In 1723, a French naval brought coffee to the Americas, notably the French colonies of Martinique and Saint-Domingue (now Haiti), where coffee was also grown by slaves on large plantations. In the years before and after the French Revolution, French colonies supplied 2/3 of the world's coffee (Topik, 2004).

The French were also responsible for introducing coffee to Brazil, by way of a Portuguese Brazilian official who was gifted the coffee seeds after seducing the wife of the governor of French Guiana in 1727 (Chanda, 2008). The availability of cheap fertile land and slave labour in Brazil allowed coffee production to flourish on large plantations, notably in the Paraíba Valley, north and west of Rio de Janeiro, and in the northeast (Skidmore, 2010). These cheap inputs also caused global coffee prices to plummet after 1820 and remain low until the end of the century, allowing Brazil's exports to jump 75-fold between 1822 and 1899 (Topik, 2004). After the abolition of slavery in 1888 and the expansion of Brazil's rail network in the south, coffee plantations were also established near Sao Paulo, which acted as a hub for coffee exports, as well as a means of attracting European immigrants to work on the new plantations (Topik, 2004). By the 19th century, nearly 80% of world coffee production could be attributed to Brazil, with the country producing 5 times more coffee than the rest of the world combined by 1906.

Spanish Jesuits are credited with bringing coffee to Cuba, Guatemala, Puerto Rico, and Mexico in 1748 and to Colombia in 1790 (Krishnamurthy, 2002). However, the Spanish elite's preference for chocolate over coffee meant that there was a 50-60 year lag between the crop's introduction and its rise as a major export crop (Topik, 2004). This meant that the growth of coffee in Latin America primarily occurred after the countries gained independence from Spain. Nonetheless, in some parts of Colombia, early coffee plantations maintained the Spanish hacienda-style model, run by wealthy Bogota merchants, whereas in other parts of the country, individual farmers began harvesting the crop on large plantations (Roseberry *et al.*, 1995). In 1879, the Colombian government passed the Coffee Act to support and promote the development of the coffee sector, resulting in an increase in production from 6.42 million kilograms to 144 billion kilograms between 1880 and 1920 (FNC, 2000).

In the late 19th century, Continental Europe and the United States became the world's largest coffee consumers, although the UK profited heavily from coffee through re-exports, insurance, and trade (Topik, 2004). In 1870, the arrival of the telegraph connecting New York and London to the South

American coffee-producing countries allowed for information about prices, demand, and supply to be communicated. This predicated the construction of warehouses that stocked a significant portion of the world's coffee, allowing importers to control trade and set prices (Topik, 2004). In response to concerns about price speculation, which caused prices to spike in 1880, the world's first coffee futures market, the New York Coffee Exchange, was created in 1882, providing more institutionalized access to information (Topik, 2004). The establishment of this and later futures markets in consuming countries, such as Germany, meant that Europeans and North Americans, rather than producer countries, were the major beneficiaries of the profits from shipping, insurance, and exportation, as well as the roasting, grinding, packaging, packing, and advertising stages that add 40-50% of the value to the final sale of coffee (Topik and Wells, 2010).

Recognizing the fact that, despite being the world's top coffee producer, Brazil did not control the coffee trade once the commodity left its borders, in 1906, the state of Sao Paulo implemented a price stabilization mechanism, known as "valorization." In an attempt to raise international coffee prices, the government withheld coffee stocks and also encouraged producers to reduce their production by imposing levies on coffee farms (Thurston, 2013). Valorization was repeated in 1917 and 1921 and, following a bumper crop in 1927/28, the Sao Paulo Coffee Institute was established to serve as a more permanent supply-control mechanism, and bought a considerable amount of coffee from the domestic market. After failing to convince other coffee producing countries to agree to production quotas, the Brazilian government burned 68.7 millions of bags of coffee between 1931-38 (Baffes *et al.*, 2005). In 1940, the Inter-American Coffee Agreement saw Brazil join forces with other Latin American coffee producers to fix trade quotas with the US, which saw the accord as a way of assuring that Latin American countries remained in solidarity with the allies during WWII (Thurston, 2013). The 1940 agreement also served to establish greater authority for what would become one of the coffee industry's most important institutions - Colombia's National Federation of Coffee Growers (FNC in

Spanish); the agreement allowed the FNC impose taxes on Colombian coffee farmers and create a national coffee fund which would play an important role in stabilizing prices and investing the industry (Ortiz, 1999). Subsequent pacts and agreements ratified during the Pan-American Conferences introduced other elements of regulation to the coffee market, including the establishment of a minimum price (FNC, 2010). Significant price fluctuations in the coffee markets during the Cold War represented a potential political threat in the Latin American countries where the United States was keen to exert its influence, leading to the signing of an International Coffee Agreement (ICA) in 1963 (Wild, 2004). Administered by the International Coffee Organization (ICO), the agreement allowed the governments of producer and consumer countries to set export quotas in order to manage supply and in turn achieve price stability by ensuring that the price of coffee was always between USD 1.20/pound and USD 1.40/pound (Petchers and Harris, 2008). Producers were allowed to exceed their quotas to meet demand only if the price rose above the ceiling. This quota system remained in place until 1989, when the U.S. – the world’s largest coffee consumer – decided to leave the agreement at the end of the Cold War (Petchers and Harris, 2008). Petchers and Harris (2008) cite additional reasons for the breakdown for the ICA, including: the struggle by producer countries to capture larger quotas, the difficulty of accessing the coffee market by new entrants, and the selling of surplus coffee to non-ICA member countries, thereby undermining prices and member country trust. Ponte (2002) adds that the trend toward market liberalization with in the Reagan/Thatcher era did not support price-fixing cartels like the ICA and rising demand in non-ICA member markets, like the Soviet Union, created a market for non-ICA coffee.

In fact, the Soviet Union and Eastern European countries, which wanted to purchase coffee without paying hard currency, supported the development of coffee production in non-ICA countries, notably Vietnam (Baffes *et al.*, 2005). Because Vietnam was not a member of the ICA, it was not bound by quota restrictions and could therefore increase its production output in the 1980s, allowing it to

begin its ascent to a global coffee powerhouse. While the initial farms were state-owned, reforms in the late 1990s – such as land ownership and liberalized input and output markets – incentivized the production of export crops by smallholders. Between 1993 and 2000, the land used for coffee production increased five-fold, from 101,300 hectares to 561,000 hectares (World Bank, 2011). Vietnam’s coffee boom effectively quashed the efforts of other producer countries to control coffee prices through the development of the Association of Coffee Producer Countries in the wake of the ICA collapse.

Today, the production and processing of coffee remains concentrated in a few countries. According to FAOStat (2013), Brazil produced 33% of the world’s green coffee in 2013, while Vietnam, Indonesia, and Colombia together produced 32% (see Figure 1).

FIGURE 1: WORLDWIDE COFFEE PRODUCTION BY COUNTRY, 2013

Source: FAOStat, 2013

Brazil and Colombia dominate in the production of Arabica coffee, while the majority of Vietnamese and Indonesian coffee is Robusta. The major producing countries all have strong institutions that provide technical assistance and conduct coffee research, but only Colombia’s FNC sets daily reference prices,

linked to the international reference price, at which farmers are guaranteed to be able to sell their coffee to the federation (FNC, 2010). True to their historic roots, coffee production is characterized by large, highly-mechanized plantation estates in Brazil and Vietnam (some of which are still state-owned in the latter), while it is dominated by smallholder farms elsewhere. Europe and the US continue to be the largest consumers of coffee and it follows that 4 out of the 5 traders which account for approximately 40% of the world's traded coffee volumes – Neumann, Ecom, Olam, Volcafe, and Louis Dreyfus – are based in Europe (George, 2014).

FIGURE 2: VOLUME OF COFFEE PROCESSED (AS % OF GLOBAL TRADE)

Source: ITC Coffee Guide, 2012

While the ICA remains in place, it does not include the market intervention provisions that had previously allowed it to effectively manipulate the coffee market. Today, the agreement serves as an industry forum in which member states can collaborate to improve production practices and promote consumption (ICO; UNCTAD, 2011). The ICO continues to serve an important role in collecting and disseminating statistics about global coffee production and trade.

3.12 Cocoa

While cocoa was first planted in Ghana by the Dutch in 1815 and Swiss in 1857, these early attempts were unsuccessful in gaining traction in turning it into an export crop. The widespread cultivation of cocoa in Ghana is attributed to an Accra native, Tetteh Quarshie, who brought cocoa pods home with him in 1879 after travelling to the colony of Fernando Po (now part of Equatorial Guinea), and planting them in the eastern part of the country. Farmers in the region bought seeds from him and planted their own cocoa farms, first in the east and slowly in the west to take advantage of unused forest land. Kolavalli and Vigneri (2011) summarize several factors that contributed to farmers' willingness cultivate new land for cocoa production, notably:

....a fall in the world price of palm oil after 1885, which pushed farmers to search for alternative export crops; a boom in rubber exports in 1890, which provided the capital for the purchase of new land; increasing population pressure in the Akuapem area, which encouraged commercial farmers to go further afield in search of alternative export agriculture opportunities; and the establishment of European produce-buying companies on the coast of West Africa that were prepared to trade the new crop.

The establishment of these farms attracted migrant workers – both domestic and from the neighbouring countries of Upper Volta (now Burkina Faso), Niger, and Mali – who worked the land under a sharecropping arrangement in which they were paid one-third of the price of the cocoa harvested (Kolavalli and Vigneri, 2011). Cocoa profits were invested into new plantations in the west and the industry benefited from the country's new road and rail system in the 1920s.

In the post-war years, cocoa prices rose sharply, as speculators took out loans to purchase and hoard cocoa, limiting the availability of physical supply. In 1921, the speculators flooded the market with cocoa in an attempt to repay their loans and the price of cocoa crashed, resulting in significant losses for many cocoa market participants. Recognizing the stability provided by cotton and wheat futures markets and the significant financial risks involved in transporting cocoa between producer and consumer countries, the New York Cocoa Exchange was established in 1925 as the world's first cocoa futures market (Commodity Research Bureau, 1959).

Britain established the first cocoa marketing board in Ghana in 1947 to ensure access to the commodity, as well as to stabilize prices (Williams, 2009). Like other marketing boards established by the British in West Africa, the board abused its power by taking resources away from the cocoa sector; rather than using the income earned by paying farmers less than the world price to stabilize prices, the money was used for industrialization, stemming inflation, and promoting economic diversification (Williams, 2009). In 1952, and then again in 1961, the Ghanaian government established cocoa-buying companies which gave it complete buying power over the country's cocoa crop. Between Ghana's independence in 1957 and the early 1990s, Ghanaian cocoa farmers were only paid 30-50% of the free on board (FOB) price, compared to 60-80% that Brazilian, Malaysian, Cameroonian, and Ivoirian farmers received during the same period (Williams, 2009). Low producer prices led to a decline in production, culminating in a record low output in the 1983/84 season, when farmers received only 29% of the FOB price. The same year, the government began to make a series of important reforms that shaped the current national cocoa board, Cocobod, notably: cutting down the administration of the cocoa board in order to increase prices received by Ghanaian farmers and ending the state monopsony by allowing private companies to compete with the recently privatized state-run cocoa purchasing company (Williams, 2009). This agreement remains in place to the current day so it is worth clarifying that the private companies do not operate in a fully liberalized environment; rather, they must purchase cocoa from producers at the producer rate and sell the cocoa at a fixed rate to Cocobod, which handles quality control and export to the international market. In the context of regulated pricing, producers are incentivized to sell to the private companies based on the inputs and services they provide, although it is worth noting that Cocobod has a significant mass spraying program and offers highly-subsidized inputs to Ghanaian farmers. The producer price is determined on an annual basis by Cocobod's Producer Price Review Committee based on projected world FOB prices, the projected exchange rate between the US Dollar and Ghanaian Cedi, and the projected crop size (Quartey, 2013).

