universität wien

MASTERARBEIT / MASTER'S THESIS

Titel der Masterarbeit / Title of the Master's Thesis

„Dynamics of the Global Coffee Market:
A Case Study of the Four Leading Coffee Producers“

verfasst von / submitted by

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angestrebter akademischer Grad / in partial fulfillment of the requirements for the degree of

Master of Science (MSc)

Wien, 2020 / Vienna 2020

Studienkennzahl lt. Studienblatt / degree programme code as it appears on the student record sheet:	A 066 913
Studienrichtung lt. Studienblatt / degree programme as it appears on the student record sheet:	Masterstudium Volkswirtschaftslehre
Betreut von / Supervisor:	Univ.-Prof. Dipl.-Ing. Dr. Robert Kunst

Acknowledgments

I would like to thank my supervisor, Prof. Robert Kunst, for his guidance and detailed feedback throughout the course of this thesis. I am very grateful for his patience and continued support. I would also like to thank my parents for their endless love and support, and special thanks to my husband Jay for helping and encouraging me throughout my entire study.

Abstract

This thesis provides insight into the dynamics of the global coffee market with a focus on the world's four leading coffee producers: Brazil, Vietnam, Colombia, and Indonesia. Annual data from 1980 to 2018 is used to perform descriptive analysis of each country to determine the underlying conditions which influence coffee production and exportation. We find that Brazil and Colombia produce Arabica coffees, while Vietnam and Indonesia produce Robusta coffees. The four countries are then compared to determine their contributions to the global coffee market. Following the comparative analysis, an econometric analysis of each country is performed using monthly data from 2010 to 2018. The empirical relationship between the domestic and world market prices is investigated using the Johansen cointegration procedure and a vector error correction model (VECM). The Johansen cointegration tests show that domestic and world prices are cointegrated. The vector error correction models indicate a larger magnitude of price transmission for Robusta producers than Arabica producers. The speed of price transmission also occurs faster for Robusta coffee producers. Furthermore, the models show that error adjustments occur more quickly in the domestic prices than world prices. This indicates two-way causality with the world prices holding more influence over domestic prices.

Keywords: Vector error correction, coffee, cointegration, price transmission, market integration

Zusammenfassung

Diese Arbeit gibt einen Einblick in die Dynamik des globalen Kaffeemarktes mit Fokus auf die vier führenden Kaffeeproduzenten der Welt: Brasilien, Vietnam, Kolumbien und Indonesien. Anhand jährlicher Daten von 1980 bis 2018 werden für jedes Land deskriptive Analysen durchgeführt, um die Rahmenbedingungen zu ermitteln, die die Kaffeeproduktion und den Kaffeeexport beeinflussen. Wir stellen fest, dass Brasilien und Kolumbien Arabica-Kaffee produzieren, während Vietnam und Indonesien Robusta-Kaffee herstellen. Die vier Länder werden dann miteinander verglichen, um ihren Beitrag zum globalen Kaffeemarkt zu bestimmen. Im Anschluss an die vergleichende Analyse wird für jedes Land eine ökonometrische Analyse anhand monatlicher Daten von 2010 bis 2018 durchgeführt. Die empirische Beziehung zwischen den Binnen- und Weltmarktpreisen wird mit Hilfe des Johansen-Kointegrationsverfahrens und eines Vektor-Fehlerkorrekturmodells (VECM) untersucht. Die Johansen-Kointegrationstests zeigen, dass Inlands- und Weltmarktpreise kointegriert sind. Die Vektor-Fehlerkorrekturmodelle deuten darauf hin, dass die Robusta-Produzenten einen größeren Umfang der Preisübertragung haben als die Arabica-Produzenten. Auch die Geschwindigkeit der Preisübertragung ist bei den Robusta-Kaffeeproduzenten schneller als bei den Arabica-Produzenten. Darüber hinaus zeigen die Modelle, dass Fehlerkorrekturen bei den Inlandspreisen schneller erfolgen als bei den Weltmarktpreisen. Dies deutet auf eine Kausalität in beiden Richtungen hin, wobei die Weltpreise einen größeren Einfluss auf die Inlandspreise haben.

Schlagwörter: Vektor-Fehlerkorrektur, Kaffee, Kointegration, Preisübertragung, Marktintegration

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Abbreviations

ADF	Augmented Dickey-Fuller (test)
AIC	Akaike Information Criterion
APT	Asymmetric Price Transmission
ARCH-LM	Autoregressive Conditional Heteroskedasticity - Lagrange Multiplier
Bappebti	Badan Pengawas Perdagangan Berjangka Komoditi (Indonesia’s Commodity Futures Trading Regulatory Agency)
BIC	Bayesian Information Criterion
BNP	Brazilian Naturals Price (world price)
CAGR	Compound Annual Growth Rate
CMP	Colombian Milds Price (world price)
COMECOM	Council for Mutual Economic Assistance
DP	Domestic Price (of coffee)
DPB	Domestic Price (of coffee) in Brazil
DPC	Domestic Price (of coffee) in Colombia
DPI	Domestic Price (of coffee) in Indonesia
DPV	Domestic Price (of coffee) in Vietnam
ECM	Error Correction Model
ECT	Error Correction Term
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
FNC	Federación Nacional de Cafeteros de Colombia (National Federation of Coffee Growers of Colombia)
FOB	Free On Board (value)
HQ	Hannan–Quinn (criterion)
IBC	Instituto Brasileiro do Café (Brazilian Coffee Institute)

ICA	International Coffee Agreement
ICO	International Coffee Organization
KPSS	Kwiatkowski, Phillips, Schmidt, and Shin (test)
LOP	Law of One Price
MARD	Ministry of Agriculture and Rural Development (Vietnam)
NCA	National Coffee Association of U.S.A.
OLS	Ordinary Least Squares
ROB	Robustas (world price)
UN Comtrade	United Nations International Trade Statistics Database
USA	United States of America
USD	United States Dollar
USDA	United States Department of Agriculture
VAR	Vector Autoregression
VEC	Vector Error Correction
VECM	Vector Error Correction Model
VICOFA	Vietnam Coffee - Cocoa Association
WP	World Price (of coffee)
WTO	World Trade Organization

1 Introduction

Coffee has become a ubiquitous beverage around the world, served in cafes from Seattle to São Paulo, Paris or Perth, and everywhere in between. Coffee, once a luxurious and mysterious beverage reserved for the elite, is now a daily staple that is enjoyed by hundreds of millions of people around the world. The consumption of coffee is a relatively recent development in human history only dating back around 600 years (Pendergrast, 2010). Since then, it has developed into one of the world's most heavily traded cash crops, with a global industry built around its production, processing, and consumption.

It is estimated that around 80% of the global coffee supply is produced by approximately 25 million smallholders, and that around 125 million people worldwide are dependent on this industry for their livelihoods (Fairtrade, 2015). When considering the number of people employed in the processing, trading, transport, and retail sale of coffee, this number increases drastically. Almost the entire supply of coffee is produced in developing nations where labor costs remain low and environmental degradation and deforestation due to intensive agriculture is often not heavily regulated. The vast majority of the coffee that is grown is exported to industrialized nations as low-value raw (unroasted) coffee. These countries then roast and process the raw coffee, greatly increasing its value, before exporting the high-priced processed coffee to the world market. This somewhat one-sided relationship is rooted in 18th and 19th century colonialism and more or less remains in place today (Pendergrast, 2010).

While the agricultural side of coffee production is built from millions of small independent farms, the roasting side of production is controlled by large multinational corporations. The ten largest of these companies are responsible for roasting 35% of the world's coffee (Panhuysen & Pierrot, 2018). As the global coffee industry consolidates under these companies, costs are cut to optimize profits which causes downward pressure in the value chain. This is increasingly felt by the producers at the farm level.

Coffee is well known for being a boom and bust commodity, with production varying year to year according to weather conditions, disease, and other factors (Fairtrade, 2015). This results in the raw coffee market being inherently unstable and prone to wide fluctuations in price. This price volatility has far more significant consequences for small share farm holders in coffee producing countries than the large companies responsible for coffee roasting and processing. Prices paid to farmers tend to adjust faster to decreases in world prices than world prices adjust to increases in production costs, often at the detriment to coffee growers (Krivonos, 2005). For the farmers whose livelihoods depend on coffee, it can be difficult to predict income from the coming season.

The domestic price paid to coffee producers can be influenced by a variety of factors. Global production and consumption (supply and demand) are the driving forces in establishing the world price. The variety and quality of coffee produced also significantly influence the prices received by producers. The cost of energy (crude oil for example) indirectly affects coffee prices through fuel use of production machinery and transportation costs. Furthermore, the local exchange rate can also have an effect on producer prices when selling coffee on the global market.

The rising global demand for coffee has increased production efforts around the world. This boost in production most certainly benefits the consumers through the ever-increasing availability of specialty coffees and exotic blends. The companies marketing these products also benefit. Coffee producers, on the other hand, may not experience the same beneficial aspects. This paper investigates how the changing coffee industry has influenced the prices paid to coffee producing nations for their unroasted coffee, otherwise known as ‘raw’ or ‘green’ coffee, in comparison to the corresponding global market prices.

1.1 Research Goals

There are three research goals to be fulfilled by the analyses carried out in this work. The first is the evaluation of the coffee sectors of the four leading coffee producing countries: Brazil, Vietnam, Colombia, and Indonesia. The second is a comparative analysis of these countries. The final goal is an investigation into the relationship between world market prices and the domestic (producer) coffee prices found in these four countries.

This paper seeks to identify the trends present in the coffee sectors of the four largest coffee producers. More specifically, it investigates how the production of coffee has evolved in these countries. We analyze the quantities of coffee produced, the agricultural footprint, and the coffee varieties which are grown. Additionally, the dynamics of coffee export quantity and value are examined. Domestic consumption is also an area of interest as it influences the production and export of coffee.

The four countries are then compared to see how they may have influenced the global coffee industry. The individual components of coffee production, exportation, and consumption are contrasted between the countries to show the differences and similarities among the countries. The growth rates that these components experience during different periods are also of interest and are computed.

Finally, we develop empirical models of the relationships between domestic and world coffee prices. The domestic price of the coffee produced in each country is tested for causality and the presence of short-run and long-run relationships with the corresponding world market price. A separate empirical model is developed for each of the four leading coffee producers.

1.2 Research Questions

To achieve the research goals set forth, three main research questions have been developed:

1. How has the coffee sector changed in the four largest coffee producing countries?
2. How do the coffee sectors of these countries compare to one another?
3. How are domestic coffee prices related to world market prices?

2 Coffee Industry

Coffee is a prepared drink made from brewing the roasted seeds found in the fruits produced by certain species of *Coffea* plants. After ripening, the coffee berries are harvested, processed, and dried. The dried coffee seeds, colloquially known as 'coffee beans', are then roasted to develop the desired flavor. The roasted beans are then pulverized and steeped in hot water. The resulting beverage and other similarly derived products are the driving forces behind a global industry with an estimated annual income of over USD 220 billion (ICO, 2019a).

2.1 History

The earliest reliable evidence of a beverage being made from roasted coffee beans comes from the monasteries of Yemen in the early 15th century (Weinberg & Bealer, 2002). From there it spread to Mecca and then on to the rest of the Islamic world. After arriving in Europe, it was carried to European colonies around the world for cultivation (Smith, 1985). Coffee plantations started developing in Indonesia and other areas of Asia, as well as in India and South America. In the mid-19th century, Brazil became the largest exporter of coffee, which remains true today. The cultivation of coffee continued to spread around the globe between the Tropic of Capricorn and Tropic of Cancer. As harvesting coffee is more labor intensive than other crops, colonial powers sought to profit from utilizing indigenous labor on their plantations. Commercial trading companies also profited from the shipment of coffee from the colonies to the colonial powers.

Despite some efforts to regulate or prohibit coffee consumption by governmental powers, the demand for coffee continued to rise. Coffee consumption increased throughout the 20th century, and the demand for soluble coffee greatly increased after the Second World War. The signing of the International Coffee Agreement (ICA) in 1962 and subsequent establishment of the International Coffee Organization (ICO) in 1963 introduced measures of cooperation and regulation between coffee producing countries and coffee consuming countries. The ICA established an export quota system aimed at keeping market prices high and stable (ICO, 2014a). The breakdown of the ICA in 1989 caused a significant decrease in prices and allowed for Vietnam to increase its coffee output (Ponte, 2001). Normalization of trade between Vietnam and the USA in 1994 also had a substantial effect on the global coffee market. The current 2007 ICA became active in 2011 and its members represent 98% of global coffee production and 67% of consumption (ICO, 2014a).

2.2 Coffee Varieties

While there are currently 129 species of the genus *Coffea* that have been identified by scientists, the vast majority of industrial cultivation consists of the two species commonly known as Arabica and Robusta (Hoffmann, 2018). There are several sub-types of Arabica and Robusta trees producing coffee fruits of different sizes, shapes, colors, and yields. Historically, global coffee production has focused primarily on the more desirable Arabica variety; however, the share of Robusta production has increased in recent decades as shown in Fig. 1.