Similar to Ghana, the first cocoa trees were introduced to Côte d'Ivoire by European missionaries in 1880, though widespread cultivation did not pick up until many years later (de Planhol, 1947). In 1908, the governor of the colony, Angoulvant, began a campaign of forced cocoa cultivation using locally available labor (i.e. slaves). As the locals were not financially motivated by this program, production suffered and, to remedy this, the French colonial government brought in expat workers and supplied them with forced labor (Hopkins, 2014). This model continued until slavery was abolished in the colony in 1946, at which point, local Ivorians rapidly took over cocoa production and promptly replaced the expat workers (Hopkins, 2014).

Following rapid expansion of cocoa production, the French established the Caisse de Stabilisation, a price stabilization mechanism, in Côte d'Ivoire. The Caisse was dismantled in 1999 as part of a series of liberalization efforts promoted by the IMF and World Bank, resulting in an abandonment of price setting. While the cocoa industry prospered despite political instability in the country between 1999 and 2010, new reforms were brought in by the post-civil war government to boost the industry. In 2012 following the model established by their Ghanaian neighbours, a new Ivorian cocoa board – le Conseil du Café-Cacao (CCC) – was founded. The role of the CCC was – and continues to be to this day – to establish a price stabilization mechanism for farmers in response to concerns about volatility and to establish a marketing mechanism to control the sale of 70-80% of the country's cocoa crop through auctions. The CCC guarantees a minimum price of 60% of the CIF (Cost, Insurance and Freight) price.

Similar to the coffee market, cocoa price volatility gave rise to the International Cocoa Agreement (ICCA), which regulated the cocoa trade from 1973-1990, and was administered by the International Cocoa Organization (ICCO). Like the ICA, the ICCA used an export quota scheme and a pre-determined price range between USD 0.23/pound and USD 0.32/pound to stabilize the market (Dand, 1997). Unlike the ICA, the ICCA had a "buffer stock" provision of 250,000 tonnes which was used to meet demand in excess of the agreed upon quotas (Dand, 1997).

The agreements broke down largely due to lack of cooperation between member countries. Dand's (1997) history of the ICCA suggests a gradual breakdown of the cocoa agreement: the third iteration of the ICCA in 1980 was a turning point for the cocoa industry in that it abandoned the quota system and determined the price band based on the availability of buffer stock, effectively raising the intervention prices. Additionally, several key market participants decided not to join the third agreement, notably: the United States, Canada, Australia, Austria, New Zealand, the Philippines, Malaysia, Côte d'Ivoire, Gabon, St. Lucia, Togo, and Zaire. Though Côte d'Ivoire, Gabon, and Togo rejoined the agreement in its fourth iteration in 1986, the new agreement added a withholding scheme to the buffer stock mechanism, which allowed for the withholding of 120,000 tonnes of cocoa from exporting countries if the physical or financial capacity of the buffer stock was exhausted (Dand, 1997). When the buffer stock surpassed its capacity in 1988, member states experienced difficulties in keeping up with levy payments, which led to disagreements on the price provisions, effectively leading to the dismantling of the ICCA's price stabilization mechanisms when the ICCA was extended in 1990.

Like the ICA, the ICCA remains in place without the market intervention provisions that had previously allowed it to effectively regulate the cocoa market. The ICCO continues to serve an important role in collecting and disseminating statistics about global cocoa production and trade, and as an industry forum in which member states can collaborate to improve production practices and promote consumption.

Currently, over 90% of cocoa is grown on smallholder farms, between 2-5 hectares in size. Approximately 70% of world cocoa production is concentrated in West Africa with Côte d'Ivoire accounting for 32% of world cocoa production, and Ghana, Indonesia, and Nigeria together producing another 43% of global cocoa supply (FAOStat, 2013, Figure 3).

FIGURE 3: WORLDWIDE COCOA PRODUCTION BY COUNTRY, 2013

Source: FAOStat, 2013

Like the coffee market, the physical trade of cocoa is concentrated in the hands of very few traders:

Barry Callebaut, Cargill, and Olam (the latter two purchased Archer Daniels Midland's cocoa and chocolate businesses in 2014) process over 50% of the world's cocoa (Nieburg, 2014, Figure 4).

FIGURE 4: VOLUME OF COCOA PROCESSED (AS % OF GLOBAL TRADE)

Source: Cocoa Barometer, 2015 and Nieburg, 2014

However, because of the multiple steps required to turn cocoa beans into a useable input for confectionary and other products, the cocoa value chain is longer than the coffee supply chain: cocoa beans need to be ground and processed into cocoa liquor and butter – usually at the source – before being exported and sold to the chocolate manufacturers. As a result, producer countries benefit from being able to participate in at least some of the processing that adds value to the final product; approximately 45% of cocoa grinding is done in origin countries (ICCO, 2016).

3.2 International crop reference prices

The history of the coffee and cocoa industries reveal a constant struggle between producer countries and the international crop reference price, with several institutions and agreements established in the 20th century to protect producers from wild price fluctuations. In this context, it is worth investigating what is the international crop reference price and how it is established. The price of coffee and cocoa is determined by supply and demand in the futures markets, the most important of which are based in New York and London. The ICE Futures U.S. Coffee “C”, the Robusta Coffee, the U.S. Cocoa, and the London Cocoa contracts are the world benchmark prices for Arabica coffee, Robusta Coffee, and cocoa, respectively (Intercontinental Exchange, 2012a and 2012b). These exchanges are the product of multiple mergers following the initial creation of the New York Coffee Exchange in 1882. To this day, the futures market plays a central role in price discovery, price risk transfer, and price dissemination for coffee and cocoa (NYBOT, 2004).

One Coffee “C” contract represents 37,500 pounds of coffee, while Robusta and Cocoa contracts represent 10,000 tonnes. There are five Cocoa and Coffee “C” contracts throughout the year (March, May, July, September, December) and six Robusta contracts (January, March, May, July, September, November). Cocoa contracts can be purchased up to 23 months in advance, while Arabica contracts can be purchased 35 months in advance, and Robusta up to 18 months in advance.

When discussing the price of commodities, it is important to differentiate between the spot price and the cash price. The spot price is the price of the futures contract if it were sold today, whereas the cash price or the physical price, is the price at the time of delivery and can be calculated by adding the spot price plus the differential (also called the basis), which adjusts for the perceived quality, origin, and point of delivery of the coffee and cocoa (Dand, 1997). To ensure standardization across markets, specific requirements for the number of defects, amount of foreign matter, size and weight of coffee and cocoa beans have been established by the exchanges to determine the premiums and discounts for the Coffee “C”, Robusta, and London Cocoa Futures Contracts. The Coffee “C” and U.S. and London Cocoa contracts also specify certain price premiums and discounts for countries of origin:

TABLE 1: COFFEE “C” (ARABICA) PRICE DISCOUNTS AND PREMIUMS BY COUNTRY

Countries	Discount(-)/Premium(+) per pound
Colombia	+400 basis points
Mexico, Salvador, Guatemala, Costa Rica, Nicaragua, Kenya, New Guinea, Panama, Tanzania, Uganda, Honduras, Peru	At par
Burundi, Rwanda, Venezuela, and India	-100 basis points
Dominican Republic and Ecuador	-400 basis points
Brazil	-600 basis points

Source: Intercontinental Exchange website, as of July 11, 2016

TABLE 2: U.S. COCOA FUTURES PRICE PREMIUMS BY COUNTRY

Group	Countries/Climes	Premium(+) per tonne
Group A	Ghana, Lome, Nigeria, Ivory Coast and Sierra Leone	+USD 160
Group B	Bahia, Arriba, Venezuela, Sanchez, Peru, and Colombia	+USD 80
Group C	Haiti, Malaysia, and all others	At par

Source: Intercontinental Exchange website, as of July 11, 2016

TABLE 3: LONDON COCOA FUTURES PRICE DISCOUNTS BY COUNTRY

Group	Countries/Climes	Discount(-) per tonne
Group 1	Côte d’Ivoire, Democratic Republic of Congo (formerly known as Zaire), Equatorial Guinea, Ghana, Grenada fine estates, Jamaica, Nigeria, Republic of Cameroon,	At par

	Republic of Sierra Leone, Togo, Trinidad & Tobago plantation and Western Samoa	
Group 2	São Tomé and Príncipe and Sri Lanka	-GBP 25
Group 3	Brazil Bahia Superior, Brazil Vitoria Superior, Ecuador and Papua New Guinea	-GBP 50
Group 4	Malaysia	-GBP 75
Group 5	All others	-GBP 100

Source: Intercontinental Exchange website, as of July 11, 2016

The indicator prices published on a daily basis by the International Coffee and Cocoa Organizations represent the cash prices in their respective markets. The International Coffee Organization calculates the price of each coffee grouping by averaging the ex-dock prices paid in the physical markets in the US, Germany, and France, weighted based on the market share that each country represents: e.g. for Colombian Milds, the US prices account for 46% of the indicator price, while the EU markets account for 56% (ICO, 2011). The ICO Daily Composite Indicator Price, which represents the price for all coffee, is calculated as a weighted average of all four coffee groups: 12% Colombian Milds, 23% Other Milds, 31% Brazilian Naturals, and 34% Robustas (ICO, 2011). In contrast, the International Cocoa Organization daily price for cocoa is calculated by averaging the futures prices of the three nearest active trading months on the ICE London Cocoa Futures and the ICE Futures US at the time of closing on the London exchange.

As the focus of this study is on the price discovery models used by futures market participants, it is important to clarify who constitutes a market participant, amongst the many actors in the coffee and cocoa industries (see Figures 5 and 6). Commercial players, which hedge their physical coffee and cocoa trade using futures, include: producer organizations, national coffee/cocoa boards, coffee roasters, cocoa grinders, and chocolate manufacturers. Speculators include a variety of investors, such as hedge funds and index funds that have commodity exposure. While commercial players account for the majority of open interest contracts – i.e. contracts that have not been closed out – in the coffee and

cocoa markets, they account for a smaller percentage of trades. For example, an 11-year study of the NYBOT Cocoa Futures market [the predecessor to the ICE U.S. Cocoa Futures market] found that hedgers accounted for 69% of open contracts but only settled 8% of their positions at the end of the trading session, while spectators accounted for 16% of open interest and settled 24% of their trades (Nardella, 2007).

FIGURE 5: COCOA MARKET ACTORS

*Note that many of the NGOs working to address quality, social, and environmental concerns are doing so in collaboration with the main cocoa grinders and chocolate manufacturers, e.g. The World Cocoa Foundation's Cocoa Action project aims to improve soil fertility and reduce child labour, among other objectives.

Source: Author

FIGURE 6: COFFEE MARKET ACTORS

Source: Author

Figures 5 and 6 reveal that there are many similarities between the structure of the coffee and cocoa markets, although there are a few key differences. Notably, the cocoa supply chain is slightly longer, and therefore involves more actors, due to the fact that cocoa requires more processing prior to becoming a useable product in chocolate and confectionary. Additionally, in the cocoa supply chain, national cocoa boards in Ghana and Côte d'Ivoire effectively control the export of cocoa from the two largest cocoa-producing countries. While coffee boards are present in some of the minor coffee-growing countries, the major coffee-producing countries are primarily organized by industry associations, which play less of a commercial and more of a supportive role (e.g. improving farmer yields, improving quality). Both commodities are embedded in systems where there is significant concern about the sustainability of crop production, as evidenced by the numerous projects aimed at developing new varieties and

improving productivity, supervised by the International Coffee and Cocoa Organizations, as well as numerous NGOs. Social and environmental third-party standards that are recognizable to consumers – e.g. Fair Trade, Rainforest Alliance, Organic – also provide training to coffee and cocoa producers, which can be significant in countries where government-supported technical assistance is minimal. In the cocoa sector, one NGO, the World Cocoa Foundation, is leading an industry-wide initiative called CocoaAction that brings together public (e.g. USAID and ACDI/VOCA) and private (e.g. Barry Callebaut, Cargill, Ecom) actors to address key challenges, such as soil fertility and child labour, and develop climate change adaptation strategies.