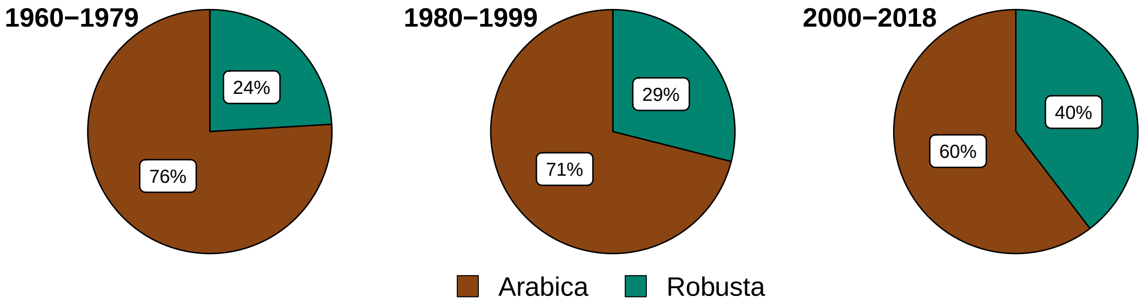

Figure 1. Historic share of coffee production attributed to Arabica and Robusta. Data: USDA (2020).

The commonly known 'coffee bean' is not actually a bean, but the seed of the coffee plant, which can be found in the fruit, or so-called coffee cherries. According to Herrera & Lambot (2017), most coffee production occurs within the tropics (Arabica 20°N – 25°S; Robusta 15°N – 15°S). While some Arabica varieties are grown in slightly cooler temperatures, most coffee types are grown in areas with temperatures that range from lows of 15 °C to highs of 33 °C (Herrera & Lambot, 2017). Depending on the variety, it will take approximately 3 to 4 years for a newly planted coffee tree to bear fruit (NCA, 2020). There is typically one major harvest each year depending on the growing season. One hectare of coffee trees, depending on variety, typically yields 5,000 – 10,000 kg of coffee cherries, which comes out to about 1,000 – 2,000 kg of green coffee beans (ICO, 2015a). In most countries, the crop is picked by hand in a labor-intensive process, though mechanized harvesting has been implemented when it is economically feasible.

2.2.1 Arabica

Arabica coffee refers to the beans harvested from the *Coffea arabica* plant and is said to have originated in the southwestern highlands of Ethiopia. Arabica is the most widely cultivated coffee species, accounting for approximately 60% of global coffee production in recent years (Fig. 1). Arabicas are generally considered to be milder and more aromatic in comparison to Robusta coffee. The beans are flatter, more elongated, and also lower in caffeine content. There are two basic varieties of Arabica coffee sold, which is dependent upon how they are processed. 'Naturals' are unwashed, meaning the beans are dried within the fruit, usually in the sun or in mechanical dryers, before being processed into green coffee (ICO, 2015b). 'Milds' are processed using a wet method. This involves physically removing the seed from the fruit, before soaking in water which facilitates a fermentation process that removes any remaining fruit flesh. The coffee beans are then rinsed once more before being dried and sold as green coffee (ICO, 2015b).

On the world market, Arabica coffees bring the highest prices (Fig. 2). As Arabicas are more susceptible to pests and environmental disturbances, the cultivation costs are passed on to the consumer. The Arabica species also tend to grow better at higher elevations, with the optimal elevation being between 1,000 m and 2,000 m above sea level. Plantations are typically located on uneven terrain, making harvesting difficult (ICO, 2015a). The better quality Arabicas are generally grown at higher altitude, though optimal altitude for growing varies with latitude.

Lower yields and less accessible growing areas result in higher production costs. These factors, along with the higher demand for Arabicas, result in market prices that can be significantly higher than those of Robusta coffees.

Arabicas are typically what come to mind when one thinks of coffee; whole roasted beans which are ground and then steeped in hot water to prepare a beverage. The majority of coffees found in supermarkets and served in coffee houses around the world are one of the Arabica varieties.

2.2.2 Robusta

Robusta is the name given to the *Coffea canephora* species due to its robust nature. The many varieties of this species are much hardier than Arabica plants. Robusta plants typically have a higher yield than Arabicas and account for around 40% of global production. The hardiness and high yields of the Robusta variety are offset by a taste generally considered inferior. As shown in Fig. 2, this less desirable flavor brings a lower market price than the Arabica varieties.

The cultivation of Robusta plants is fairly recent, only beginning in 1870 in the Congo basin of Africa (Herrera & Lambot, 2017). Robustas grow at lower elevations and higher temperatures than Arabicas and are also more resistant to pests and disease, making them easier to care for (Hoffmann, 2018). Due to their sturdy nature and high yields, Robustas are much easier to mass produce, making them an enticing option to coffee farmers. For these reasons, many of the newly planted coffee plantations around the world are of the Robusta variety.

Robustas have lower acidity and a more bitter taste when compared with Arabicas. They also have as much as 50% more caffeine content (Nesbitt & Prance, 2005). Robustas are primarily used in coffee blends and in soluble (instant) coffee. They are also used for producing coffee extracts, which provide flavoring to a number of products.

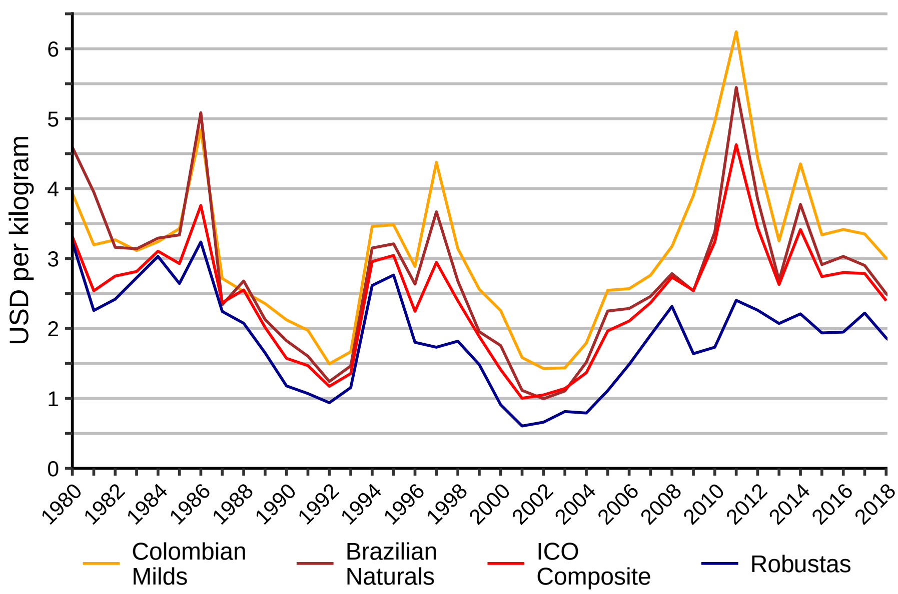

Figure 2. Indicator prices published by the International Coffee Organization. ICO Composite price provides a benchmark for coffee of all types and origins. Data: ICO (2019)

2.3 Coffee Production

Coffee production is the industrial process of growing the coffee plant and converting the raw fruit into finished products ready for consumption. This can be divided into two major components. The first is the cultivation and post-harvest processing of raw coffee beans. This is followed by the roasting, processing, and packaging of the coffee into consumer-ready products.

2.3.1 Cultivation

The cultivation of coffee occurs in close proximity to the equator, within a zone known as the 'coffee belt'. The majority of coffee growing countries are developing or impoverished countries (USDA, 2019b). All major coffee producing nations listed by the International Coffee Organization are located in the tropics. As seen in Fig. 3, South American countries grow mostly Arabica coffee, while coffee plantations in Asia primarily grow Robustas. Africa grows both types of coffee, with western Africa focused on Robusta and eastern Africa on Arabica. Currently, the four leading coffee producers are Brazil, Vietnam, Colombia, and Indonesia.

As coffee tends to grow in mountainous areas with uneven terrain, most harvesting must be done with manual labor. Coffee harvesting is labor intensive, typically being picked by hand using two distinct methods (Hoffmann, 2018). Strip picking is the harvesting of all coffee cherries in an area despite different levels of ripeness. Selective picking, as the name implies, is when only the ripe coffee cherries are picked with the unripe cherries being left for later harvesting. Selective picking results in higher quality beans, but greatly increases the amount of labor required driving up the production costs. Recently, mechanized strip picking has been implemented that greatly decreases the labor required for harvesting. This machinery is cost prohibitive for most small farmers and is mostly used by large plantations that can justify the expense.

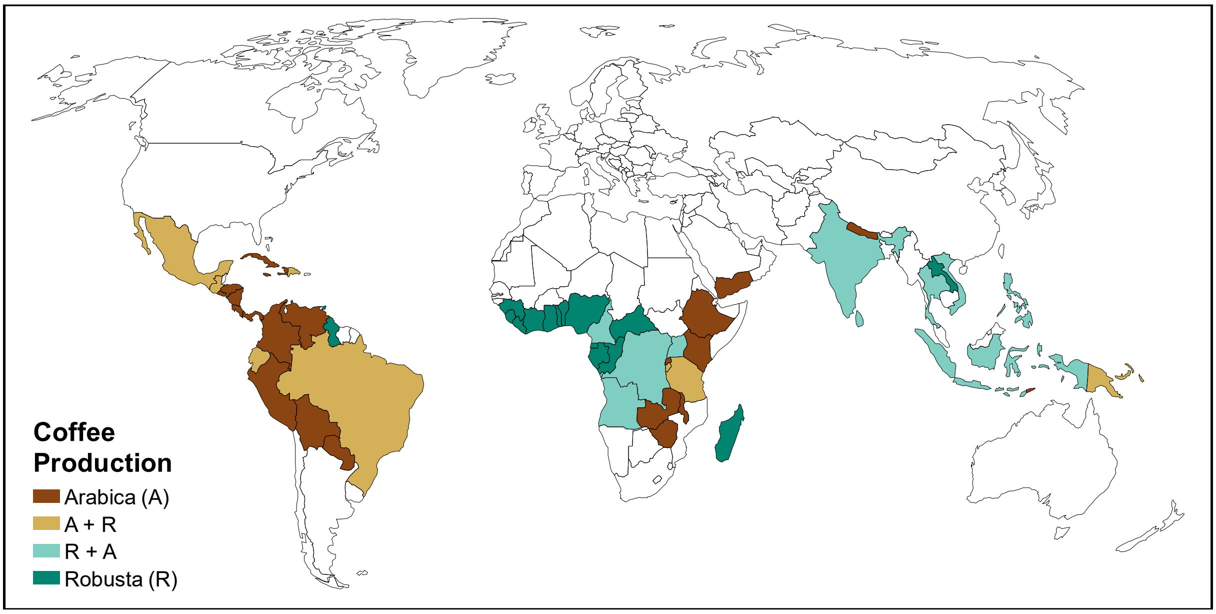

Figure 3. The majority of coffee cultivation occurs in the tropics.
Data: ICO (2019)

Herrera & Lambot (2017) stated that the quality of green coffee is determined by the combination of three categories: environmental factors, genetic factors, and agricultural practices. Another important aspect that affects quality is the post-harvest processing. After the coffee cherries are harvested, the seeds must be removed and then dried to produce unroasted or ‘green’ coffee beans. Drying, storing, and transporting techniques vary greatly between countries and can have significant influence on the quality of exported coffee.

Many of the coffee growing countries lack the ability to process the green coffee into consumer products. Moreover, the knowledge and industrial equipment required to roast large quantities of beans is cost prohibitive for many of the developing nations. As a result, around 80% of global coffee production is exported as green coffee for processing in other countries (USDA, 2020).

2.3.2 Processing

Roasting transforms the green coffee beans into the familiar roasted coffee products that are consumed. The roasting process produces the characteristic coffee flavor by causing a change in the taste of green coffee due to the chemical reactions that occur because of high heat. Different flavors can be obtained by controlling the temperature and duration in which the beans are roasted. After roasting, the whole beans can be packaged for sale or processed further. Most Arabica coffee ends up being sold as roasted whole beans or ground coffee. Robusta beans, on the other hand, tend to be processed into instant coffee. As price is more important than flavor in the soluble coffee industry, Robustas are favored over Arabicas. Almost 50% of global coffee production is used to make soluble coffee (Ramalakshmi et al., 2009).

The International Coffee Organization monitors the global coffee trade (ICO, 2019b). Most green coffee exports are destined for the European Union (EU), accounting for approximately 65% of global imports. The United States is the second largest destination, with 25% of green coffee imports. Within the EU, Germany and Italy are the largest importers. These industrialized nations have the manufacturing capacity to process vast quantities of raw coffee. Because roasted beans command a much higher price than green coffee, the industrialized nations convert the raw beans into consumer products. After roasting and processing, the beans are then packaged and sold in the domestic markets of these nations or re-exported to international markets.

2.4 Coffee Consumption

According to the USDA Foreign Agricultural Service, over 9.89 million tonnes of coffee were consumed worldwide in 2018 (USDA, 2020). The European Union (EU) accounted for 2.76 million tonnes of that consumption. At 1.63 million tonnes of coffee consumed, the United States was the second largest consumer. Brazil, the largest producer of coffee, was the third largest consumer at 1.39 million tonnes. Globally, the majority of coffee is consumed in Europe, with North and South America consuming around the same amount (Fig. 4). Mainland Asia consumes slightly less than the Americas, while South East Asia & Oceania and Africa are comparable.

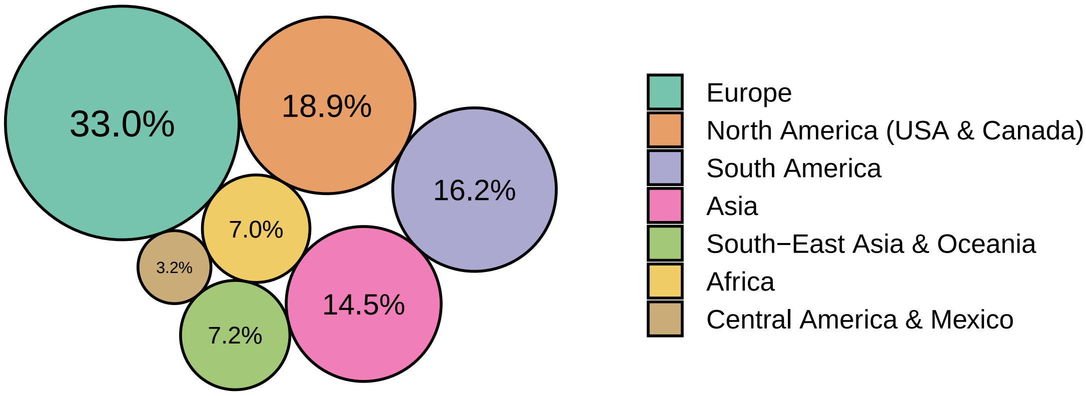

Figure 4. Global coffee consumption in 2018 by geographic region.
Data: ICO (2019)

Although coffee is grown predominantly in developing countries near the equator, most coffee consumption occurs in the industrialized nations of Europe and North America. The highest coffee consumption rates are found in northern Europe (Fig. 5). Scandinavian countries have the highest per capita consumption; Finland is the world leader at 12 kg per year. With the exception of Brazil, the majority of coffee producing nations have modest annual per capita consumption of under 2 kg, and several of the less developed countries consume less than 0.5 kg per capita.

Domestic consumption remains low in coffee producing countries. Due to the lack of processing facilities, low cost raw coffee is exported, but high cost roasted coffee must be imported for consumption. As the nations which cultivate coffee tend to be developing or impoverished countries, the price of roasted coffee is a barrier to access. This combined with a weak 'coffee culture' results in low rates of consumption throughout the coffee belt. As stated earlier, Brazil is an exception to this rule. Brazil has some limited processing ability that is able to meet some of the demand for domestic coffee products. A long history of Brazilian coffee culture also lends itself to higher rates of consumption.

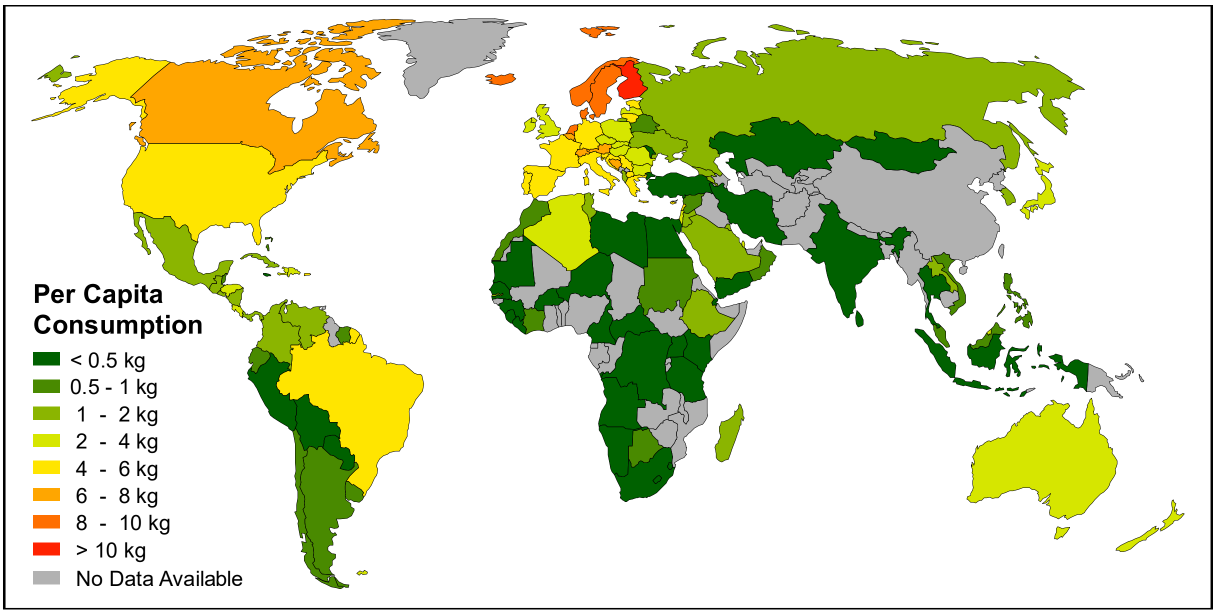

Figure 5. The majority of coffee consumption occurs in Europe and the USA. Brazil is the only coffee producing nation with high domestic consumption.
Data: ICO (2019)

3 Theoretical Foundation

There has been a wide range of economic literature dedicated to the study of the relationships between agricultural prices. In a competitive market, an increase of production costs is passed along to consumers. Similarly, a reduction of production costs is also expected to be reflected in the price paid by consumers. In economic theory, the Law of One Price (LOP) is the understanding that in the absence of trade frictions (such as transport costs or tariffs), and under conditions of free competition and price flexibility, identical goods sold in different locations must sell for the same price when the prices are expressed in a common currency. Or to put it simply, identical goods have same value despite different origins. The LOP is supposed to regulate spatial price relations, while pricing along the production chain depends exclusively on production costs. According to the LOP, if an identical good had a different price in two locations, with no transportation costs or economic barriers between those two locations, arbitrage would result in a single homogeneous price for that good. In the real world, however, the assumptions built into the LOP do not hold true. Transportation costs and product differentiation result in price differences for many kinds of goods, which can be readily observed.

In economic literature, price transmission is known as the price linkage between two markets. Price transmission can be described as either spatial transmission or vertical transmission. Spatial price transmission measures the degree to which markets at geographically separated locations share a common long-run price on a single commodity. Vertical price transmission measures the price differences along different stages of the supply chain. Price transmission can occur symmetrically, meaning that changes in prices are transmitted in both directions at equal speed and magnitude. Alternatively, asymmetric price transmission (APT) refers to a situation in which downstream prices react in a different manner to upstream price changes (Tappata, 2009). For example, an increase in production costs may be transmitted to consumers faster than a reduction in production costs. A well-known real-world example of this would be an increase in crude oil prices that immediately transmits an increase in the price of gasoline, whereas a decrease in crude oil prices is transmitted to gasoline prices at a much slower rate. Prior research has discussed several elements which may play a role in market price transmission. Conforti (2004) listed six major factors that can affect price transmission: transport and transaction costs; market power; increasing returns to scale in production; product homogeneity and differentiation; exchange rates; and, border and domestic policies. All of these factors are influential to the transmission of prices between coffee producers and buyers.

Price transmission plays a role in market integration, which occurs when prices among different locations or related goods follow similar patterns over a long period of time. The prices of goods often move proportionally to each other and when this relation is very clear among different markets it is said that the markets are integrated. The international coffee market shows signs of integration in that price transmission occurs both spatially and vertically. Spatial transmission occurs as price changes in one market cause changes in other markets as coffee is so widely traded. Vertical price transmission occurs along the supply chain and between producers, roasters, and retailers. Domestic coffee prices show evidence of integration with world market prices, and the prices of different coffee types also show signs of integration with one another.

Recent research contributions have focused on the dynamics of the transmission process using the properties of cointegrated time series. Cointegration between the time series implies that two prices may behave differently in the short term, but share a common long-term relationship. If this property is verified, the dynamic relationship between the prices can be described by an error correction model (ECM). The short-run adjustment parameter of this type of model can be interpreted as a measurement of the price transmission speed, whereas the long-run multiplier can be interpreted as a measure of the magnitude of the price transmission (Conforti, 2004). Cointegrated series exhibit causal relationships as defined by Granger (1969). A bivariate cointegrated system must have causality in at least one direction (Engle & Granger, 1987). The direction of this causality is tested by assessing if past observations of one series can predict the other series. Some bivariate cointegrated systems may show evidence of two-way causality, meaning that the variables Granger cause each other.

The price transmission of major food crops has been heavily studied in agricultural economics. Vertical price transmission has focused on evaluating the links between farmgate, wholesale and retail prices (Vavra & Goodwin, 2005). There is extensive literature on the price transmission of food crops; however, our interest lies in the price transmission of a non-essential commodity, which is coffee. There are several recent studies concerning the price transmission of coffee, which have found mixed results concerning the transmission of Arabica and Robusta coffee prices (Fafchamps & Hill, 2008; Li & Saghaian, 2013; Mai et al., 2018; Mofya-Mukuka & Abdulai, 2013). While these studies provide a glimpse into the price transmission of different markets and in different times, it should be noted that price transmission results from previous studies cannot necessarily be applied to other products or for other periods (Aguiar & Santana, 2002).

The price of green coffee as a commodity is subject to high volatility due to weather, disease, bad harvests, and other external shocks. This volatility results in asymmetric price transmission that benefits roasters and retailers while the prices are slower to transmit in the opposite direction (Mehta & Chavas, 2008). Some studies have found that retail prices are more responsive to increases than decreases (Feuerstein, 2002). These studies tend to be focused on short-term price transmission and utilize lag structures of days or months. However, a coffee tree must grow for 3 – 5 years before producing and will continue to produce coffee for another 15 – 25 years. This results in a significant production lag length that can last several years. Furthermore, coffee harvests occur at different times around the world dependent upon geography. This causes somewhat of a decoupling between green coffee production and export prices. Historically, this had been regulated by the ICA and other governing bodies, which worked to stabilize the prices between production and exports. Following the dissolution of the ICA in 1989, Russell et al. (2012) found that the liberalization of state-controlled coffee sectors by replacing it with markets run by private agents has been beneficial to producers. While the pace and extent of liberalization has varied between countries, it has led to more international competition which has resulted in producer prices that more accurately reflect the world and domestic market conditions (Russell et al., 2012). Similarly, Muradian & Pelupessy (2005) concluded that participation in voluntary regulatory systems did not necessarily ensure better economic performance, but may facilitate coordination between roasters/traders and some growers, which is beneficial to both parties.

The work of this paper will provide insight into the price transmission which occurs within the green coffee industry. Assessing the asymmetric transmission of prices is beyond the scope of this study; therefore, we will assume symmetric price transmission and analyze the speed and magnitude of the transmissions which occur between the world market prices and domestic prices of the four largest coffee producers. Possible explanations for differences in the speed and magnitude of price transmission will be explored using the coffee industry profiles developed for each country. As coffee types and production methods vary between these countries, we will provide an overview of how the four coffee producers have developed production strategies which utilize their strengths to capitalize on the global market.

4 Methodology

This project is divided into three major components. The first section is an overview of the economics of the coffee industries in the four major producers. The second is a comparative analysis of the coffee sectors of those four producers. The third and final section is an empirical model which evaluates the relationship between global green coffee prices and the domestic price of green coffee in each of the four countries. All maps are produced using ArcMap software. We conduct all data analysis using R software and the statistical packages vars and tsDyn. All graphs are created in R using ggplot2.

4.1 Major Producers

We independently analyze the coffee industries of the four leading coffee producers. Several time series covering the production, export and consumption of coffee are collected from a variety of sources. These time series are used to establish a framework which describes the development and dynamics of the coffee sectors. The data is presented in graphical form, showing how the coffee industry has changed over time.

Production is evaluated in terms of the area used for cultivation and the total quantity of green coffee produced. A graph showing total production over area harvested is prepared. From these values the production yield is calculated. The ratio of Arabica to Robusta production is used to show which species of coffee each nation specializes in.

Following production, green coffee exports are examined. Export quantity and the total value of exports are presented as linear graphs. From these values the export price is generated by dividing the export value by quantity. The export price is then compared to the ICO Composite price to provide insight into how that nation's coffee is valued against the rest of the world.

Finally, we investigate domestic coffee consumption in each country. The total annual domestic consumption quantity is divided by the nation's reported population in that year. We use this method to obtain the annual per capita consumption rate. These values are then plotted as linear graphs to show the changes in consumption behavior over time.

4.2 Comparative Analysis

Our comparative analysis of the four coffee producers is the second major portion of this thesis. In this section, the coffee industries of the four largest producers are combined and then compared with one another. The three major components of the coffee sector described in the previous section (production, exports, and consumption) are now contrasted among the four leading coffee producing nations. The data of each nation is plotted against one another to show how the industries have developed. Furthermore, the global shares of both production and exports of each coffee producing nation are calculated and graphed to show the importance of these countries to the world coffee market.

We calculate the compound annual growth rate (CAGR) of the variables using the formula:

$$GR = \left(\frac{V_e}{V_s}\right)^{\left(\frac{1}{n}\right)} - 1 \quad (1)$$

In the above equation, the annual growth rate (GR) is calculated using the starting value (V_s), the ending value (V_e) and the number of years (n) between the two values. The CAGR is calculated for three 10-year periods spanning 1980 – 1990, 1990 – 2000 and 2000 – 2010. Additionally, the growth rate of the 2010 – 2018 period is calculated along with the growth experienced during the entire period of 1980 – 2018. The compound annual growth rates of the major components of each coffee sector are compiled into tables to allow for comparison between the coffee producers.

4.3 Empirical Model

We develop an empirical model using the theoretical framework set out in section 3. We investigate the speed and magnitude of price transmission between green coffee prices at the global and domestic levels. The relationship between the world price and the domestic price found in each major producer is estimated using vector autoregression (VAR) or vector error correction (VEC) methods. Using the VEC method avoids potential spurious regression between the prices. After selecting appropriate time series from ICO and the four coffee producers, we test the data for stationarity, Granger causality, and cointegration before applying the appropriate model.