4. Plant Phenology and Environmental Conditions for Coffee and Cocoa Production

Having reviewed the market dynamics, it is also useful to understand the physical elements of the coffee and cocoa plants that allow them to produce the crops that are widely traded and consumed. This section will elaborate on plant phenology and the environmental conditions that allow coffee and cocoa to grow in their respective countries. The fact that coffee and cocoa are tropical commodities whose production is largely concentrated in 3-4 countries in similar climatic conditions makes them ideal subjects for a Master's thesis, where limits on scope can assist in evaluating various environmental factors.

4.1 Cocoa

Environmental conditions

Cocoa (*Theobroma cacao* L.) is a crop that is typically grown within 10° north or south of the Equator due to its requirements for hot, humid conditions (although the plant has been cultivated at latitudes as far as 20° north or south). Notably, cocoa can only be grown in environments with a maximum annual

temperature of 30 - 32°C and a minimum average temperature of 18 - 21°C (ICCO, 2013), as higher temperatures can exceed the physiological tolerances of the plant and low temperatures, below 10°C, damage the seedlings during sprouting (FiBL, 2011). In addition to requiring a highly humid environment - 100% relative humidity during the day and 70-80% at night - cocoa production is also depending on heavily rainfall during the year, between 1500-2000mm annually (ICCO, 2013). As the cocoa plant is highly water-sensitive, rainfall of less than 100mm per month over a period of three or more months will result in poorer yields (ICCO, 2013), although a short dry period is necessary to protect the plant against fungal diseases, like black pod (FiBL, 2011). Although cocoa grows naturally in the rainforest and is therefore well-adapted to shaded conditions, new cocoa cultivars have been developed to grow in full-sun conditions. Cocoa grows best in soils up to 1.5m in depth, with 3.5% organic matter in the top 15cm and a nitrogen-to-phosphorus ratio of around 1.5, ideally with a pH of 5.0-7.5 (ICCO, 2013). The optimum altitude for cocoa growth is 100-250 masl (CIAT, 2011), although cocoa can be grown at higher altitudes around the Equator, e.g. in Uganda at 1400 masl (FiBL, 2011).

Crop lifecycle

It takes 3-5 years from when the cocoa tree is planted to the first harvest. When the tree is strong enough to bear fruit, thousands of pink and white flowers form on the trunk and branches; after the flowers are pollinated by insects, some flowers will produce young pods, called cherelles (Dand, 1997). The tree will undergo a process called cherelle wilt, which reduces the number of cherelles that become full, mature pods after approximately 6 months (Dand, 1997). Of the some 10,000 flowers that form on the cocoa tree each year, only 10-50 will develop into pods. These phenological processes are important in that they influence some of the most important physiological yield determinants: fruit morphology, photosynthesis, and maintenance respiration (Zuidema *et al.*, 2005 and Almeida and Valle, 2007).

Cocoa has two harvest seasons (Figure 7), a mid-crop – which generally accounts for 15-20% of production – and a main crop, which generally occurs 5-6 months after the start of the wet season (ICCO, 2014). After a tree begins to bear fruit, it takes 5 years for it to reach its peak productivity period, which continues for another 10 years before it begins to decline. Cocoa has a productive lifespan of approximately 25 years, although can bear fruit for up to 50 years.

FIGURE 7: TIMING OF HARVEST SEASON AND RAINY SEASON IN LARGE COCOA-PRODUCING COUNTRIES

4.2 Coffee

Environmental conditions

While there are approximately 100 species of the coffee genus (*Coffea*), Arabica (*C. arabica*) and Robusta (*C. canephora*) account for 99% of the world's coffee production (DaMatta and Ramalho, 2006). Native to the highlands of Ethiopia, Arabica coffee is typically grown at higher altitudes of 1600-2800masl, while Robusta is from the lowlands of the Congo Basin and grows between sea level and 800masl (Camargo, 2010). Consistently, the ideal mean annual temperature range for Arabica growth is lower than Robusta – 18 - 21°C vs. 22-26°C (Alegre, 1959, as cited in DaMatta et al., 2007). While some varieties of Arabica can adapt to temperatures as high as 24-25°C, quality usually suffers in temperatures over 23°C and its growth is inhibited at temperatures of less than 17-18°C (DaMatta et al., 2007). Both species thrive in an optimum annual rainfall range of 1200-1800mm, though Robusta can

adapt to more intense rainfall exceeding 2000m (Alegre, 1959 and Coste, 1992, as cited in DaMatta et al., 2007). Likewise, Robusta coffee can grow in more humid environments than Arabica, which needs less humidity. Both species require a dry season of 3-4 months that coincides with the coolest period of the year (Camargo, 2010).

Crop lifecycle

Unlike cocoa, which grows in a cauliflorous manner (i.e. the flowers grow from the trunk and branches), sexually mature coffee trees (approximately 3 years old), form nodes on their branches, which then turn into leaves (DaMatta et al., 2007). On these same branches, buds begin to form, which flower following the first rains proceeding the dry season (DaMatta et al., 2007). Not all buds begin to flower at the same time and up to 4 blossoming periods have been observed in major coffee-producing regions, such as Brazil, depending on water availability (Figure 8). Once the flowers open up, they are pollinated, which initiates the developmental stage of the fruit. It takes 8-9 months for a flower to become a ripe cherry. Similar to cocoa, coffee trees take about three years to begin producing fruit, after which it takes approximately 5 years to reach peak production, which continues for 20 years before beginning to decline (Wickens and Greenfield, 1973).

FIGURE 8: TIMING OF HARVEST SEASON AND RAINY SEASON IN LARGEST COFFEE-PRODUCING COUNTRIES

* Note that in some regions, March-June is the main crop season and October-November is the middle crop, whereas in other regions, September-December is the main crop season and April-May is the middle crop.

** Java's main crop season runs from July -September, while November - January represents the harvest season for Sumatra.

TABLE 4: SUMMARY OF OPTIMAL GROWING CONDITIONS FOR BOTH COCOA AND COFFEE

	Cocoa	Coffee
Average Annual Mean Temperature	18-32°C	18-23°C (Arabica) 22-26°C (Robusta)
Average Annual Rainfall	1200-2000mm	1200-1800mm (Arabica) 1500-2000mm (Robusta)
Soil pH	5.0-7.5	4.4-5.4
Soil nutrient values	Nitrogen:Phosphorus ratio of ~1.5 Soil organic matter: 3.5% in first 15cm of soil	P: 20-100mg/kg K: 0.4-2.0mg/kg Ca: 1.6-10mg/kg Mg: 0.8-4mg/kg
Altitude	100-250 masl	1600-2800 masl (Arabica) 0-800 masl (Robusta)

Sources: ICCO, ICO, CIAT, DaMatta and Ramalho (2006), Coste (1992), Wickens and Greenfield (1973), Alègre (1959)

The foregoing background information on commodities trading, the evolution of the cocoa and coffee markets, and the phenology and environmental conditions for cocoa and coffee production sets the stage for an analysis of the various crop forecasting models developed in the academic literature and by the market participants.

5. Methodology

It will be recalled that a key objective of this Master's thesis is to better understand whether additional longer-term environmental factors can and should be incorporated into supply forecasting models used by coffee and cocoa market participants to better reflect evolving growing conditions. In order to understand what *additional* data could be added, it was first necessary to understand what is already accounted for in *current* models. A review of media articles and academic literature was conducted and produced little in the way of granular details concerning current models, probably due to the proprietary nature of these models. However, some high-level themes – such as rainfall, extreme weather events, and pests and disease – were frequently cited as causes of fluctuations in the coffee and cocoa futures markets. The suggestion made here is that coffee and cocoa output is not simply a function of short-term environmental shocks but is also influenced by longer-term evolving environmental conditions, such as climate change and deteriorating soil conditions, which may not be considered in current short-term oriented pricing models given their more gradual effects on yield.

In the absence of detailed information being accessible concerning current models used by cocoa and coffee market participants, a multi-disciplinary and comprehensive review of crop yield forecasting literature was conducted by the author. Specifically, models from the fields of economics, econometrics, agro-forestry, and ecophysiology were studied. This exercise served a dual purpose in first better understanding modelling systems across different disciplines and secondly in assisting in revealing the most important economic and environmental factors that affect coffee and cocoa yield outcomes. The findings of this literature review are discussed in Section 6.

In addition to the media and literature reviews mentioned above, a critical piece of the study was the execution of 15 semi-structured, open-ended interviews with key coffee and cocoa market participants, including investors, traders, roasters, processors, and intergovernmental organizations (see Appendix A for survey questions). These institutions were chosen because they represent both types of players on the futures markets: speculators and hedgers (see Section 2). To determine which

speculators should be included as interview participants, media searches were conducted to identify investors who were considered experts in a given commodity and whose models were based on the fundamentals of the coffee or cocoa industry (i.e. as opposed to quantitative strategies, which do not consider market fundamentals). With the exception of one hedge fund and one bank, the non-commercial actors interviewed were specialized commodity research houses that provide fundamental analysis to the investor community, as well as commercial actors. Hedgers were selected for interviews based on an analysis conducted to identify the largest coffee and cocoa traders and processors by market share. In general, interviewees held the position of head researcher, economist, or trader at their particular institution. The purpose of conducting interviews was to access information about the proprietary models that is not publically reported. The semi-structured interview format was chosen over unstructured or structured interviews as it provided focus through a predetermined set of questions but also allowed for further probing to delve into a given subject. Qu and Dumay (2011) also note that the semi-structured interview “enables interviewees to provide responses in their own terms and in the way that they think and use language.” This flexibility was necessary given the diversity of actors interviewed and the differences in their models (e.g. type of commodity, time horizon, etc.). The semi-structured interview approach was approved by the Ryerson Research Ethics Board.

Following the completion of all interviews, the results were analyzed and compared to the environmental factors cited as affecting coffee and cocoa yields in the academic literature. This analysis allowed for the identification of gaps between the environmental factors in the models used by industry players and those used in forecasting models of other disciplines. Based on the outcome of this comparison, recommendations were developed for the inclusion of environmental factors that may be incorporated into the industry players’ models to improve accuracy. Where possible, the recommendations also included the expected impact of these indicators on crop yield as per the literature review findings.

6. Qualitative Review of Models Used in the Literature

6.1 Econometric

Econometric models of crop yield tend to be fairly homocentric in that they view the producer's decision to plant as being the primary determinant of crop supply and perceive price to be the main factor which affects the producer's decision. Once the producer determines how many units of each crop he wants to plant, econometricians model crop yield using a production function in which the producer is limited by labour and available capital (acreage and technology), with little to no consideration of the environmental constraints that may affect crop yield. The econometrics literature generally only mentions weather and climate variables in discussions of whether they are exogenous or endogenous to econometrics models of crop yield. Several papers note that weather and climate variables are important but data is not readily available or accessible.

In 1956, Marc Nerlove introduced the idea of farmers deciding how much of a crop to plant not based on current prices, but on the price they expect to receive for the crop at harvest time, which is only dependent to a limited extent on current prices. Future crop supply, therefore, can be determined by estimating quantities from futures prices, lagged prices, or prices using an autoregressive model. Using Nerlove's approach, supply shocks due to weather events are considered exogenous to the model, as are potential future supply shocks due to weather. It is important to note that Nerlove's model was developed for annual crops, which are planted and harvested yearly.

Bateman (1965) followed the Nerlovian approach in trying to develop a supply function for cocoa, a perennial crop, assuming that cocoa farmers' future price expectations are based on current prices. Bateman states that the farmer's motivations for planting cocoa and the relationship between

acres planted and output harvested are the two main determinants of cocoa yield, although notes that acreage data isn't available and therefore hasn't been incorporated in his model. Bateman is one of the few econometricians to incorporate cocoa tree physiology in his model by considering the changes in crop yield output due to tree age, as well as climatic factors by considering rainfall. Bateman's model accounts for a lag period between when the cocoa is planted and when it starts to bear fruit (after approximately 8 years), as well as the second increase in yield after 12-13 years (Bateman 1965). The model also considers the importance of rainfall during the main cocoa flowering and fruiting periods in Ghana in determining crop yield. Bateman notes that rainfall also affects humidity, which in turn may produce ideal conditions for "black pod" disease to develop. Bateman found that producers responded differently to prices depending on the soil quality of the region, with farmers operating on Class I soils being less elastic than those operating on Class III soils. His model produced different price elasticities for farmers depending on soil quality, rainfall, and humidity in the areas in which they were operating.