4.3.1 Selection of Variables

The variables selected for analysis are the domestic coffee prices for each of the four countries and three global coffee index prices. We apply bivariate analysis to each country using the domestic price and the index price which corresponds to the majority of coffee produced in that nation. The relation between these prices will be determined from the result of this analysis.

4.3.2 Data Description

The data used for analysis are monthly time series collected from several sources. The serial data covers the period from January 2010 through December 2018, providing 108 observations for each series (9 years $\times$ 12 months $=$ 108 obs.). We perform a natural logarithmic transformation of the data to stabilize some of the observed variance in the time series and these transformations are used in all sub-sequential empirical analyses. A more detailed description of the data and the sources can be found in section 5.2.

4.3.3 Stationarity

A stationary series can be defined as one with a constant mean, constant variance, and constant autocovariance for each given lag. To determine the stationarity of the time series used for the econometric model, two methods are used. In this paper, the augmented Dickey Fuller (ADF) test and the Kwiatkowski, Phillips, Schmidt, and Shin (KPSS) test are applied to verify the stationarity of the data.

Augmented Dickey-Fuller Test

The ADF test is used to determine the presence of a unit root, which if present would imply that the series is non-stationary. There are three versions of ADF test that can be applied depending on what is to be tested (Verbeek, 2012):

(i) Test for a unit root

$$\Delta Y_t = \pi Y_{t-1} + c_1 \Delta Y_{t-1} + ... + c_{p-1} \Delta Y_{t-p+1} + \epsilon_t \tag{2}$$

(ii) Test for a unit root with a constant

$$\Delta Y_t = \delta + \pi Y_{t-1} + c_1 \Delta Y_{t-1} + ... + c_{p-1} \Delta Y_{t-p+1} + \epsilon_t \tag{3}$$

(iii) Test for a unit root with a constant and deterministic time trend

$$\Delta Y_t = \delta + \gamma t + \pi Y_{t-1} + c_1 \Delta Y_{t-1} + ... + c_{p-1} \Delta Y_{t-p+1} + \epsilon_t \tag{4}$$

In Equation 2 the difference operator is indicated as Δ, the lag order p is identified by selection criteria, ϵ_t is an error term (white noise) and the coefficient π is our test parameter. The null hypothesis ($\pi = 0$) is presence of unit root and the alternative ($\pi < 0$) is absence of a unit root. Equation 3 expands this test by adding a constant term (δ). The null hypothesis of test (ii) is that a unit root is present implying the data is non-stationary. Equation 4 tests for a unit root with a time trend by including γt. Under test (iii), the null hypothesis is the presence of a unit root and the alternative is that the data is trend stationary.

We apply tests (iii) and (ii) to our variables to test for the presence of a unit root. The first differences of the variables are then subjected to tests (ii) and (i). The lag length of each test is determined using the Akaike Information Criterion (AIC). The results of the ADF tests are then corroborated with the results of KPSS tests.

Kwiatkowski, Phillips, Schmidt, and Shin Test

To support the findings of our ADF tests, KPSS tests are also used to test the stationarity of the data (Kwiatkowski et al., 1992). Unlike the ADF test, the null hypothesis of KPSS test is that the time series is stationary against the alternative hypothesis of a unit root. The level data is tested for stationarity with the KPSS test, then the first difference of the time series is tested. According to Verbeek (2012), the first step of the KPSS test is to run an auxiliary regression of y_t upon an intercept and a time trend t. The next step is to compute the partial sums of the ordinary least squares (OLS) residuals e_t using $S_t = \sum_{s=1}^{t} e_s$ for all t. The KPSS test statistic is then given as:

$$KPSS = T^{-2} \sum_{t=1}^{T} {S_t}^2 / \hat{\sigma}^2 \tag{5}$$

The estimator for the error variance is designated as $\hat{\sigma}^2$. If the null hypothesis is stationarity rather than trend stationarity, the trend term should not be included in the auxiliary regression. If the test statistic exceeds the critical values determined by Kwiatkowski et al. (1992), then the null hypothesis is rejected.

We compare the results of the KPSS tests with the ADF test results to determine if the time series are stationary. If the time series are not stationary at levels, but the first differences are found to be stationary, then the first differences will be used for further empirical analysis.

4.3.4 VAR

The vector autoregression model can be used to evaluate the linear interdependence among multiple time series. Each variable has an equation based on its own lagged values, the lagged values of the other model variables, and an error term. The generalized VAR(p)-process is described by Verbeek (2012) as:

$$Y_t = \delta + \phi_1 Y_{t-1} + ... + \phi_p Y_{t-p} + \epsilon_t \tag{6}$$

The VAR consists of a constant (δ) and a set of K endogenous variables $Y_t = (y_{1t}, ...y_{kt}, ..., y_{Kt})$ for $k = 1, ...K$. ϕ_i are $(K \times K)$ coefficient matrices for $i = 1, ..., p$ and ϵ_t is a K-dimensional error process.

4.3.5 Lag Selection

To find the optimal lag length for our estimation model of monthly prices, VAR models with lag lengths from one to twelve are considered. The AIC, Bayesian Information Criterion (BIC), and Hannan–Quinn criterion (HQ) are examined and the optimal lag is identified through these criteria. We select the VAR(p) with the lowest criteria values to identify the optimal lag length of our model.

4.3.6 Granger Causality

The next stage in our analysis is the examination of Granger causality using the Toda & Yamamoto (1995) procedure. In the first step, we designate the maximum order of integration as m using the ADF and KPSS tests. We then specify an unrestricted VAR(p) with p being the optimal lag order as identified by the selection criteria. After verifying that the VAR(p) model is well specified with no autocorrelation between the residuals, we then specify a VAR($p + m$) model for our causality tests. We apply a Wald test to the coefficients of the equations produced by the VAR to identify Granger causality between domestic price (DP) and world price (WP).

$$DP_t = \alpha_0 + \sum_{i=1}^{p+m} \alpha_i DP_{t-i} + \sum_{i=1}^{p+m} \beta_i WP_{t-i} + \epsilon_t \tag{7}$$

$$WP_t = \delta_0 + \sum_{i=1}^{p+m} \delta_i WP_{t-i} + \sum_{i=1}^{p+m} \gamma_i DP_{t-i} + \epsilon_t \tag{8}$$

For Equation 7:

$H_0 : \beta_i = 0$ for $i = 1, ..., p$; or WP_t does not Granger cause DP_t

$H_1 :$ If any $\beta_i \neq 0$ for $i = 1, ..., p$; or WP_t Granger causes DP_t

For Equation 8:

$$H_0 : \gamma_i = 0 \text{ for } i = 1, ..., p; \text{ or } DP_t \text{ does not Granger cause } WP_t$$
$$H_1 : \text{If any } \gamma_i \neq 0 \text{ for } i = 1, ..., p; \text{ or } DP_t \text{ Granger causes } WP_t$$

It should be noted that the coefficients of the m lags are not included in the Wald test and that the Wald test statistics are asymptotically χ^2 distributed with p degrees of freedom under the null. A rejection of the null hypothesis implies a rejection of Granger non-causality, which supports the presence of Granger causality.

4.3.7 Cointegration

The Johansen procedure is used to test for cointegration between the variables if the data series are found to be stationary at the first difference (integrated of order one, or I(1)). Both trace statistics and the maximum eigenvalue are used to identify the number of cointegrating vectors. The number of cointegrating vectors is called the cointegrating rank, and is represented as r. The cointegrating rank is determined from the results of the Johansen test. If there is cointegration between the series, a VEC model is used for exploring the relationship between the coffee prices.

4.3.8 VECM

Cointegration between two variables may be represented with an error correction mechanism. A cointegrating relationship may be used to describe an equilibrium relationship in which the cointegrated variables are influenced by the extent of any deviation from the long-run equilibrium. Cointegrated variables will return towards the equilibrium values, showing that deviation from the equilibrium is not permanent. This shows the stability of the long-run relationship. Considering the VAR model in Equation 6, when variables are I(1) and when possible cointegration exists, a VECM may be a better tool for analysis. Verbeek (2012) formulates the VECM as:

$$\Delta Y_t = \delta + \Gamma_1 \Delta Y_{t-1} + ... + \Gamma_{p-1} \Delta Y_{t-p+1} + \gamma \beta' Y_{t-1} + \epsilon_t \tag{9}$$

The linear combinations $\beta' Y_{t-1}$ present the r cointegrating relationships, also known as the error correction terms (ECT). The coefficients in γ measure how the elements of ΔY_t are adjusted to the r 'equilibrium errors' $Z_{t-1} = \beta' Y_{t-1}$. If we take expectations in the ECM, we can derive:

$$(I - \Gamma_1 - ... - \Gamma_{p-1}) E\{\Delta Y_t\} = \delta + \gamma E\{Z_{t-1}\} \tag{10}$$

If $E\{\Delta Y_t\} = 0$, there is no deterministic trend in any of the variables. The assumption that the matrix $(I - \Gamma_1 - ... - \Gamma_{p-1})$ is nonsingular requires that $\delta + \gamma E\{Z_{t-1}\} = 0$, where $E\{Z_{t-1}\}$ corresponds to the vector of intercepts in the cointegrating relations. If this restriction is imposed, intercepts appear only in the cointegrating relationships and the VECM can be rewritten as:

$$\Delta Y_t = \Gamma_1 \Delta Y_{t-1} + ... + \Gamma_{p-1} \Delta Y_{t-p+1} + \gamma(-\alpha + \beta' Y_{t-1}) + \epsilon_t \tag{11}$$

In this form, α is an r-dimensional vector of constants, satisfying $E\{\beta' Y_{t-1}\} = E\{Z_{t-1}\} = \alpha$. As a result, the terms in this expression all have mean zero and no deterministic trends exist.

When examining the model estimations, we can make inferences about the price transmission between the domestic and world prices. In Equation 11, the β' coefficient can be interpreted as the magnitude of price transmission, while the γ coefficients are used to describe the speed of price transmission between the two prices. We can further specify the VECM model we use in our analysis with the following two equations:

$$\Delta DP_t = \gamma_1 \left(DP_{t-1} + \beta_1 WP_{t-1} - \alpha\right) + \delta_1 \Delta DP_{t-1} + \rho_1 \Delta WP_{t-1} + \epsilon_t \tag{12}$$

$$\Delta WP_t = \gamma_2 \underbrace{\left(DP_{t-1} + \beta_1 WP_{t-1} - \alpha\right)}_{\text{Error Correction Term}} + \underbrace{\delta_2 \Delta DP_{t-1} + \rho_2 \Delta WP_{t-1}}_{\text{lagged differences}} + \epsilon_t \tag{13}$$

In these equations, DP and WP are the domestic price and world price time series respectively. The γ_p values represent the ECT coefficients, which we can interpret as the speed of price transmission. The magnitude of price transmission is represented by the β_1 coefficient (long-run multiplier) in the error correction term. Depending on the outcome of the lag selection process, some of our VEC models may include lagged differences. The δ_p and ρ_p coefficients can be used to explain short-run relationships. We will use this VECM to evaluate the price transmission that occurs in each of the four coffee producing countries.

4.3.9 VECM Diagnostics

Following our estimation of one of the previously discussed models, the model is subjected to several diagnostic tests to determine the stability of the model. We test for autocorrelation of the error terms with both Portmanteau and Breusch-Godfrey tests. As the error should be white noise, there should be no autocorrelation found. The null hypothesis of these tests is that no serial correlation is present. We then test the null hypothesis of normality of the error terms using a Jarque-Bera test. We also apply separate tests to check the errors for skewness and kurtosis. Finally, we test the models for autoregressive conditional heteroskedasticity (ARCH) with a multivariate ARCH-LM test. The null hypothesis of this test is that there are no ARCH effects present.

5 Data Description

Two sets of data have been collected for analysis based on the frequency of observations. Annual time series are used to investigate the coffee sector dynamics of the four leading producers. Monthly time series are used for the empirical modeling of coffee prices. Detailed descriptions of the data used and the sources from which they are collected are provided below.

5.1 Annual Data

As the focus of the research concerns the four largest coffee producers, we collected data for Brazil, Colombia, Indonesia, and Vietnam. The annual time series data spans the period from 1980 through 2018, providing 39 observations. Table 1 provides a brief overview of the data and their sources.

The FAOSTAT database compiled by the Food and Agricultural Organization of the United Nations (FAO) was the source of data for coffee production and export information, as well as population numbers (FAO, 2020). The USDA Foreign Agricultural Service (USDA, 2020) supplied the quantity of domestic consumption and production of Arabica and Robusta coffee varieties. Additional variables were derived from calculations using this sourced data.

Table 1. Three types of annual data were gathered from three sources. Additional variables were calculated by the author using collected data.

Variable	Definition (Measure)	Source
Production Data		
Prod. Quantity	Physical quantity of green coffee produced	FAO
Area Harvested	Area from which coffee crop was gathered	FAO
Producer Prices	Farm-gate price of green coffee paid to producers	FAO
Yield	Amount of coffee produced per area of harvest	Author's calc.
Arabica Prod.	Estimated mass of Arabica production	USDA
Robusta Prod.	Estimated mass of Robusta production	USDA
Export Data		
Export Quantity	Physical quantity of green coffee shipped out of country	FAO
Export Value	Value of exports and services involved with exportation	FAO
Export Price	The price of exported coffee leaving the country	Author's calc.
Yield Value	Export value of one hectare of coffee production	Author's calc.
Consumption Data		
Domestic Cons.	Green coffee equivalent of coffee consumed in all forms	USDA
Population	Total population of the country	FAO
Per Capita Cons.	Annual per capita consumption in green coffee equivalent	Author's calc.