In 1973, Wickens and Greenfield attempted to build upon Nerlove's model to make it applicable to tree crops, such as coffee and cocoa, which take several years to produce fruit. They concluded that Nerlove's model was therefore not as successful for tree crops as for field crops because it did not account for the long lag in productivity. Wickens and Greenfield divided the supply function of their model into 3 parts which explain the structural relationships underlying coffee supply: the investment function, the harvesting decision, and the vintage production function. They note that the reason the model not usually built this way is because of data deficiencies. The investment function shows that the potential production is equal to the number of trees times the average yield of these trees. However, it is difficult to measure the discounted net revenue from production because the productivity of a tree changes over time. Coffee trees take about 3 years to bear fruit, then takes another 5 years to reach peak production, they have a further life of about 20 years, and then yields begin to decline. Therefore, they developed different lag coefficients for years 0-9.

In 2013, Roberts and Schlenker challenged the Nerlovian model, arguing that futures markets incorporate production expectations and therefore the futures price is endogenous to supply. Environmental “shocks” are included as instrumental variables in that they affect inventory, which affects futures prices (Roberts and Schlenker, 2013). Roberts and Schlenker approximate weather shocks using deviations of yield from trend and apply their model to the world’s supply of calories incurred from maize, soybeans, wheat, and rice from 1961–2007. In addition to using yield shocks as an endogenous component, the authors perceive weather variables – average temperature and total precipitation – as exogenous. They concluded: “we found it more practical to use yield shocks (deviations from time trends of output per land unit) instead of using weather directly, which gives a weaker first stage as global annual production has to be linked to aggregate annual weather measures. We obtain similar point estimates using both weather and yield shocks. The use of weather variables instead of yield shocks may be a promising direction for future research. To make such an approach viable will require rich weather data and a parsimonious model linking weather to yield.” (pg. 2292)

Hendricks *et al.* (2014) argue that instrumental variables are unnecessary in crop supply forecasting models because shocks are somewhat predictable and therefore are factored into other components of supply change elasticity, namely total growing area and the composition of growing area across crops and countries. Therefore, the authors suggest adding the yield shock to regressions of growing area and model different regression equations for total growing area and the trend yield to show how adding or removing shocks makes minimal difference in the outcome. They note: “Futures markets can incorporate additional information about exogenous factors affecting planted area—such as excess rainfall preventing planting—at the time of planting rather than in the months preceding planting.” (pg. 8)

6.2 Agricultural Sciences

The scientific literature review was focused primarily on studies that were able to quantify the impacts of different environmental factors on coffee and cocoa yield output. As the purpose of this thesis is to assess the viability of including additional environmental variables in coffee and cocoa forecasting models, the literature review focused on studies that have global applicability, or at least were relevant to the major coffee- and cocoa-producing countries, rather than localized case studies. Within the agricultural science literature, multiple types of models have been developed to predict crop yield which generally take into account weather and climactic variables. The majority of relevant articles focused on the response of plant internal chemistry (physiology) and biological development (phenology, which is influenced by physiology) to the surrounding environment and were generally classified as “ecophysiological models,” although studies that focused on large-scale shifts in climate suitability tended to use the term “agro-meteorological models.” There is also a significant body of work focused on assessing the impact of shade on coffee and cocoa yields, which tend to be categorized as “agro-forestry models.” While the nomenclature is not especially relevant to this work, it is worth mentioning, if only to underscore the fact that many of these models often include the same inputs but are sometimes operating in silos. As such, rather than discussing the models by type, the review of the scientific literature will be organized by the environmental factors that were deemed to be most relevant in forecasting coffee and cocoa yields: rainfall, temperature, atmospheric carbon, El Niño and La Niña events, shade and soil.

Rainfall

The timing and quantity of rainfall appeared prominently in the coffee and cocoa literature. While some studies focused explicitly on the yield impacts of these factors (e.g. Zuidema *et al.*, 2005 and Alvim, 1988), others signaled that changes in precipitation would affect the suitability of areas currently being used for cocoa and coffee cultivation (e.g. Craparo *et al.*, 2015 and CIAT, 2011).

The cocoa literature emphasizes two key points related to rainfall: the amount of rainfall during pod production significantly affects the yield at harvest time and climate change is predicted to change precipitation patterns in West Africa, where approximately 70% of cocoa is grown. Zuidema *et al.* (2005) found that annual radiation and rainfall during the two driest months of the crop cycle accounted for 70% of the variation in bean yield, echoing Alvim's (1988) finding that there is a positive correlation between cocoa yield and rainfall up to 6 months before the harvest period. Mariano and Monteiro (1962, as referenced in Almeida and Valle, 2007) found that pod production decreased by 60% after a multi-week flooding. Given that the timing of precipitation is relevant to cocoa yields, it is significant that Owusu and Waylen (2013) were able to show that changes in seasonal rainfall have already started to occur in Ghana. Notably, between the time periods 1951-1970 and 1981-2000, Owusu and Waylen (2013) observed shorter rainy seasons and reductions in rainfall of 20mm-80mm during both the major and minor rainy seasons. These findings are consistent with one of the most widely-cited studies on climate suitability for cocoa, which predicts that by 2050 in Ghana and Côte d'Ivoire, there will be less monthly and yearly rainfall, with a decrease in the number of dry months from 4 to 3 (CIAT, 2011). While other climate models for West Africa predict decreases in precipitation (Held *et al.*, 2005; Laux *et al.*, 2008; Adiku and Stone, 1995), some predict increases (Haarsmaa *et al.*, 2005); Dietz *et al.* (2004) and Minia (2004) indicate that wetter areas will become wetter and drier areas will become drier. Christiansen *et al.* (2007) anticipate a 20% increase in high-intensity rainfall events, flooding, and very wet seasons in West Africa. Given the importance of the timing of rainfall, these predictions are likely to negatively impact the suitability of Ghana and Côte d'Ivoire as cocoa-growing regions.

The coffee literature emphasized the timing of rain, as "relatively modest changes in rainfall have little or no relation to the longer-term yield and production variability" (Craparo *et al.*, 2015). Yet, coffee is not a very drought-resistant crop; only some cultivars can survive 6-7 months without rain at the expense of strong declines in yield (DaMatta and Ramalho, 2006). As such, the distribution of rainfall

during the coffee lifecycle is critical. Rainfall dispersed over many days during the flowering period causes unsynchronized fruit ripening following the dry, dormant period (Craparo *et al.*, 2015 and DaMatta *et al.*, 2007). Because of this effect, in a study conducted by Craparo *et al.* (2015), yield was negatively correlated to a higher number of days of rainfall during the flowering period. Similarly, by analyzing the influence of temperature and rainfall on key stages of the coffee lifecycle in Brazil, Dos Santos and Camargo (2006) found that the most important variable in predicting yield was water availability during the flowering and coffee bean formation phases of the coffee lifecycle (Dos Santos and Camargo, 2006). Because of the importance of rainfall at these critical stages of the coffee lifecycle, the coffee literature – similar to the cocoa literature – indicates that changing rainfall distribution and quantity may negatively affect coffee yields. One coffee climate suitability model predicted, by 2050, a decrease in the number of dry months from 6 to 5 in Central America, from 7 to 6 months in South Africa, and from 5 to 4 months in East Africa, while the Andes would see an increase in the number of dry months from 1 to 2, and there would be no change in Brazil (Ovalle-Rivera *et al.*, 2015). However, the latter two regions would experience changes in the amount of precipitation: an estimated decrease of 50mm during the dry season in Brazil and an increase of 100-170mm during the wet season in the Andes (Ovalle-Rivera *et al.*, 2015).

Temperature

The literature on temperature focuses primarily the extreme cold and hot limits that coffee and cocoa can withstand (e.g. DaMatta and Ramalho, 2006), as minimal evidence exists that slight changes in temperature have an effect on yield. As such, many of the reviewed works focused on the potential climate suitability for coffee and cocoa in key producer regions in light of the anticipated climate change effects (e.g. CIAT, 2011 and Ovalle-Rivera *et al.*, 2015). For example, a 2011 study by the International Center for Tropical Agriculture (CIAT) on the impact of climate change on cocoa-growing regions in Ghana and Côte d'Ivoire found that under current IPCC climate change predictions, by 2050, the average

annual temperature will increase by 2.1°C and the optimum altitude at which to grow cocoa will rise from its current optimal level of 100-250 metres above sea level to 450-500 masl (CIAT, 2011). Of all the bioclimatic variables analyzed, the authors concluded that the temperature of the warmest month was the most important factor in determining climate suitability for cocoa production, accounting for 25.3% of the change in suitability (CIAT, 2011).

Some of the same CIAT authors replicated the climate suitability model for Arabica coffee in 19 countries. Ovalle-Rivera *et al.* (2015) used 19 bioclimatic variables, which were primarily focused on temperatures and precipitation levels at various times of the year, to predict climate suitability in 2050, using the 21 global circulation models (GCM) in the IPCC’s fourth assessment report for scenario A2a. Using the most pessimistic GCMs, 33% of current coffee area would lose 40% climate suitability and half of the coffee area would lose 20-40% suitability; the most optimistic scenario found that 34% of the current coffee area would lost 10-40% suitability and the median scenario showed a loss of 20-40% suitability for 37% of the current coffee area and a loss of 10-20% suitability for 27% of the coffee area (Ovalle-Rivera *et al.*, 2015). The authors found that current coffee growing areas at lower altitudes would generally experience the most significant decline in climate suitability, which is most concerning for countries that do not have any land at high altitudes, such as Nicaragua, El Salvador, and Brazil (Ovalle-Rivera *et al.*, 2015). On the other hand, countries with mountainous areas such as Peru, Ecuador, Colombia, Guatemala, Mexico, Honduras, and Costa Rica would gain climate suitability at higher elevations, which may offset the losses at lower altitudes (Ovalle-Rivera *et al.*, 2015, Table 5).

TABLE 5: FORECASTED CHANGE IN CLIMATE SUITABLE AREAS FOR COFFEE-PRODUCTION (EXCLUDING PROTECTED AREAS) BY 2050

Country	Average change in climate suitability by 2050
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Mexico	-29%
India	-28%
Honduras	-27%
Brazil	-25%
Vietnam	-25%
Tanzania	-22%
Costa Rica	-20%
Ecuador	-20%
Peru	-20%
Bolivia	-20%
Guatemala	-19%
Indonesia	-18%
Colombia	-16%
Kenya	-12%
Ethiopia	-11%
Papua New Guinea	-9%
Burundi	-9%
Rwanda	-9%

Source: Ovalle-Rivera *et al.*, 2015

The authors note that various CIAT partners conducted regional climate suitability assessments for Nicaragua (Laderach *et al.*, 2010), México (Morales *et al.*, 2013 and Schroth *et al.*, 2009), El Salvador, Costa Rica, Honduras and Guatemala (Haggar *et al.*, 2011 and Laderach *et al.*, 2010), Brazil, Tanzania and Vietnam (Haggar *et al.*, 2011) and Indonesia (Schroth *et al.*, 2014). Outside of the CIAT group, Camargo conducted a similar review for Brazil (2008).