5.1.1 Production Data

The majority of production data was obtained from the FAO. The harvest year is dependent on the growing season of each country. *Area Harvested* refers to the area under cultivation from which coffee is actually harvested. Planted areas of coffee trees that have not yet matured enough to produce coffee cherries are not counted toward the total. Similarly, crops damaged by disease or disaster which are not harvested do not count toward the area harvested. *Production Quantity* is the total harvested production by weight. This includes on-holding losses and wastage, marketed quantities, and quantities consumed directly on the farm. The price received by farmers (prices paid at the farm-gate) for their production defines the *Producer Price* and is reported in US dollars per kilogram. *Yield* represents the harvested production for area under cultivation and was obtained by dividing the production quantity by the area harvested. As production data for each variety of coffee was unavailable from the FAO, production estimates from the USDA were used to calculate the share of production attributed to both Arabica and Robusta.

The summary statistics in Table 2 show that the coffee industry of Brazil dwarfs the other nations. The table also indicates that Colombia and Indonesia have comparable coffee production, with Colombia having slightly larger yields. The Vietnam statistics show high yields from a small harvested area and production numbers that range from a minimum of nearly nothing to the second highest maximum.

Table 2. Summary statistics of production, area harvested and yield.

Variable	Country	Min	Mean	Median	Max
Production	Brazil	930.1	2005.3	1910.6	3556.6
(1000 tonnes)	Colombia	462.0	712.4	713.5	1100.0
	Indonesia	281.3	522.3	524.7	722.5
	Vietnam	4.8	625.8	553.2	1616.3
Area Harvested	Brazil	1802.4	2296.1	2264.1	3041.4
(1000 ha)	Colombia	675.3	856.2	806.9	1087.0
	Indonesia	498.0	985.1	900.0	1381.7
	Vietnam	9.2	297.4	269.8	618.9
Yield	Brazil	401.9	901.2	778.9	1905.8
(kg/ha)	Colombia	612.4	837.4	845.0	1117.9
	Indonesia	433.4	537.2	541.1	606.7
	Vietnam	405.7	1714.6	1801.8	2611.7

5.1.2 Export Data

Export data was available from the FAOSTAT database (FAO, 2020) for both export quantity and export value. *Export Quantity* is defined as "the physical quantity of domestic origin or manufactured products shipped out of the country." and is expressed as the total weight of green coffee exports in tonnes. *Export Value* is described as the 'Free On Board' (FOB) value of the total export quantity. This includes the value of the goods plus the cost of the services required to deliver the goods to the point of export and is reported in US dollars. The *Export Price* is expressed in US dollar per kilogram and was derived by dividing the export value by export quantity. *Yield Value* is the potential value of one hectare of production area.

Statistics show that the quantity and value of Brazilian exports are much higher than the other exporters (Table 3). Colombia has a mean export quantity comparable to Vietnam, but much lower maximum export quantity than Vietnam. Indonesian export prices are slightly above Vietnam, while the Colombian prices are the highest. The mean Brazilian export price is located at the midpoint between Colombian price and the average of Vietnam and Indonesia prices. Indonesia has substantially lower yield values when compared with the other producers.

Table 3. Summary statistics of export quantity, value, price and yield value.

Variable	Country	Min	Mean	Median	Max
Export Quantity (1000 tonnes)	Brazil	477.91	1241.03	1094.69	2005.03
	Colombia	396.36	613.32	600.72	967.54
	Indonesia	210.60	351.34	346.09	532.16
	Vietnam	2.70	621.65	482.00	1613.49
Export Value (1000 USD)	Brazil	970.44	2841.81	2230.84	8000.42
	Colombia	768.57	1725.46	1650.65	2988.31
	Indonesia	182.90	624.25	565.24	1244.15
	Vietnam	3.30	961.87	499.65	3093.05
Export Price (USD/kg)	Brazil	0.77	2.25	2.27	4.47
	Colombia	1.30	2.90	2.95	6.05
	Indonesia	0.68	1.76	1.77	2.99
	Vietnam	0.42	1.43	1.46	2.56
Yield Value (USD/hectare)	Brazil	493.67	2114.40	1587.48	5613.41
	Colombia	1192.09	2369.07	2155.85	3915.20
	Indonesia	318.10	952.92	999.56	1627.93
	Vietnam	516.73	2567.62	2488.15	5470.81

5.1.3 Consumption Data

Consumption data was sourced from the USDA. *Domestic Consumption* is reported as the green coffee equivalent of coffee consumed in all forms (roasted, soluble, etc.). The domestic consumption value was divided by the population data furnished by the FAO to obtain the *Per Capita Consumption* for each nation. These values were in line with per capita consumption rates published by the International Coffee Organization (ICO, 2019b). The summary statistics for domestic consumption and the per capita consumption of each country can be found in Table 4.

Table 4. Summary statistics of domestic and per capita consumption.

Variable	Country	Min	Mean	Median	Max
Domestic Consumption (1000 tonnes)	Brazil	456.0	808.6	759.0	1392.0
	Colombia	63.9	91.3	90.0	121.2
	Indonesia	57.0	108.3	98.7	258.0
	Vietnam	0.2	45.0	19.5	176.4
Per Capita Consumption (kg/year)	Brazil	3.2	4.5	4.4	6.4
	Colombia	1.4	2.5	2.3	4.0
	Indonesia	0.3	0.5	0.5	0.8
	Vietnam	0.0	0.5	0.2	1.8

5.2 Monthly Data

To develop our empirical models, higher resolution data and more observations are needed. Data collected at monthly intervals is able to show the relationship between price variables better than annual averages. To carry out the empirical analysis, several time series have been collected representing the months of 2010 through 2018, providing 108 observations for each time series. The data pertains to the domestic prices of raw coffee in the producer countries as well as the average market price of several varieties of coffee on the commodities market (Table 5).

Table 5. Two sets of monthly price data were collected from a variety of sources.

Variable	Definition (Measure)	Source
Domestic Prices		
Brazil	Export price (export value / export quantity)	UN Comtrade
Colombia	Export price (export value / export quantity)	FNC
Indonesia	Averaged forward, future and spot prices	Bappebti
Vietnam	Producer prices (farm gate)	FAO
World Prices		
ICO Composite	Composite price of all coffee types and origins	ICO
Brazilian Naturals	Global price of unwashed Arabicas	ICO
Colombian Milds	Global price of washed Arabicas	ICO
Robustas	Global price of Robustas of all quality	ICO

The coffee prices have been obtained from several sources and are converted into US dollars per kilogram for standardization purposes. The prices are for raw green coffee, which must still undergo the roasting process before being consumed. The domestic coffee prices are gathered from national coffee organizations of international trade databases and represent the price of coffee at different points in the supply chain. As the availability of domestic prices is somewhat limited, the price point at the producer level could not be obtained for all countries. Nevertheless, the domestic price of coffee is a good proxy for the prices paid to the producers (farmers).

The world market prices are obtained from the International Coffee Organization and are indicator prices for specific types of beans. Brazilian Naturals, despite the name, are produced around the world and are Arabica beans that have been dried and mechanically processed as described in section 2.2.1. Colombian Milds, considered the highest quality coffee beans, are also of the Arabica variety. Colombian Milds have undergone a washing process, followed by fermentation, which is said to mellow and enhance the flavor. These beans are grown in several areas outside of Colombia, although in limited quantities due to the more intensive processing. The ICO Composite price is an averaged benchmark price of all coffee traded in the world, regardless of the source or quality. This weighted average price is the best overall representation of the global price of the green coffee commodity. Robustas are the average price of all Robusta varieties grown around the world. Considered the 'inferior' coffee bean, less effort is invested in differentiating between the different types of Robustas. Table 6 contains summary statistics of the domestic prices as well as the world market prices of the different coffee varieties.

Table 6. Summary statistics of monthly coffee prices.

	Variable	Min	Mean	Median	Max
Domestic Prices (USD/kg)	Brazil	2.20	3.06	2.79	4.86
	Colombia	3.13	4.20	3.93	6.72
	Indonesia	1.25	1.87	1.92	2.57
	Vietnam	1.25	1.80	1.83	2.41
World Prices (USD/kg)	Brazilian Naturals	2.20	3.39	3.03	6.01
	Colombian Milds	2.74	4.04	3.62	6.88
	ICO Composite	2.16	3.12	2.89	5.09
	Robustas	1.48	2.07	2.13	2.68

Considering the domestic coffee prices, Colombia receives the highest price for the coffee it produces. Brazil receives the second highest producer price, while Indonesia and Vietnam receive very similar prices. Indonesia and Vietnam primarily produce Robustas, bringing a much lower price than the Arabicas grown in Brazil and Colombia. When examining the world market prices, the highly regarded Colombian Milds bring the highest prices. Brazilian Naturals, which require less processing input, bring slightly lower prices. Robustas, on the other hand, are significantly lower in value than the two Arabicas. The ICO Composite price, being a weighted average of the coffee types, lies between the Robustas price and Brazilian Naturals price.

6 Major Producers

The following section will individually detail the coffee sectors of the four leading coffee producing nations. These countries are Brazil, Colombia, Indonesia and Vietnam. A detailed look into the production, exportation, and consumption of coffee will provide insight into how these domestic coffee industries have grown and developed over recent decades.

6.1 Brazil

The cultivation of coffee in Brazil began in the 18th century and spread rapidly. Throughout this expansionary period, the Brazilian economy was tightly coupled with the coffee economy, and the coffee market was highly regulated by the Brazilian federal government until the mid-1990s (Volsi et al., 2019). Between 1952 and 1989, the Instituto Brasileiro do Café (IBC) was responsible for the regulation and control of the Brazilian coffee industry. Increasing consumer demand for access to higher quality coffee caused disagreement between members of the ICA, and failed renegotiation meant that the 1983 agreement was allowed to expire (Dishneau, 1989). The breakdown of the ICA in 1989 and the dissolution of the IBC in 1990 brought an end to the regulatory policies (Volsi et al., 2019). With this deregulation, the Brazilian coffee sector was exposed to the free market and coffee growers experienced a period of crisis and low price levels. While coffee was one of the most important crops throughout the history of Brazil, its importance has recently declined relative to grains and other more profitable crops (USDA, 2020).

6.1.1 Production

Brazil is the world's largest coffee producer and is responsible for approximately one third of global production (USDA, 2020). The coffee marketing year in Brazil spans from July to June of the following year, with the harvest usually beginning in late April. Coffee typically grows on hillsides making access for machinery difficult. Brazil, on the other hand, has large relatively flat plantations that allow easy access for machines. As a result, an increasing portion of production is harvested by automated strip picking machines reducing production costs associated with manual labor. Between 1980 and 1990, production averaged around 1.5 million tonnes annually (Fig. 6a). 1989 saw the largest area harvested before a decline following the collapse of the IBC. 1995 reported the lowest production at 900,000 tonnes. Both area harvested and production increased from 1995, however, area harvested began a slow decline in 2003 while production has continued on an upward trend. The annual fluctuation in production output is caused by the alternating cycle of 'on-year' and 'off-year' crops (ICO, 2014b). This cycle is driven by Arabica production as the trees need time to recover following a large crop. As can been seen in Fig. 6b, the share of Robusta production has increased since the 1980s, which has led to increased yields. This combined with the shift toward modernizing cultivation has resulted in larger coffee outputs from a smaller footprint. Better crop management has also supported a steady increase in production (USDA, 2019a). Annual yields have substantially increased, with recent yields being more than three times higher than production yields in the 1980s.

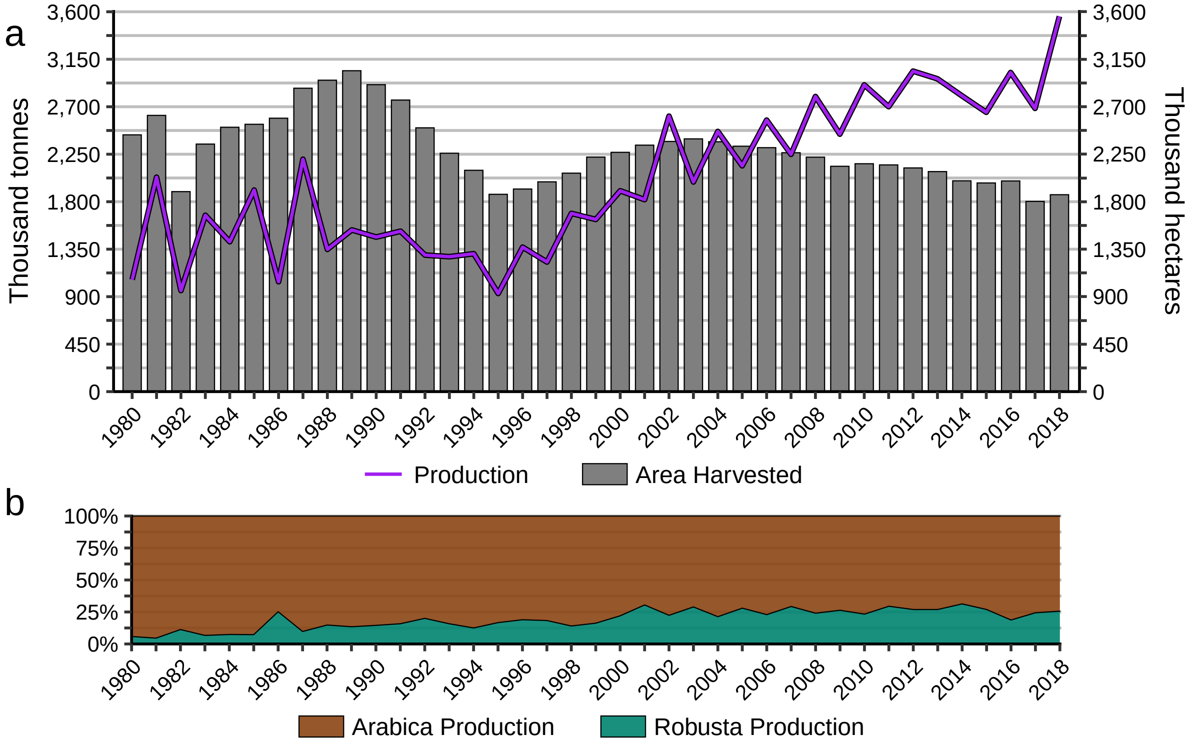

Figure 6. Brazil green coffee production and total crop area harvested (a). Production share of Arabica and Robusta coffee crops (b).