The papers that focused on the physiological impacts of temperature changes highlighted the impacts of temperature extremes but were less alarmist about the effects of changing temperatures on coffee yields. Coffee is very sensitive to cold weather and photosynthesis almost stops entirely when the temperature reaches 5-10°C; even a few days being exposed to cold weather can inhibit CO₂ uptake (Larcher, 1981 as cited in DaMatta and Ramalho, 2006). High temperatures during the flowering period may halt blossoming (Camargo, 1985), while extremely high temperatures during photosynthesis may cause the fruit to grow faster than the photosynthetic resources available, resulting in smaller cherries (Dos Santos *et al.*, 2015). However, if coffee is exposed gradually to cold or hot weather, the coffee plant

might be able to acclimate (Quartin *et al.*, 2004 and DaMatta, 2004). For this reason, DaMatta and Ramalho (2006) were skeptical about the findings of a 1968 study conducted under controlled and constant conditions that observed a 10% decrease in Arabica yield for every 1°C increase in temperature above 24°C (Nunes *et al.*, 1968).

Despite these models, a recent study was able to prove that climate change has already had a negative effect on Arabica coffee yields in Tanzania. By observing climate variables between 1961 and 2012, Craparo *et al.* (2015) found that increasing night-time temperature, or minimum temperature, was the single most important factor in declining coffee yields. Based on this result, the authors predict that every 1°C increase in minimum temperature will result in annual crop yield losses of $137 \pm 16.87 \text{ kg ha}^{-1}$ (Craparo *et al.*, 2015). While similar analysis has yet to be done on a global level, the findings of this paper are significant in light of minimum temperatures increasing faster than average temperatures, particularly in countries like Tanzania, whose minimum temperature is on the cusp of suitability for coffee growth.

Atmospheric Carbon

There is evidence to suggest that the impact of increasing temperatures on coffee might be mitigated by rising atmospheric carbon, which is expected to increase by $450\text{--}600 \mu\text{L L}^{-1}$ by the year 2050 and between 730 and $1020 \mu\text{L L}^{-1}$ by 2100 (Dos Santos *et al.*, 2015). Ramalho (cited in Dos Santos *et al.*, 2015) found that under enhanced CO_2 conditions of $700 \mu\text{L L}^{-1}$ photosynthesis in coffee plants was unaffected up to a temperature of 37°C. Similarly, Ghini *et al.* (2015) found that under higher CO_2 conditions ($550 \mu\text{mol mol}^{-1}$) yields increased by 14.6% and 12% for coffee cultivars Catuaí and Obatã. Van Oijen *et al.* (2010a) found that doubling the atmospheric CO_2 concentration increased coffee production and carbon sequestration, which also made nitrogen fertilization more effective. While the cocoa literature did not emphasize atmospheric carbon as a significant contributor to yield, as a C3

plant, higher atmospheric carbon will increase the plant's photosynthetic rate, which can have a yield impact – albeit one that has not yet been quantified.

El Niño/La Niña

A study conducted by the International Cocoa Organization analyzed the impact of El Niño and La Niña weather events on global cocoa supply between 1950 and 2008. The study found that El Niño weather events reduced world cocoa supply by 2.43%, resulting in a corresponding price increase of 1.66%, while La Niña events did not have a significant impact on world cocoa supply (ICCO, 2010). However, El Niño events impacted the cocoa yields of some countries more than others; notably, El Niño resulted in a decrease of cocoa supply in Ecuador by 6.16, in Indonesia by 2.39%, in Côte d'Ivoire by 2.03%, in Ghana by 1.72%, and in Nigeria by 1.15% (ICCO, 2010). In only one country did the study find that La Niña had a statistically significant impact on cocoa yield, with an increase of 1.68% observed in Papua New Guinea, which the authors attribute to reduced pests and disease (ICCO, 2010). On another note, the study found that 17 El Niño and 13 La Niña events between 1950 and 2008 affected cocoa supply over 18 cocoa cycles, meaning that the impact of some of the events lasted more than one season. The authors highlight that one limitation of the study was the use of annual cocoa production figures, rather than monthly production figures, which would have allowed for stronger analysis of the impact of El Niño and La Niña during key crop cycle events, notably pod development. While the ICCO study focused on the impact of El Niño and La Niña directly, another study conducted in Indonesia found that El Niño-induced droughts reduce cocoa yield by 62% (Keil *et al.*, 2008).

Shade and Soil

In general, most researchers agree that shade decreases crop yield but that it may be beneficial in sub-optimal conditions because it “reduces photosynthesis, transpiration, metabolism and growth and therefore, the demand on soil nutrients and so enables a crop to be obtained on soils of lower fertility”

(Purseglove, 1968). Vaast *et al.* (2006) found that coffee grown in sub-optimal conditions in Costa Rica over a 3-year period yielded 16% less under full sun than dense shade and 49% less under full sun than light shade; however, in optimal conditions, artificial shade reduced coffee yield by 18% compared to full sun. Pinard *et al.* (2014) also found that coffee yields increased by 55% under the shade of non-leguminous trees (especially *P. americana* and *F. thonningii*), which provided low light interception at the canopy level and enriched the soil with potassium, calcium, and magnesium. Lin (2009) found that 60–80% shade cover reduced soil evaporation on coffee plots by 41% compared to coffee grown under low-shade conditions (10–30% cover). Even with 30–65% cover, Lin (2009) observed that soil moisture was maintained during the dry season, which could possibly be explained by the presence of trees that draw water from higher to lower layers of the soil column (Burgess *et al.*, 1998).

The agro-forestry models of John Beer (1987, Beer *et al.* 1998) have been some of the most influential as applied to the coffee and cocoa sectors. Beer details the advantages and disadvantages of using shade for coffee and cocoa cultivation; specifically, shade can help to improve climatic and site conditions by reducing air and soil temperature extremes, reducing wind speeds, buffering humidity and soil moisture, and improving or maintaining soil fertility (Beer *et al.* 1998). The reduced quality and quantity of light available to the crop tree allows for an avoidance of over-bearing in coffee and excessive vegetative growth for cocoa and therefore could be beneficial for farmers that do not have access to fertilizers (Beer, 1987); however, on the other hand, shade may limit yield potential due to reduced sunlight, cause increase competition for water, and increase the occurrence of pests and disease in some areas (Beer *et al.* 1998). Beer concluded that shade trees could help to protect against adverse weather conditions, notably by buffering temperature fluctuations of up to 5°C and producing up to 14 Mg ha⁻¹ yr⁻¹ of litterfall and pruning residues, containing up to 340 kg N ha⁻¹ yr⁻¹ (Beer *et al.* 1998). Shade was found to increase the incidence of some pests and diseases, such as *Phytophthora*

palmivora and *Mycena citricolor* and decrease others, such as *Colletotrichum gloeosporioides* and *Cercospora coffeicola*.

Several long-term studies in Ghana (Ahenkorah *et al.*, 1974; Dawoe *et al.*, 2014; Tondoh *et al.*, 2015; and Vanhove *et al.*, 2016) found that non-shaded cocoa plantations experienced faster soil degradation than their shaded counterparts and therefore required more fertilizer. Ahenkorah *et al.* (1974) found that non-shaded cocoa trees that were continuously cropped yielded three times more cocoa than shaded cocoa trees over the 17 year study period. However, this intensive cropping was found to only be useful for 10 years, after which, nitrogen and organic soil carbon decline and only begin to recover after 15-20 years (Tondoh *et al.*, 2015 and Dawoe *et al.*, 2014). Vanhove *et al.* notes that Ahenkorah *et al.*'s study ended around the time when yields would begin to decline, and therefore used a 22-year old cocoa plot needing rehabilitation as their area under study. Yield outcomes in Vanhove *et al.*'s study were variable, depending on the clone of cocoa planted, which they attribute to physiological differences; while one clone was found to have a 46% higher yield in an agro-forestry system, another was 20% lower under shade (2016). One of the main takeaways from this study was therefore that varieties of cocoa able to adapt to local conditions and better resist pests and disease may be the best way to rehabilitate old plantations.

One of the most comprehensive coffee studies done of late has come from van Oijen *et al.* (2010a, 2010b), who conducted a literature review of coffee agroforestry systems in Central America to identify quantitative data in order to create a process-based agroforestry model. They found that most of the models in the literature either contained qualitative data or quantitative data on coffee trees, shade trees, and soil that are only applicable to specific sites (van Oijen *et al.* 2010a). Despite finding significant gaps in the availability of data, they were able to create a model that can capture the underlying mechanisms and processes of coffee growth more generally. After running simulations that

looked at the system without shade trees, with one environmental factor changed or shade tree species substituted, and with different weather conditions, the authors found that coffee yields tended to decrease with tree density, regardless of whether or not the trees were nitrogen fixers.

6.3 Bioeconomic Models

Bioeconomic models, as the name suggests, include both biophysical and economic data, making them ideal for multidisciplinary study. In his review of this integrated model type, Douglas R. Brown (2000) found that there is a spectrum of bioeconomic models, ranging from biological process models that include an element of economic analysis to economic optimization models that include bio-physical components, with integrated models that capture the interaction between economic and biophysical processes in the middle. Typically, bioeconomic models have been used to determine the economic outcome of policies and, in the realm of agriculture, how certain economic factors will affect farm income. For example, Diao and Sarpong (2007) used a bioeconomic model to assess the effects of land degradation in Ghana on agricultural gross domestic product. However, some studies have explicitly used bioeconomic models to assess the impacts of environmental factors on commodities prices – e.g. the previously cited ICCO study on the impacts of El Niño and La Niña weather events found that the 2.43% decrease in world cocoa supply resulted in a price increase of 1.66% (ICCO, 2010). This type of interdisciplinary model more closely resembles the models of commodity market participants than any of the aforementioned model types and therefore is of interest to this study.

Brunner (2002) created a model to determine the impact of El Niño Southern Oscillation (ENSO) weather events on the prices of the 30 non-oil commodities included in the International Monetary Fund's commodity price index. Using sea surface temperatures and sea-level air pressure anomalies in the Pacific Ocean as ENSO variables, and average CPI inflation, average GDP growth, and real commodity price inflation as economic variables, Brunner found that a one standard deviation in a positive ENSO event raises real commodity prices by 3.5-4% and that 20% of commodity price inflation movements

between 1964 and 2000. However, as coffee and cocoa only account for approximately 7% of the index, the results for these two commodities were not as strong, nor were they found to be statistically significant at the 5% level; the model showed that a one standard deviation in positive ENSO event would decrease coffee milds prices by 4.7% and increase Robustas and cocoa prices by 0.9% and 2.4%, respectively (Brunner, 2002).

In 1995, Ruf created a bioeconomic model to correct what he saw as shortcomings in the speculative models, namely that they use too short of a time horizon and that they cannot account for shifts in production centres. Ruf (1995) developed a list of 15 basic cocoa “laws” of supply: forest rent; the interaction with forest rent and other natural resources; monoculture; labour rent; tree capital; monetary capital; accumulators and family support; institutional factors; information, plant material, and pre-conditions for a boom; farming household life cycles; price; land holding rent; sales cycles; dual nature of smallholdings and estates; and state interventions. The model aims to understand the linkage between cocoa cycles, price, cost, and changes in cocoa supply centres (Ruf, 2005). Unique to Ruf’s model is his notion of “forest rent”, which is defined as the difference in cost between one tonne of cocoa produced on a plantation created after forest clearance and tonne of cocoa produced by replanting on fallow land or after the felling of the first plantation (Ruf, 2005). The idea behind this concept is that the forest provides many ecological benefits, such as soil fertility; protection against erosion, pests, disease, and wind; and moisture retention. Without considering these factors in pricing models, Ruf estimates that the hidden and externalized costs of deforestation therefore account for 80-100% of the cost to establish a plantation (Ruf, 2005). In the long-term, farmers that are best equipped to capitalize on this “forest rent” are those with the technical know-how to exploit it for long-term gain.

Fleming and Milne (2003) developed bioeconomic models to help policy-makers set priorities for the cocoa industry in Papua New Guinea. The authors developed two models, one for smallholders

and one for estates, both of which included estimates of economic surplus; tree or palm area; land suitability; input-output relations; break-even values; export volumes and values; export price formation; and domestic price formation (Fleming and Milne, 2003). The models assessed various price policies to determine their effectiveness in maximizing economic surplus, including: short-term output price support; price stabilization; exchange rate manipulation; counter-cyclical planting subsidies; subsidies on purchased fertilizer inputs; and policies influencing the opportunity cost of rural labour (Fleming and Milne, 2003). Of these different policy options, the authors found that fertilizer subsidies (a 10% reduction in the price of fertilizer) had the greatest impact on yield, increasing yields by 10% and economic surplus by 7% on smallholder farms and 9% on estates (Fleming and Milne, 2003). Quoting Allen *et al.* (1995), Fleming and Milne (2003) caution that the effectiveness of fertilizer decreases over time and agricultural intensification can lead to land degradation.

Gay *et al.* (2006) developed a multiple regression model with both economic and climatic determinants of coffee production in Veracruz, Mexico to understand how coffee yields may be affected by climate change. The climatic variables assessed were seasonal rainfall, seasonal temperature, and the variance from these mean seasonal values (i.e. extreme weather events), while the economic variables assessed were: real minimum wage in the state of Veracruz, coffee prices in Veracruz, international coffee prices, Veracruz state population, coffee stocks in Mexico, coffee stocks in the United States, and a producer price index (Gay *et al.* 2006). Using projections of climate change for the year 2020, which include a 41.2% decrease in average spring rainfall and 8.6% increase in average winter temperature from a 1990 baseline, the authors estimate a 24.5% decrease in coffee production in the state of Veracruz (Gay *et al.* 2006). This decrease is even more pronounced in the scenarios in which the state government decides to raise minimum wage rates, as labour costs represent the highest input cost for coffee farmers in this region (Gay *et al.* 2006).

While the aforementioned bioeconomic models vary considerably in their outcomes, they are worth highlighting in that they are similar in structure to the models used by the coffee and cocoa market participants, who consider both economic and environmental variables in the crop yield and futures price forecasts.

6.4 Models used by market participants

In light of the absence of publically-available data about the price-building models used by futures markets participants, it was necessary to speak directly to them to understand the factors they include in their models. To collect data about factors considered in the crop forecasting models used by market participants, interviews were conducted by phone with 15 key players in the coffee and cocoa markets, representing both speculators and hedgers. Speculators were selected based on their expertise in a given commodity, identified through media searches, and commercial traders were selected based on their prominence in the coffee and cocoa markets. While the initial understanding was that all market participants selected for interviews used these crop forecasting techniques as part of their futures price forecasting models, some interviewees indicated that they did not model futures prices and only had crop supply and demand forecasts. Those that did model futures prices almost unanimously indicated that demand for coffee and cocoa was fairly stable (2-5% annual growth), therefore crop supply (2-4 times more variable) accounted for the bulk of futures price movements (anywhere between 20-100%). These proprietary models are largely used by physical traders to determine their positions in the market and for supply planning, while the brokers/research houses use this information to guide others in taking a position on the market. Based on the nature of the futures markets, the time horizon of these models are 6 months – 2 years. However, research revealed one industry organization interviewed also has a longer-term model which is qualitative in nature, in addition to its short-term forecast.

The means by which market participants forecast crop supply is by estimating the amount of a commodity stored from previous seasons and the yield from the current season. Stocks are particularly important to the coffee market, as coffee stores quite well in the regions in which it is grown, while cocoa is not stored for as long, given its susceptibility to mould and bacteria in hot, humid production areas. Of particular interest to this study, however, is that in forecasting coffee and cocoa output for a particular season, interviewees rely on historic weather data to determine the magnitude of a particular environmental factor or event on crop output, based on the yield effect in the past. One interviewee succinctly described the challenge of using this approach in the context of 2015 being the driest winter in West Africa in recent history: “When you look at a weather event that only happens once every 60 years because you’ve never seen these circumstances, you can’t really get good data.” Another noted that greater variation in weather patterns year-to-year and more frequent weather events have a significant impact on other environmental factors, which are not adequately captured in the models. Nonetheless, the standard approach involves making assumptions on what is considered to be “normal” weather and modelling expected deviations from the norm. As a result of this approach, market participants do not use attribution factors or coefficients to explain the effect of individual environmental variables on crop yield but rather go by “gut feel” or “experience” to estimate the magnitude of the impact.

Like the econometric models reviewed in the literature, market participants consider price to be a determinant in forecasting crop supply. Price determines how much stored coffee and cocoa will be traded and will also influence producers’ decision to plant new trees. Interviewees expressed difficulty in estimating stocks and noted that they were often caught off-guard by how much coffee and cocoa flooded the markets when prices were high. Producers also plant new trees when prices are high, even though the trees will not begin to produce for several years, when the additional crop supply usually has a deflationary effect on prices. One of the most interesting findings to come out of the interviews was

the near unanimous agreement that the biggest challenge posed to the long-term viability of the coffee and cocoa markets was that prices are not high enough to keep farmers in the market or attract new farmers. This was seen as particularly problematic for the cocoa industry, as cocoa trees and farmers are aging and productivity is low as a result of producers not being able to afford fertilizers. On a related note, other interviewees also mentioned the fact that farmers lack access to capital and start-up costs for coffee and cocoa are highly capital-intensive; therefore, it is possible that farmers will begin to use their land for other, more lucrative crops.

Coffee

By far the most common factors included in the coffee forecasting models were temperature and volume of rainfall (both included in 73% of the models), with timing of rainfall and farmers' use of inputs as close seconds (both included in 64% of the models). Coffee market participants indicated that this weather data was readily available from the largest producing countries, Brazil and Vietnam, and therefore daily temperatures and rainfall were included in the coffee forecasting models; data availability for other countries meant that they could only track temperature and rainfall on a weekly or monthly basis. The timing of the rainfall was considered particularly important during key points of the crop cycle, namely flowering and the dry period. Participants indicated that not enough rain during the flowering period and too much rain during the dry period could result in lower crop yields. El Niño and La Niña weather events were also considered relevant by 36% of interviewees in predicting the amount of rain during a given period; as one interviewee explained: "Sometimes it [El Niño] brings extra rain at the right time, sometimes at the wrong time". One interview participant explained that stronger El Niño is associated with more rainfall in Brazil and below average rainfall in Vietnam. The inclusion of this data reflects the market participants' attitudes of the importance of data coming from Brazil and Vietnam versus the other coffee-producing countries (27% of interviewees specifically identified weather events

in Brazil – e.g. droughts, frosts – as a factor that affects coffee supply). Accordingly, 36% of interview participants considered the biennial coffee production cycle in Brazil to be relevant in forecasting coffee yield, vs. the 18% of interviewees that indicated the previous year’s production was relevant to forecasting the current year’s yield. One interviewee elaborated on the fact that the yield differences between years can be attributed to the fact that coffee farmers do not prune all of their coffee trees at once; although this is starting to change in Brazil, where the yield differences between years are becoming less pronounced.

Coffee market participants interviewed for this study indicated that more important than forecasting the NY “C” Coffee Price was the ability to forecast the differential between the NY “C” Coffee Price and the prices for Brazilian Milds, Colombian Milds, Other Milds, and Robustas. In this regard, it is worth noting that 27% of interview participants included shade in their models for Central American production, as they indicated that shade could help in mitigating hotter than normal temperatures and handling rust outbreaks. 45% of interviewees indicated that pests and disease could negatively affect coffee production and many linked the outbreak of certain diseases to weather patterns. The same number of interview participants indicated that farm maintenance was important and several participants highlighted the disparity in yields between the different systems used in the major coffee-growing countries: large estate plantations in Brazil and Vietnam vs. smallholder farms in Central America. In addition to pruning practices previously mentioned, part of the difference in the farm maintenance highlighted by the interviewees was the use of inputs; access to pesticides and fertilizers was largely seen as a function of coffee price, with price-sensitive smallholders having less access to inputs than the larger producers.

Unlike cocoa market participants, few coffee market participants cited crop cycle events as being relevant to yield outputs (18% mentioned node growth and cherry count, 27% mentioned

flowering) and even fewer interviewees (9%) indicated that altitude, soil moisture, or humidity were relevant factors in their models.

FIGURE 9: SUMMARY OF COFFEE MARKET PARTICIPANT RESPONSES

Cocoa

Cocoa market participants clearly indicated that pod count and volume of rainfall were the key determinants in forecasting cocoa supply (included in 78% of the models), while 56% of interviewees also considered the timing of rainfall and the Harmattan [a dry wind that passes over West Africa] to be key factors. Shade was considered to be the next most important factor (included in 44% of models),

while temperature, soil moisture, El Niño/La Niña weather events, and farm maintenance were included in one-third of the models.

In contrast to the major coffee-producing countries, interview participants indicated that temperature and rainfall data are extremely difficult to access in Côte d'Ivoire and Ghana, and therefore there appeared to be an information imbalance between market players. Specifically, cocoa market participants with substantial operations on the ground, mostly the physical traders, had their own meteorological stations in the major cocoa-growing regions. This afforded them access to the most accurate weather rainfall data, while other market participants were reliant on third-party weather data, which was generally from a meteorological station close to a major airport, far away from the cocoa-growing regions. Those with their own weather stations were able to monitor temperature and rainfall on a daily basis, while most other interviewees mentioned that they looked at a 10-day weather cycle. One interviewee explained that, compared to coffee, temperature is less important than rainfall in predicting cocoa yield, given that temperatures are relatively stable in the major cocoa-producing countries.

In the absence of reliable data on the area of land under production, cocoa market participants relied heavily on teams on the ground to conduct pod counts to estimate yield. Interviewees explained that pod counts were done by having local teams visit the same sample group of trees to compare the number of pods to previous seasons. Using the crop output from previous seasons allows them to forecast crop yield for the current season, based on the number of pods on the trees. Historical data also assists participants in estimating the survival rate of pods during certain weather events. One interviewee explained that her organization has a “flowering threshold” which gives a high probability of survival to pods that grow to over 3 inches. Interviewees noted that the amount of rainfall during flowering is crucial in determining the flowering of the buds on the trees and drier conditions during this

period generally result in lower yields. However, too much rainfall can create humid conditions that encourage the development of fungus and black pod disease, which ultimately lower crop yield.

Shade cover, farm maintenance, and input use (each cited by 33% of interviewees) appeared to be treated slightly differently by interview participants. Shade cover was not seen to be particularly relevant by interview participants and even those that considered it only did so in a qualitative fashion. One interviewee explained that the absence of shade cover affects soil productivity after about 10 years, which is concerning given that less than 50% of cocoa farmers use fertilizer (due to price constraints) and even fewer are trained on how to fertilize properly so they cannot address soil fertility. The lack of input use in fighting disease was cited by several interviewees as the reason for which yields were so low.

The weather events that cocoa participants signaled were relevant to cocoa yields were the Harmattan (56%) and El Niño/La Niña (33%). One interviewee explained that his model shows the Harmattan and El Niño usually having a negative effect on cocoa yields, while La Niña is associated with higher than normal yields. Other interviewees indicated that too strong of a Harmattan results in crop losses. Two participants cited the ICCO's finding that global cocoa production is 2.4% lower during El Niño years, while La Niña does not have any significant impact on production.

FIGURE 10: SUMMARY OF COCOA MARKET PARTICIPANT RESPONSES

Potential Limitations to the Interviews

Given that interview participants were asked to elaborate on the factors that they considered most relevant to forecasting coffee yields, and that the market participants are competitors, it is possible that for their own reasons they chose to not provide the researcher with an exhaustive list of every single factor that they include in their models. In analyzing the results of the interviews, it became clear that it was possible that some interviewees considered the same factors but used more generic language to describe them (e.g. “weather events” as opposed to “El Niño/La Niña”) and therefore were not included in the percentages cited above. Knowing in advance that the focus of this study was on environmental factors considered in commodity supply forecasting, it is possible that some participants did not detail the social and economic factors that they consider to be relevant, even when prompted to do so. This appeared to be the case in instances where coffee market participants appeared to assume that acreage and currency factors would naturally be considered in the models, given their relevance to yield and futures prices, respectively (total cocoa acreage is not known and this was explicitly mentioned by all cocoa market participants).