6.1.2 Export

Brazil exports around 65% of the coffee it produces with the majority of it destined for the USA and Germany. Before its dissolution, the IBC controlled all aspects of coffee exportation in Brazil. The IBC functioned by stockpiling coffee beans produced in Brazil with the aim of regulating supply and demand and in turn moderating price fluctuations (Volsi et al., 2019). The IBC also directed lower-grade beans to Brazilian coffee roasters for sale in the domestic market, while reserving higher-quality beans for export. This tactic allowed for the Brazilian government to regulate much of the international coffee market through its domestic policies and coffee quotas. As seen in Fig. 7a, the quantity of exports increased after these quotas were removed. The value

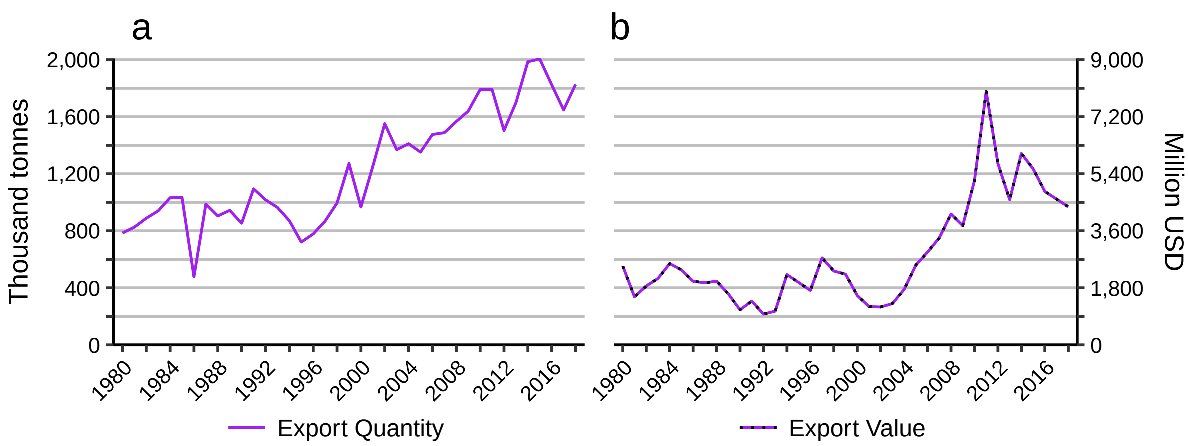

Figure 7. Export Quantity (a) and Export Value (b) of Brazil.

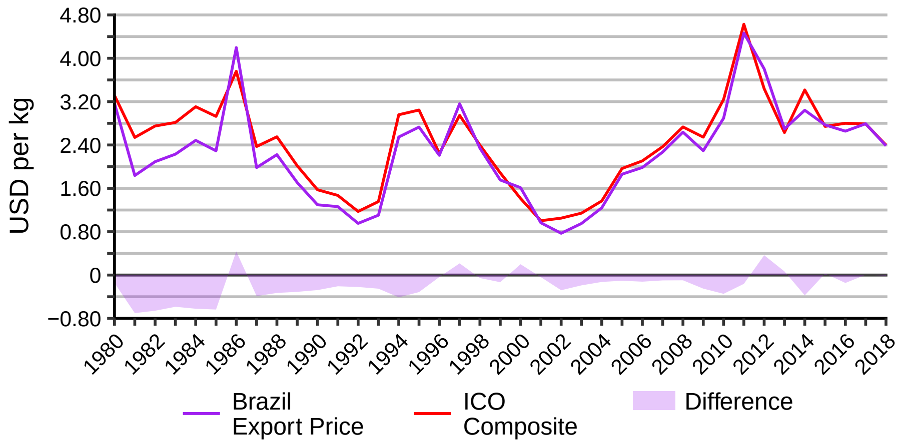

Figure 8. Export price of Brazilian green coffee and ICO Composite price.

of exports reached 2.7 billion USD in 1984 and 1997, whereas the periods following the IBC collapse of 1989 and the coffee crisis of 2000 saw prices less than half of that (Fig. 7b). The low production of 1986 and corresponding low quantity of exports visible in Fig. 7a caused a global shortage in the coffee supply. This resulted in the spike of the 1986 export price seen in Fig. 8. A global Arabica shortage increased coffee prices to record highs in 2011, resulting in 8 billion US dollars of Brazilian coffee exports. The differences in Fig. 8 show that 1986, 1997, 2000, and 2012 are the only years in which the Brazilian export price was above the ICO Composite price. However, the difference between the two prices has grown smaller over the years. Annual time series do not provide the resolution needed to analyze price transmission between export and global market prices as there is no lag. There is a high degree of positive correlation (r = 0.927) between the differenced natural log of the prices.

6.1.3 Consumption

Brazil is the world's second largest national consumer of coffee following the USA. The per capita consumption rate is currently the 15th highest in the world at approximately 6 kg per year. According to the USDA (2019), Brazilians consume 95% of their coffee in roasted/ground form, and the remaining 5% in soluble form. Brazil has a long history of coffee consumption and also

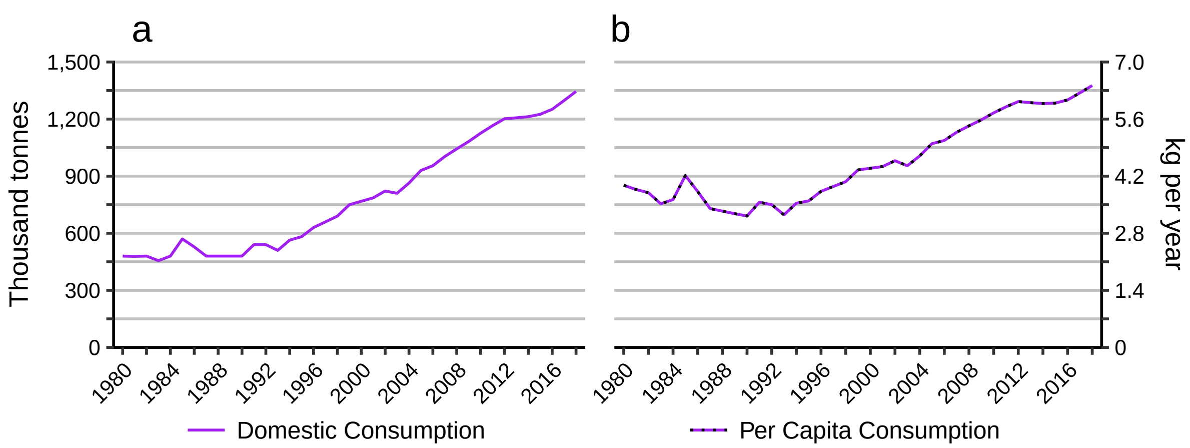

Figure 9. Brazil domestic consumption and per capita coffee consumption.

possesses the required infrastructure to process a large portion of green coffee into roasted beans ready for consumption. This allows for locals to consume cheaper domestically roasted coffee rather than costly imported beans from the USA or EU, which are subject to trade tariffs. Total domestic consumption remained stable from 1980 to 1990 and the annual per capita consumption rate decreased from around 4 kg to 3 kg. The decrease in 1986 exports discussed above resulted in a brief increase of consumption. After the abolition of the IBC, Brazil was no longer under production and export quotas and domestic consumption has been increasing since. The rising domestic demand of coffee has seen increases in production facilities that divert coffee from the export market toward Brazilian consumers. Per capita consumption was above 6 kg in 2018 and is projected to rise even higher in coming years (USDA, 2019a).

6.2 Colombia

The history of coffee cultivation in Colombia begins in the 18th century, with the introduction of coffee by Jesuits. Production expanded under direction of Jesuit landholders and the first exports began in 1835 (FNC, 2020). By the end of the 19th century, it was the main foreign exchange export product in Colombia. In 1935 the Federación Nacional de Cafeteros de Colombia (FNC) was established, and is the organization responsible for aiding and representing local coffee growers' interests. Colombia was once the world's second largest coffee producer but has slipped to a distant third in recent years. Nevertheless, it is still the world's largest producer of 'washed Arabica'. Colombian coffee is known for its mild, well balanced taste, partially due to how the raw beans are processed. About 40% of all Colombian coffee produced receives a price premium for being specialty coffee (USDA, 2019c). Although coffee production has maintained strong levels because of an increase in productivity, the costs associated with wet processing are quite high. Due to these costs, the Colombian government is supporting coffee farmers through subsidies so they do not transition to more profitable crops.

6.2.1 Production

There are around 560,000 coffee growing families operating farms that are an average size of 4.5 hectares. These small farms are responsible for approximately 69% of coffee production in Colombia (USDA, 2019c). All commercially grown coffee in Colombia is of the Arabica variety, and is typically processed using wet or 'washed coffee' methods. The fermentation that takes place during this process produces the mild taste associated with Colombian coffees. To take advantage of recent trends, Colombia has shifted its focus to production of smaller quantities of higher quality coffee that brings a better market price.

The high-quality coffees produced by Colombia require the beans to be selectively harvested by hand. This labor-intensive process means that yields are lower than in areas which use strip picking. As shown in Fig. 10, the yield is typically under 1,000 kilograms per hectare. The area harvested has seen a steady decrease since the early 1980s while production levels have remained more or less the same. It should also be noted that Arabica accounts for 100% of production.

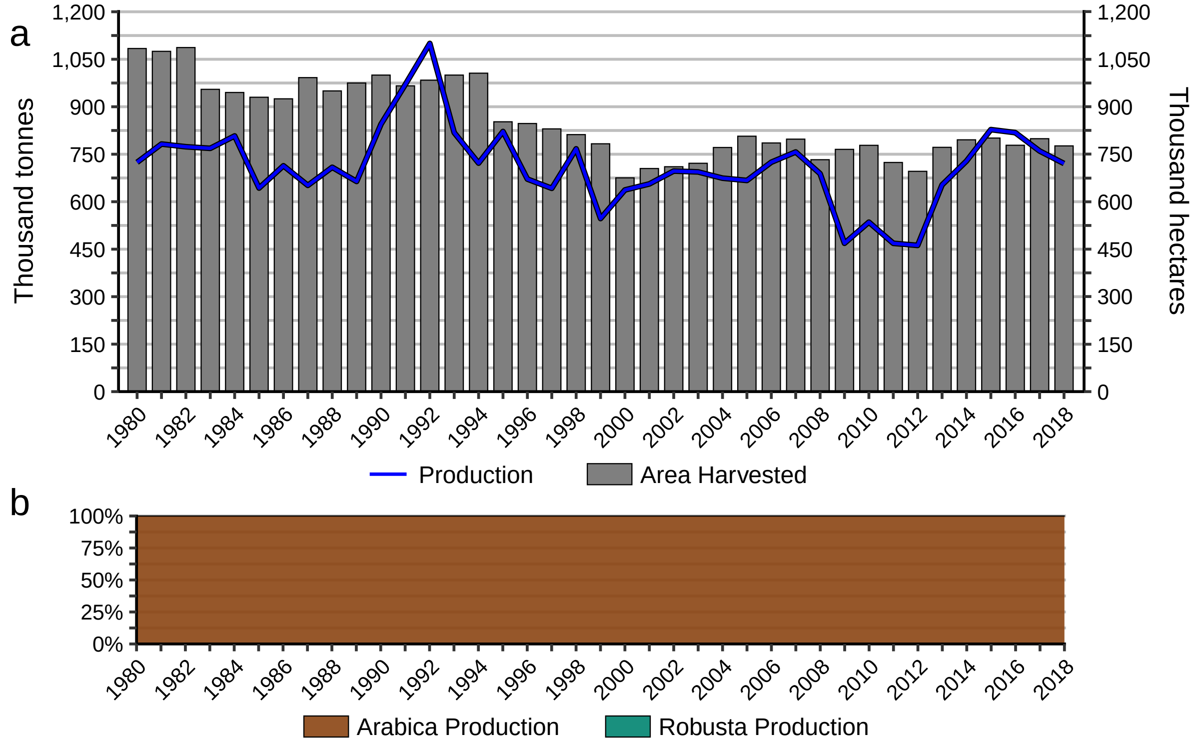

Figure 10. Colombia green coffee production and total crop area harvested (a). Production share of Arabica and Robusta coffee crops (b).

6.2.2 Export

Colombia exports approximately 90% of all the coffee it produces. The majority of exported coffee is imported by the USA (44%), followed by the EU (25%), Japan (10%) and Canada (7%). Exports peaked at nearly 1 million tonnes in 1992, but saw a sharp decrease to around 600,000 tonnes in 1995 (Fig. 11a). This remained fairly stable until a large slump from 2008 to 2012, where it has been recovering since. The value of exports has varied quite a lot in the past 40 years, with the early 2000s being the lowest period (Fig. 11b). By producing valuable high-quality coffee, the annual export price of Colombian coffee has consistently been higher than the ICO Composite price, with the value gap increasing over time (Fig. 12).

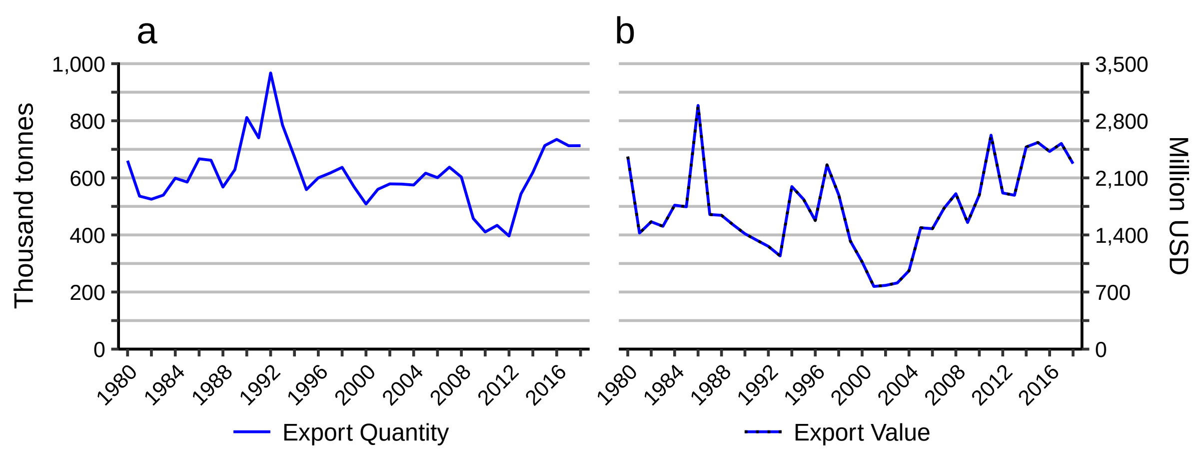

Figure 11. Export Quantity (a) and Export Value (b) of Colombia.

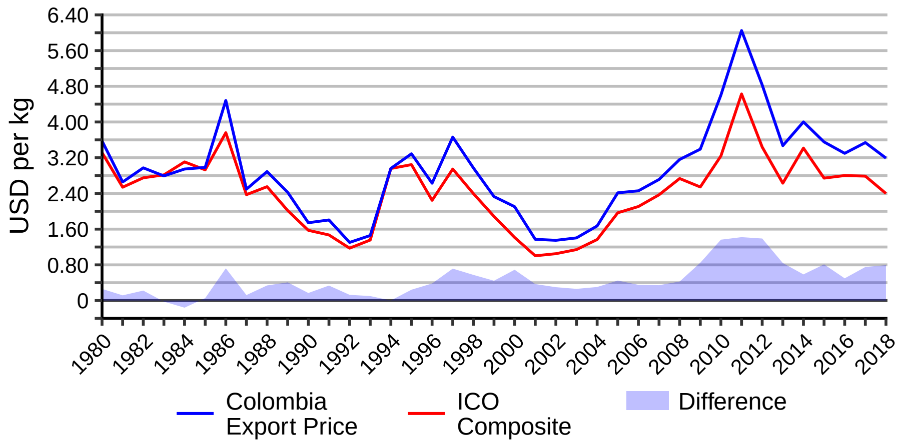

Figure 12. Export price of Colombian green coffee and ICO Composite price.

6.2.3 Consumption

Coffee consumption in Colombia has decreased since the 1980s (Fig. 13a). The lack of adequate roasting facilities means that the majority of produced coffee must be exported, and the majority of consumed coffee must be imported. The annual per capita consumption rate decreased at a faster pace than domestic consumption. An improving economy has led to an increased consumer demand for coffee products. Since 2009, domestic coffee consumption in Colombia has grown due to an increasing number of coffee shops. The creation of new coffee products to satisfy the rising demand of young professionals and foreign visitors has also increased national consumption. The recent increased domestic consumption has shown a gentle increase in per capita consumption from around 2009 to the present (Fig. 13b).

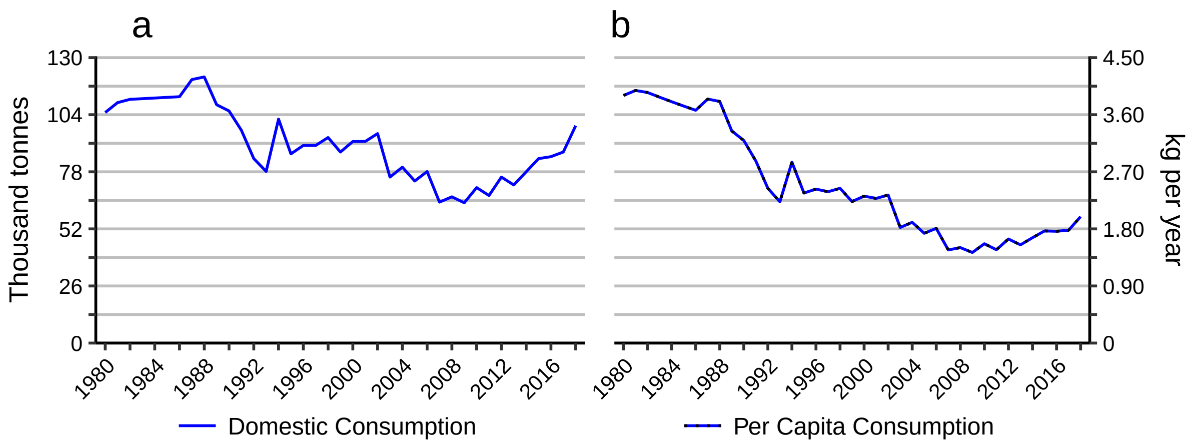

Figure 13. Colombia domestic consumption and per capita coffee consumption.

6.3 Indonesia

Coffee was first introduced to the Indonesian archipelago by the Dutch, who established coffee plantations on the island of Java in the 17th and 18th centuries. Indonesia was the first place, outside of Arabia and Ethiopia, where coffee was widely cultivated (Pendergrast, 2010). It has since spread to Sumatra and many of the other islands as the climate is considered to be near ideal for growing coffee. Arabica coffee was grown in large plantations until disease eradicated them in the 1870s, and they were replaced by the hardier Robusta species. Today, most Indonesian coffee production is of the lower quality Robusta type; however, Indonesia is also famous for having specialty coffees. The most famous is probably 'Kopi luwak' (also known as civet coffee), which is coffee that has been digested by the Asian palm civet and regarded as especially mild and smooth tasting due to the fermentation process that occurs inside the animal. It is sometimes known as the 'world's most expensive coffee' due to its scarcity and unique processing method. Despite producing a few expensive specialty coffees, the majority of exported Indonesian coffee receives a low value on the global market as it is predominantly of the Robusta variety.

6.3.1 Production

Indonesia's coffee plantations cover a total area of approximately 1.25 million hectares, with one quarter of the area dedicated to Arabica production and the remaining portion reserved for Robusta (Fig. 14a). Smallholder plantations averaging between 1 to 2 hectares account for 98% of all production area, though several large plantations up to 4,000 hectares can be found on the islands of Sumatra and Java (USDA, 2019d). As Indonesia does not have many large coffee

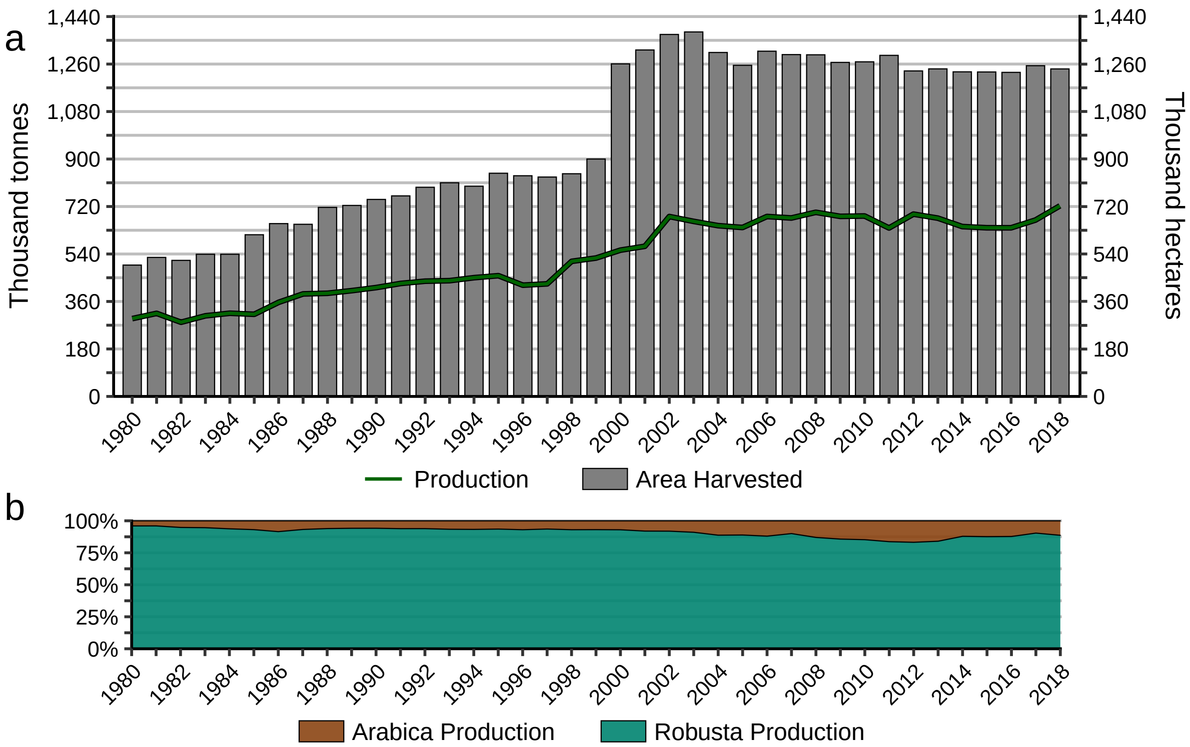

Figure 14. Indonesia green coffee production and total crop area harvested (a). Production share of Arabica and Robusta coffee crops (b).

plantations, difficulties in maintaining stable production volumes and quality often arise. This results in a loss of competitiveness on the international market.

Arabica coffee in Indonesia, whether it is grown by smallholders or on large estates, is typically picked by hand. After harvest, the Arabica is processed by either the dry or wet methods described earlier. Almost all Robusta farmers process the cherries by drying them in the sun. As most coffee is produced by small family farms, heavy fertilizer inputs, modern machinery and advanced cultivation methods are not used. Yields are typically quite low, though production has increased along with the area harvested at a steady rate. The early 2000s saw a large jump in harvested area, but in recent years these farms have been being converted into palm oil plantations. The share of production which is Arabica (Fig. 14b) has increased in the past two decades but has not crossed the 25% threshold. The future of Indonesia coffee is uncertain as production growth has been stagnant and plantation area is being lost to other crops.

6.3.2 Export

Around 70% of all coffee produced in Indonesia is exported. Of this, around 80% is of the Robusta variety, which is in line with the production share. The quantity of coffee exports from Indonesia has been trending upward, though highly variable between annual observations (Fig. 15a). This may be due to the limitations in coffee supply and inconsistent quality that are inherent with small independently organized farms as discussed earlier. The value of the exported coffee has also been highly dynamic, marked by peaks in 1986, 1994, and 2012. The lowest value of total exports was in 2001, when they dipped to just above 150 million USD. Export value had increased to over 1.2 billion in 2012 before falling below 900 million USD in 2018.

The export price of Indonesia is very low in comparison with the other nations. The reason behind this is that Indonesia mainly exports Robustas, which have a lower market value. When comparing the annual price of Indonesian exports to the ICO Composite price, it is easy to see the difference. As seen in the differences in Fig. 16, the export price of Indonesia is consistently well below the ICO Composite price. This price gap becomes more pronounced when the composite price increases in response to the more dynamic Arabica price.

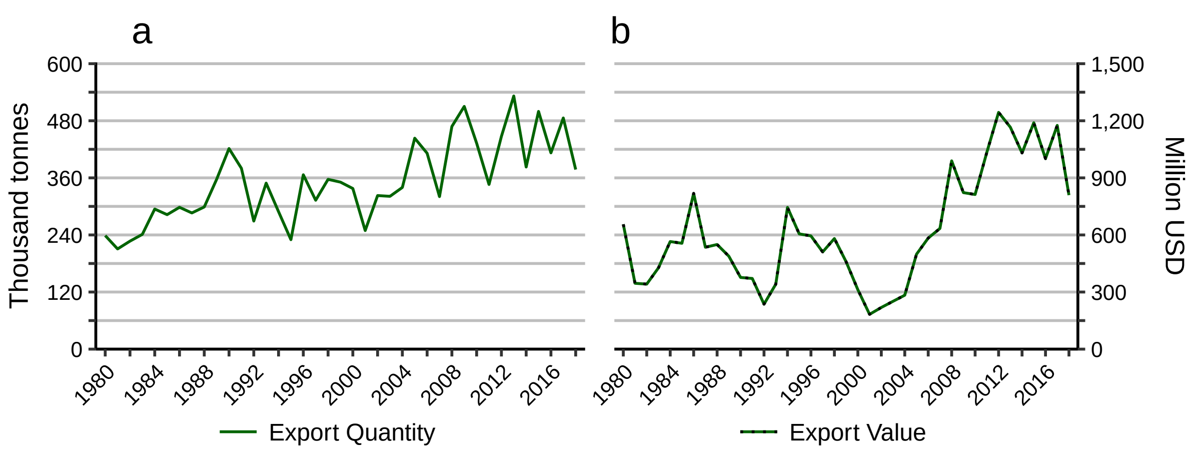

Figure 15. Export Quantity (a) and Export Value (b) of Indonesia.