7. Synthesis and Discussion

In both the market participants' models and the models found through literature review, timing of rainfall appears to overwhelmingly be the most important variable used in predicting coffee and cocoa yields. Both coffee and cocoa market participants stressed that rainfall during the flowering period was most essential, while coffee market participants also highlighted the importance of the amount of rain during the dry period. Similarly, the coffee literature emphasized the importance of the number of days of rainfall during the flowering period in ensuring even fruit ripening (Craparo *et al.*, 2015 and DaMatta *et al.*, 2008). The cocoa literature quantified the yield impact of rainfall more explicitly: Zuidema *et al.* (2005) found that annual radiation and rainfall during the two driest months of the crop cycle accounted for 70% of the variation in bean yield and Alvim (1988) found a positive correlation between cocoa yield and rainfall up to 6 months before the harvest period. This is important to consider in the context of CIAT's 2011 forecast that climate change will result in less monthly and yearly rainfall and decrease the number of dry months from 4 to 3 in Ghana and Côte d'Ivoire by 2050. Cocoa market participants also noted that special attention was paid to the amount of rainfall during pod development; the literature cited a 60% decrease in pod production after multi-week flooding (Monteiro, 1962, as referenced in Almeida and Valle, 2008) and a reduction in yield when drought conditions are present during pod production (Orchard and Saltos, 1988; Hutcheon, 1977; Sale, 1970; and Khan *et al.*, 1988, as referenced in Almeida and Valle, 2008). Likewise, coffee market participants and the literature indicated that the amount of rainfall during the development of the coffee fruit was strongly correlated to yield (Dos Santos and Camargo, 2006); van Oijen *et al.* found that doubling the amount of rainfall reduces yield (2010b).

While coffee market participants spoke about the impact of El Niño/La Niña events in the context of changes to the amount of rainfall, with only one exception, they did not note a clear link to

the yield outputs. This response differs from cocoa market interviewees, who largely responded in line with the prevailing study on the impact of El Niño and La Niña on crop yield, conducted by the ICCO.

Temperature was also one of the most important indicators for coffee in both the literature and in the models of the coffee market participants. While the market participants indicated that they monitored temperature on a daily basis in the major coffee-producing countries, the literature suggested that slight changes in temperature do not have a significant yield impact. However, temperatures that fall within the extreme cold or extreme hot range are likely to reduce yields and therefore producer regions whose average temperatures are on the border of “normal” should be monitored in case they fall outside of this average range (e.g. the case of Tanzania in Craparo *et al.*’s study). Market participants were not particularly concerned about changes to climate suitability, as it generally fell beyond the time horizon of their futures forecasting models, though climate suitability models featured prominently in the literature. While the climate suitability models predicted changes that would be observed by 2050, based on the IPCC AR4 model, it is worth noting that some regions may experience climate change sooner than others. Additionally, the magnitude of the change will depend on which cultivars are being grown; for example, Robusta coffee beans are more resilient than Arabica beans in warmer climates. Whether these temperature changes actually result in farmers abandoning their farms or moving to new regions will largely depend on economic factors, such as farmers’ access to credit and non-farm income.

The cocoa literature gave less weight to the importance of pod counts than the market participants, who considered it to be the main yield determinant besides rainfall. This may be explained by different data collection techniques used by interviewees and academics, which were generally more reliant on desktop models rather than field visits, thus making it difficult for academics to conduct pod counts on an ongoing basis. In turn, the market participants emphasized the importance of the

Harmattan wind in affecting the survivability of the cherelles – an environmental factor that is entirely absent from the literature, save for a brief mention when explaining the climate in which cocoa is grown. Instead, the literature put a stronger emphasis on the ecophysiological *reasons* for pod count variations – i.e. how changes in rainfall, weather events affect pod growth – than the market participants.

In contrast, the academic literature assigned more weight to the importance of shade and soil quality in predicting yield than the market participants. This is likely a function of the difference in time horizons between the models – the academic studies tending to be longitudinal studies – and the difficulty in applying a localized variable, such as soil quality or shade, to the forecast of global coffee or cocoa supply. As one interviewee noted: “I don’t know that you can meaningfully account for shade as an aggregate – you don’t need to dig down that far.” Perhaps it is for this reason that the market participants, notably in coffee, considered shade as an effective risk management tool in Central America, which is consistent with the literature that observed shade is useful in protecting against extreme weather and pests and disease (Purseglove, 1968; Beer *et al.* 1998; Vaast *et al.*, 2006). Historically, the literature on the effects of shade on coffee and cocoa have found that highly-shaded plots produce lower yields (Purseglove, 1968; Ahenkorah *et al.*, 1974; Beer *et al.* 1998; Vaast *et al.*, 2006) but recent literature (Vanhove *et al.*, 2016) has suggested that this is only true up until a certain point – approximately 22 years – after which the lack of shade causes land degradation. This speaks to what Ruf (2005) calls “forest rent” which is the extra added ecological benefits of forested land, such as soil fertility and moisture retention. Given the literature’s focus on declining soil quality, it is notable that this variable is largely not accounted for in the market participant models, especially since cocoa is often grown on deforested land, nor is tree or plot age a factor in most participants’ models (11% of cocoa market participants indicated that they considered tree age, while 36% of coffee market participants consider the age of the farm). It could be argued that the coffee market participants

consider fertilizer use to be a proxy for poor soil quality; however, this is not universally the case, as many farmers operating in soil-poor environments are not using fertilizers due to cost constraints.

Another difference between the literature and market participants' models that can be attributed to the difference in time horizon is the potential change in climate suitability in the major coffee- and cocoa-producing regions. While the literature raised this as a serious potential threat, market participants did not express concern, even when directly probed on this issue. To date, they have not observed major changes in the production centres of these crops. However, as this risk materializes, farmers (and those who buy from them) will have to internalize the high capital output costs require to start new farms in new environments.

On a related note, the approach of coffee market participants appears to be largely in line with the econometrics literature in how they treat price in their models. Notably, they have observed that the current price of coffee provides a signal to farmers about the future prices that they can expect to receive and, based on this information, the farmer chooses whether or not to plant more coffee. The market participants noted that the lag in price can result in an oversupply of coffee in the 3-5 years after planting, which causes the market price to drop and generally incentivizes farmers to store their coffee until the price climbs higher. Cocoa market participants, on the other hand, did not mention price being a contributing factor to forecasting yield.

8. Conclusions

Prior to undertaking the research, , the author was under the impression that coffee and cocoa market participants predicted crop output by assigning attribution factors to different variables in the model. However, upon completion of the interviews, it became apparent that the importance of one factor over another is constantly changing and therefore market participants cannot forecast yield by assigning attribution factors. Instead, the organizations surveyed tend to estimate crop output “by feel” based on

the effect of similar conditions on crop yield, as historically witnessed. Using this approach, it is possible that, in the medium- to long-term, they will experience increased difficulty in estimating crop yield as climate change causes extreme weather events and an increase in frequency of some not previously seen. There may also be changes in multiple environmental factors simultaneously, such as changing rainfall distribution patterns and higher temperatures.

The interview participants appeared to be extremely confident in their models' ability to predict yield and/or futures prices, yet only 40% indicated that they conducted any sort of backtesting to verify if their assumptions were correct. Of those that did, only 2 could provide statistics on the outcome of their models; one organization cited a 2% gap in production figures, while another interviewee reported an R^2 of 80-85% for his cocoa model and 60-75% for his coffee model. One participant said that the market was his feedback mechanism. It follows that very few participants (33%) have actually changed the inputs to their models over time and only one participant indicated conducting sensitivity analyses of model inputs to determine their relevance. Of those that did not review model inputs on a systematic basis, those that were amenable to making changes to their models did so on an "as needed" basis when it became apparent that they were missing key market fundamentals in their analysis. For example, upon realizing the role of hedge funds as speculators on the cocoa market, one interviewee began incorporating this factor into his model and it now accounts for 10% of his futures price forecast (the other weights and factors being: 10% currency, and 40% supply and 40% demand).

In the medium to long-term, it may be difficult to pinpoint one new variable that needs to be added as climatic changes tend to alter the interaction between variables. Ovalle-Rivera et al. (2015), writing about the shift of coffee production to higher elevations as warmer temperatures render current coffee-growing areas unsuitable for production, eloquently states: "An important proviso is that the areas at higher elevation are available for conversion to coffee farms, are accessible, have suitable soil

conditions, and whose current or future inhabitants are willing to grow Arabica coffee rather than other crops. Very often, these conditions may not all come together, with the consequence that Arabica coffee production may locally decline.”

Additionally, the current market mechanisms – i.e. the length of the futures contracts – reward short-term thinking and therefore it may be difficult to persuade market participants to consider long-term variables, unless they are absolutely proven to have an effect on short-term yields. However, there is increasing recognition of the fact that the short-term liquidity provided by futures is not sufficient to address the industry’s long-term challenges, as evidenced by industry-wide initiatives such as Cocoa Action, which seeks to address two of the cocoa industry’s biggest problems related to low farmer income: lack of fertilizer usage and child labour. The disconnect between the futures market and physical coffee market has led some coffee buyers to forego the futures market altogether in lieu of direct trade relationships with farmers in order to ensure a certain quality standard (Warnau, 2015). Small tweaks to futures pricing models may allow market participants to internalize some of these risks, which they are often already paying heavily for elsewhere (e.g. farmer climate adaptation strategies).

Making matters more difficult is the fact that most participants were less concerned about the drivers of environmental or social change – i.e. *why* a certain phenomenon was taking place – as opposed to capturing the short-term effects of these changes in their models – i.e. the *occurrence* of particular weather events. Not capturing the reason behind the changes may result in the failure to address a systematic problem in the market and price this risk into the model. For example, as previously noted, interview participants identified low coffee and cocoa prices as being the reason that many farmers are deciding to cease operations but this producer flight is not explicitly captured in production forecasts.

Additionally, interviewees acknowledged the importance of certain environmental factors such as soil quality but expressed difficulty in quantitatively including them in their models or did not feel that they would have a pronounced short-term impact on crop output. Again, this results in certain risks not being priced into the model. For some of the long-term environmental challenges that do not have an immediate short-term yield impacts but could drastically change the industry over the long-term, the failure to price in risk is concerning. One such example that was raised in the academic literature and not mentioned by any of the market participants is land suitability for coffee and cocoa production. While changes in land suitability would happen over a long-term period, the fact that it is being ignored by the market because it does not neatly fit into a 6-24 month futures price model means that it will not be captured at all over a 10-20-year period, when the risk will start to materialize.

8.1 Recommendations

Based on the foregoing analysis, the following recommendations are made:

Recommendation #1: Market participants could use the attribution factors mentioned in the literature, which have taken into account variances in other environmental factors, to understand the impact on yield. For example, attributing 70% of cocoa yield output to the 2 driest months of the year could allow for market models to capture the yield impact of weather patterns not previously observed.

Recommendation #2: When estimating yields during or immediately following climatic events (e.g. strong Harmattan winds, droughts, extreme temperature swings), market participants can adjust the expected yield impact for production areas that are shaded. Given that the literature indicates shade can buffer temperature fluctuations of up to 5°C and retain soil moisture during dry periods, it is likely that shaded areas will not suffer the same yield reductions as unshaded areas and therefore this should be accounted for in the models.

Recommendation #3: Market participants could use a different model to estimate yield for production areas that are more than 10 years old and exposed to sunlight (i.e. not shaded), which is approximately the length of time when soils are depleted and the benefits of the plant being exposed to direct sunlight decrease. Adjustments could be made accordingly where there is evidence of pruning and fertilizer usage.

Recommendation #4: Market participants could use Bateman's model (1965) of assigning different price elasticities to farmers based on the soil quality, rainfall, and humidity in the areas in which they are operating. Those operating in more challenging environments are more price elastic and therefore will need to be enticed by higher prices in order to continue farming and adapt to changing conditions.

8.2 Opportunities for future study

It is apparent from the interviews that there is serious information asymmetry in the market, with companies operating on the ground – mostly the physical traders – having access to significantly more data than those conducting desktop research or speculating on the market. One interviewee even quantified the number of entities that have “put any effort into forecasting” following the closure of the research departments of the major cocoa buyers: 10-12 entities for cocoa and 6 entities for coffee. Numerous interviewees cited the lack of market research being conducted for coffee and cocoa as cause for concern, with one participant singling out the failure of the ICE to fulfill its role as an exchange in facilitating market transparency by not supporting the market through research or development. This is somewhat ironic, given that the New York Coffee Exchange was created in 1882 to decrease the information imbalance between commercial and non-commercial traders, following a market collapse in 1880 caused by excess speculation (Topik, 2004). Understanding that some market players are privy to more information than others, it may be worth revisiting the assumption that futures markets are efficient markets, i.e. prices fully reflect all available information, as per Fama's efficient market hypothesis (Fama, 1970). While Nardella (2007) tested the efficient market hypothesis for the cocoa

futures market and found that it was efficient, he only considered the release of *public* information to the market. While this satisfies Fama's "semi-strong" test for market efficiency – i.e. the incorporation of all public information into pricing – as this study demonstrates, coffee and cocoa market players that have the ability to collect data on the ground may benefit from having access to non-public information that would allow them to more accurately predict futures prices. Therefore, using Fama's "strong form" test, i.e. in which some groups have privileged access to some market information, futures markets may not be seen as efficient.

The increased role of speculators is perceived to have caused increased disruption on the coffee and cocoa markets, but particularly for cocoa, a market 25% controlled by hedge funds. As these speculators do not know very much about coffee or cocoa and rely on other sources for data (largely traders and news sources), they cause the markets to run on speculation. Coupled with the reduction of other soft commodity market participants, as one interviewee noted, this causes a real liquidity issue in a multi-year market where futures only provide liquidity for one year. While it is beyond the scope of this thesis to measure the impact of less-informed speculators on futures price movements, this topic has been studied at least to some extent by UNCTAD (Maurice and Davis, 2012), ICCO (Nardella, 2007), and several academics (Holt and Irwin, 2000; Irwin and Yoshimaru, 1999; Streeter and Tomek, 1992) and is deserving of further investigation.

Within the scientific literature, it would be useful to explore in greater depth the relative importance of temperature changes versus rising atmospheric carbon on coffee yields. While DaMatta and Ramalho (2006) have long maintained that coffee plants may be able to adapt to gradual temperature changes over time, and even benefit from higher atmospheric carbon, Craparo *et al.*'s study (2015) challenges this thinking, by attributing yield declines to rising minimum temperatures.

Replicating Craparo *et al.*'s methodology would serve to test if their conclusions are observed in other geographies, or if rising carbon may offset the yield declines caused by temperature changes.

8.3 Contribution to the Academic Literature

This thesis fills a gap in the academic literature on price-building models in the coffee and cocoa futures markets. To the author's knowledge, this study is also the first to explore the possibility of pricing in long-term environmental risk factors into commodities futures forecasting models. As mentioned in the introduction section, the financial industry as a whole is still grappling with how to capture long-term risks, especially environmental and social risks, in short-term models. The United Nations Principles for Responsible Investment (UNPRI) has issued multiple guidance documents for institutional investors on how to implement long-term strategies for different asset classes at the same time, leading institutions, such as CPPIB and McKinsey, are pushing for the industry to adopt a more long-term approach. However, by their very nature, futures markets will never be long-term and therefore need to be able to capture long-term risk in short-term models to provide incentive for farmers to continue to produce. Investors have made progress in doing so for some asset classes, notably equities, for example by applying a lower discount rate to discount cash flow models to companies that have strong environmental and social risk management systems in place.

The UNPRI's guidance document on best practice in responsible investment in commodities recommends investing in physical commodities that are certified to recognized environmental and social standards, suggesting that these producers are better managing environmental and social risks (UNPRI, 2011). Although for commodity derivatives, such as futures, the guidance centers around the institutional investors' role in ensuring that its position in a market does not disrupt its price discovery function and pushing for greater transparency amongst key market actors, such as commodity futures exchanges and investment managers (UNPRI, 2011). The guidance does not address what would constitute best practice for these key market actors, beyond providing greater transparency. In light of

the dearth of information surrounding the price building models in futures markets identified by the UNPRI, by providing an overview of the forecasting models used by key market players in the coffee and cocoa markets, this thesis aims to contribute to a gap in the literature.

Appendix A: Interview Questionnaire

- Which factors do you include in your coffee/cocoa supply function?
- Do you consider any environmental factors? If so, which ones?
- Do you consider any social factors? If so, which ones?
- What weight is given to these environmental/social factors relative to other factors that are major determinants in supply?
- How often is your model updated?
- From where do you collect the environmental/social data that flows into the model?
 - o Is there other data that you would include in your model but cannot include due to lack of data availability?
- How much weight is given to the supply function in your model of price discovery (supply/demand)?
- Do you have a feedback loop in your model to compare your forecasts to the spot prices of coffee and cocoa? If so, how often were the price forecasts accurate (say, within 10%)?
- What do you perceive to be the greatest challenge for coffee/cocoa production in the next 20 years?

Appendix B: Variables Considered in Market Participants' Models

The chart below is a summary of the findings of the interviews that were conducted with the market participants. Their names have been anonymized, although the markets in which they participate have been noted.

	Type of market participant	Coffee	Coffee	Coffee	Coffee	Coffee	Coffee	Coffee & Cocoa	Coffee & Cocoa	Coffee & Cocoa	Coffee & Cocoa	Coffee & Cocoa	Cocoa	Cocoa	Cocoa	Cocoa
Coffee variables	Acreage	-		-		-	-				-					
	Age of field	-		-		-					-					
	Maintenance of the fields	-		-		-			-		-					
	Use of inputs	-	-	-		-			-		-					
	Weather events in Brazil	-														
	Weather events elsewhere/ globally		-								-					
	Biennial production cycle	-	-		-		-		-		-					
	Rainfall - timing		-	-	-	-	-		-		-					
	Rainfall - amount		-	-	-	-	-		-		-					
	Shade		-		-						-					
	El Nino/La Nina		-		-			-	-							
	Previous season/year's yield			-	-	-	-	-	-		-					
	Temperature			-							-					
	Price															
	Impact of previous year on this year's weather events					-					-					
	Pests/disease			-	-	-		-			-					
	Node growth				-	-										
	Flowering				-	-		-								
	Cherry count					-		-								
	Altitude					-										
Cocoa variables	Soil moisture					-										
	Humidity						-									
	Harmattan								-			-	-	-		
	Wind temperature								-							
	Rainfall - amount							-	-		-	-	-	-	-	-
	Pod count							-			-	-	-	-	-	-
	Temperature										-		-	-		
	Rainfall - timing							-					-	-	-	-
	Relative humidity												-	-	-	-
	El Nino/La Nina												-	-	-	-
	Maintenance of fields							-			-	-				
	Use of inputs							-			-	-				
	Sea level temperature												-			
	Shade							-			-	-	-	-		-
	Tree age											-			-	-
	Soil Moisture							-			-	-				-
	Disease							-			-	-				
	Flowering							-			-	-				

Appendix C: Variables Considered in Models in the Literature

The following charts summarize the findings of the literature review. Factors that were considered in yield forecasts are marked by an empty circle ○; factors found to have a significant yield impact are marked by a black circle ●.

	Author	Not crop-specific				
		Nerlove	Roberts and Schlenker	Hendricks <i>et al.</i>	Brunner	Beer
	Year	1956	2013	2014	2002	1987, 1998
Economic considerations	Price	○			○	
	Previous year's yield					
	Farm household income (not from coffee/cocoa)					
	State interventions in coffee/cocoa market					
	Cost of labor					
Tree characteristics	Tree age					
	Variety of coffee/cocoa					
	Leaf area					
Plot characteristics	Soil quality					○
	Shade cover					●
	Species of shade trees					
	Slope					
	Monoculture vs. intercropped plots					
	Area under production			○		
	Altitude					
Main tenance	Smallholder vs estate					
	Pruning					
Weather variables	Fertilization					
	Rainfall-amount			○		
	Rainfall-timing			○		
	Humidity					○
	Pests/disease					○
	Weather events		○	○	●	
Physiological processes	Temperature					○
	Photosynthesis					
	Maintenance respiration					
	Evapotranspiration					
	Radiation					
	Biomass production					○
	Net carbon assimilation					
Plant lifecycle stages	Orthotropic growth					
	Flush cycle					
	Budding					
	Flowering					
	Cocoa pod production					
	Coffee bean formation					
	Coffee bean maturation					
Other	Age of farmer					
	Institutional support (training)					

		Cocoa											
Author		Bateman	Zuidema et al.	Ahenkora et al.	Almeida and Valle	Mariano and Monteiro	CIAT	Vanhove et al.	ICCO	Ruf	Fleming and Milne	Alvim	Alvim
Year		1965	2005	1974	2007	1962	2011	2016	2010	2005	2003	1977	1988
Economic considerations	Price	•								•	•		
	Previous year's yield												
	Farm household income (not from coffee/cocoa)												
	State interventions in coffee/cocoa market									•	•		
	Cost of labor									•			
Tree characteristics	Tree age	•											
	Variety of coffee/cocoa							•					
	Leaf area							•		•			
Plot characteristics	Soil quality	•	•	•	•			•		•			
	Shade cover		•	•	•			•		•			
	Species of shade trees												
	Slope									•			
	Monoculture vs. intercropped plots									•			
	Area under production						•				•		
	Altitude						•			•	•		
	Smallholder vs estate									•	•		
Main tenance	Pruning										•		
Weather variables	Fertilization	•					•						
	Rainfall-amount	•	•		•	•	•					•	•
	Rainfall-timing	•	•		•	•	•						
	Humidity	•						•					
	Pests/disease	•							•				
	Weather events						•						
Physiological processes	Temperature						•						
	Photosynthesis		•		•								
	Maintenance respiration		•		•								
	Evapotranspiration		•		•		•						
	Radiation		•		•								
	Biomass production		•										
Plant lifecycle stages	Net carbon assimilation												
	Orthotropic growth												
	Flush cycle												
	Budding												
	Flowering												
	Cocoa pod production		•		•	•							
	Coffee bean formation												
	Coffee bean maturation												
										•			
Other	Age of farmer									•			
	Institutional support (training)									•			

		Coffee											
Author		Wickens and Greenfield	Vaast et al.	van Oijen <i>et al.</i>	Ovalle-Rivera et al.	Dos Santos and Camargo	Camargo	Gay et al.	Craparo et al.	DaMatta and Ramalho	DaMatta et al.	Ghini et al.	Tondoh et al.
Year		1963	2006	2010	2015	2006	2003	2006	2015	2006	2007	2015	2015
Economic considerations	Price												
	Previous year's yield												
	Farm household income (not from coffee/cocoa)												
	State interventions in coffee/cocoa market												
	Cost of labor												
Tree characteristics	Tree age												
	Variety of coffee/cocoa												
	Leaf area												
Plot characteristics	Soil quality												
	Shade cover												
	Species of shade trees												
	Slope												
	Monoculture vs. intercropped plots												
	Area under production												
	Altitude												
Main tenance	Smallholder vs estate												
	Pruning												
	Fertilization												
	Rainfall-amount												
	Rainfall-timing												
	Humidity												
	Pests/disease												
Weather variables	Weather events												
	Temperature												
	Photosynthesis												
	Maintenance respiration												
	Evapotranspiration												
	Radiation												
	Biomass production												
Plant lifecycle stages	Net carbon assimilation												
	Orthotropic growth												
	Flush cycle												
	Budding												
	Flowering												
	Cocoa pod production												
	Coffee bean formation												
Other	Coffee bean maturation												
	Age of farmer												
	Institutional support (training)												

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