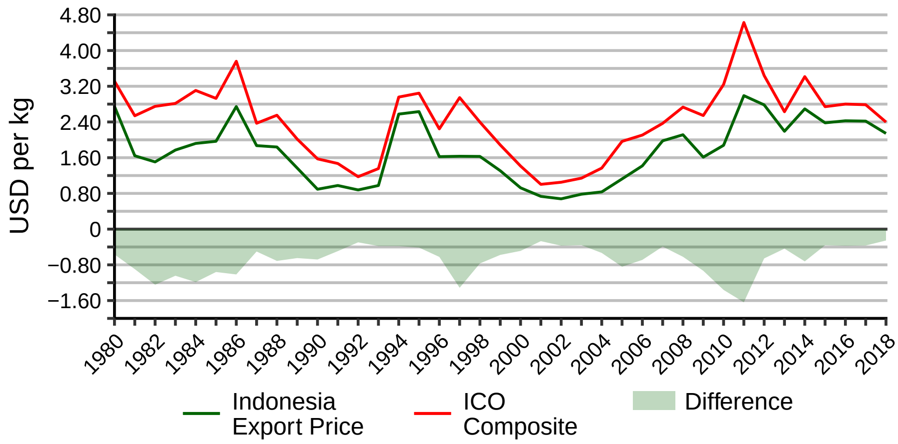

Figure 16. Export price of Indonesian green coffee and ICO Composite price.

6.3.3 Consumption

Domestic consumption in Indonesia is quite low, however, consumption has increased in recent years due to strong demand for ready-to-drink coffee products and the expansion of coffee retail outlets (USDA, 2019d). As the consumption of coffee has grown, exports have declined as Indonesians prefer to drink local coffee which removes it from the global market. As noted, however, imported soluble coffee and ready-to-drink products are what is driving the increase in consumption. Even with the recent upswing in consumption, the annual per capita consumption rate is still very low. Aside from a point in the mid-1990s, per capita consumption remained below 0.5 kg per year until 2012. The aforementioned recent increased consumption due to retail outlets and innovative products has driven the per capita rate to 0.8 kg per year in 2018. Consumption has been predicted to continue to increase in the coming years (USDA, 2019d).

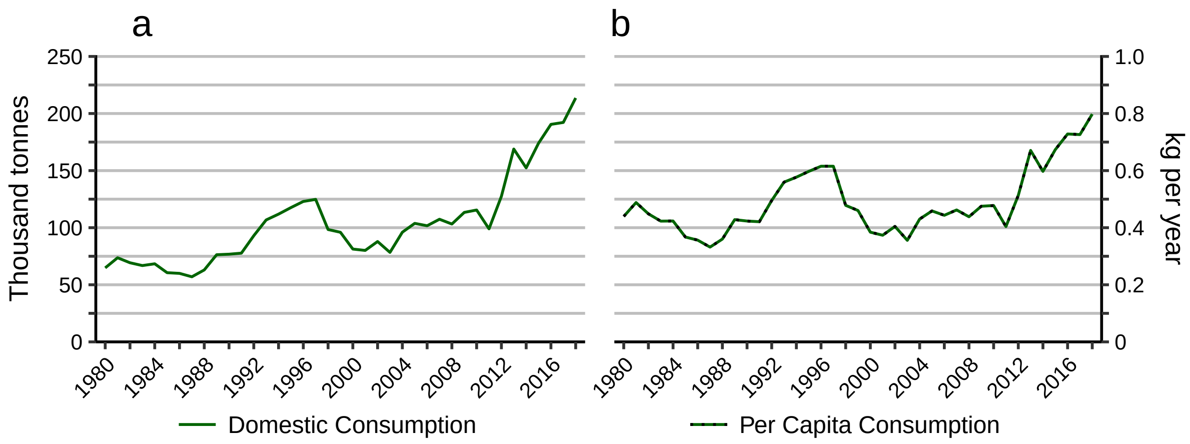

Figure 17. Indonesia domestic consumption and per capita coffee consumption.

6.4 Vietnam

Coffee has been present in Vietnam since being introduced by French colonists in 1857. The height of French coffee production occurred in the early 20th century as small-scale production shifted towards larger plantations (VICOFA, 2018). The onset of warfare in the mid-20th century brought devastating effects to the coffee industry (Fortunel, 2000). Following North Vietnam's victory over the South, the coffee industry was collectivized under the communist regime. Vietnam was a member of the Soviet-led Council for Mutual Economic Assistance (COMECON) and coffee exports during this time went to other communist governments in return for industrial goods.

The Vietnamese Ministry of Agriculture and Rural Development (MARD) developed a program to improve the production of coffee in 1981. Afterward, coffee production began to slowly increase. It was not until 1986, when Vietnam implemented its economic reforms allowing private ownership of farms, that the industry began to grow in earnest (World Bank, 2004). The economic reforms and resulting privatization caused a huge surge in coffee production levels as the number of small, independent coffee farms rapidly increased.

The Vietnamese economy opened up for international development following the end to the USA's economic embargo in 1994 (U.S.-Vietnam Trade Council, 2010). The resulting infusion of foreign investment further enhanced the Vietnamese coffee industry. It was during this time that many Vietnamese companies involved in coffee processing were established. The two largest, Trung Nguyen and Highlands Coffee, are privately owned and primarily serve the domestic market. There are also several state-owned companies, such as Vinacafe, which control a significant portion of production.

Coffee has become the most important cash crop of Vietnam (WTO, 2019). International trade has been the driving force in the development of the coffee industry. Following its membership to the ICO in 1991, formalized trade relations with the USA in 1994, and membership in the WTO in 2007; Vietnam has gained access to many new markets. The rising demand for coffee has given Vietnam the opportunity to transform its once modest coffee sector into a global player.

6.4.1 Production

Vietnam has become the second largest producer of coffee in the world. Production in Vietnam has been predominantly focused on Robusta rather than the more lucrative Arabica beans due to climate limitations. Arabica production accounts for only 3 – 5 percent of Vietnam's total coffee production and its planted area accounts for about 6 percent of the total area (USDA, 2019e). The growth of coffee production has been unlike any other country in the world. From nearly nothing in the early 1980s, coffee production exploded in the mid-1990s and has been increasing ever since (Fig. 18a). Despite the very high production growth rate, the area dedicated to coffee plantations has remained relatively stable since 2000. Experiencing ample growth during the

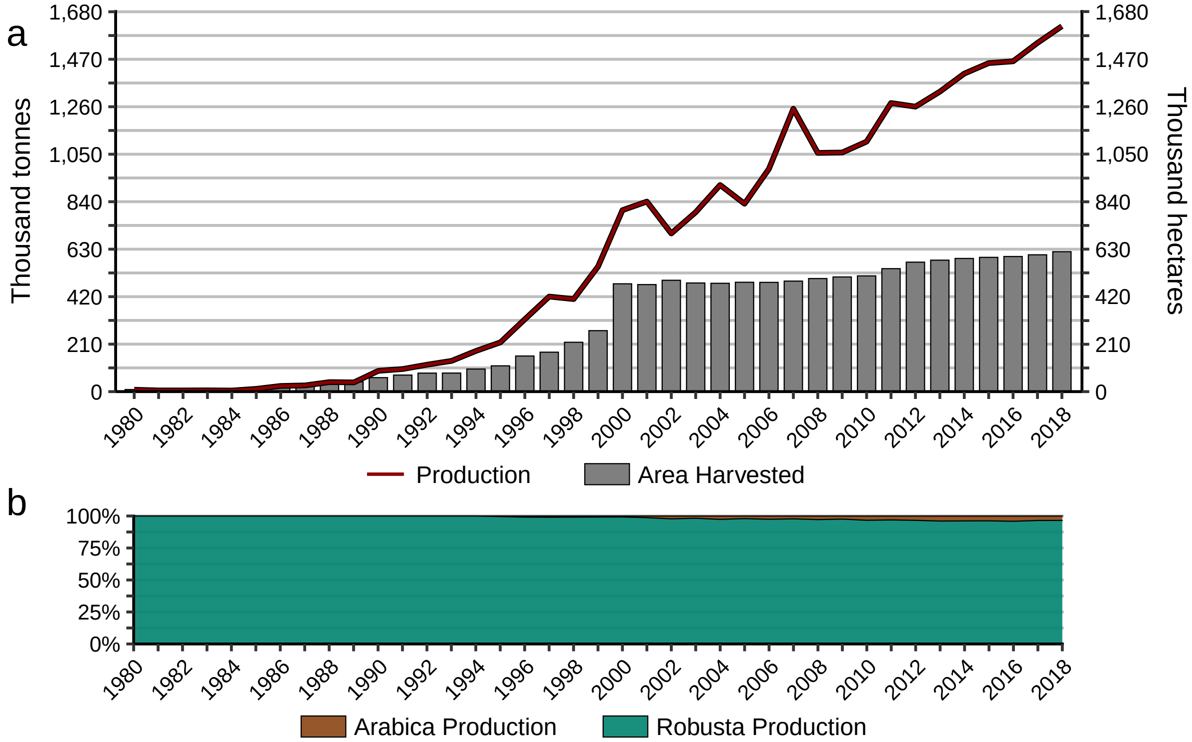

Figure 18. Vietnam green coffee production and total crop area harvested (a). Production share of Arabica and Robusta coffee crops (b).

1990s and then a substantial jump in 2000, it has remained around 525,000 hectares for the past 18 years. Vietnam experiences high production yields due to intensive irrigation and fertilization methods not used elsewhere. These intensive methods, combined with the more productive Robusta plants, provide Vietnam with the highest production yields in the world.

Vietnam coffee production has been dominated by the Robusta variety because of its hardy nature and resistance to disease. Coffee in Vietnam is primarily produced by small independent farms, but several large companies have been consolidating production in recent years. As the domestic coffee market develops, some producers have branched out into growing Arabica in areas where the climate allows.

6.4.2 Export

Vietnam exports between 90 and 95 percent of the coffee it produces. The lack of processing capabilities means that the coffee must be exported for roasting and packaging. There is a national effort to increase processing capabilities to meet the demands of the growing domestic market.

The quantity of coffee exported, seen in Fig. 19a, follows the same upward trend as coffee production. Exports reached 900,000 tonnes by 2001 and have since nearly doubled to over 1.6 million tonnes in 2018. The export value has also grown significantly from the 1980s. Aside from a 10-year period of stagnation that lasted from 1995 through 2004, the value of exports has been increasing along with the quantity (Fig. 19b). The export value had a fairly substantial dip from 2012 to 2015 as the export quantity also decreased during this time.

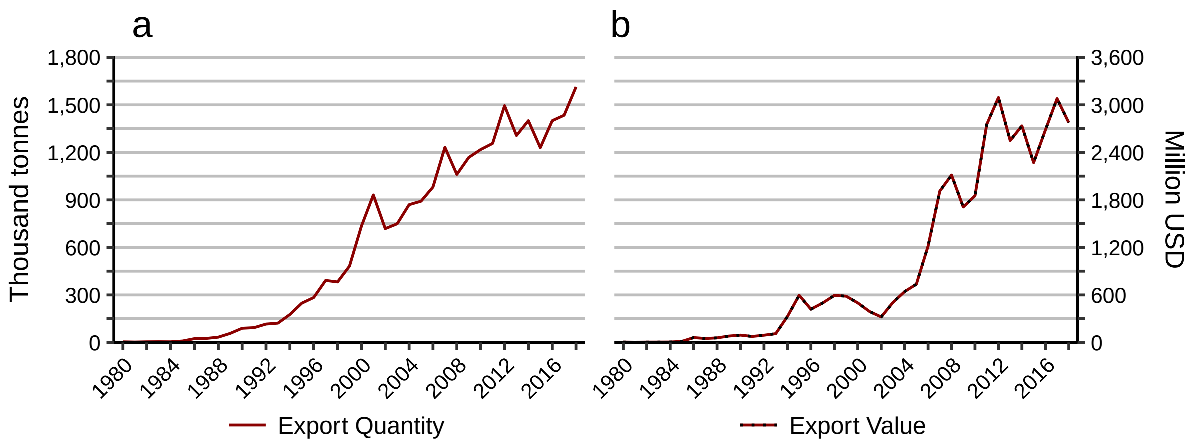

Figure 19. Export Quantity (a) and Export Value (b) of Vietnam.

Coffee produced in Vietnam is generally considered to be of lower quality than in the other countries. Vietnam approaches coffee production with a quantity over quality strategy. As the coffee is mainly grown on small lots by independent farmers, it is difficult to achieve a constant quality standard. There has been a recent push to develop quality standards that apply across the country, but so far efforts have failed. The MARD's strategy for the future is to cap production at current levels and focus on improving the quality of coffee being produced. As a result of the perceived low quality, Vietnamese coffee receives a low price on the world market. The differences in Fig. 20 show that the export price of Vietnamese coffee is considerably lower than the ICO Composite price. This is most obvious in 2011, when the ICO price was more than double of Vietnam's export price. The ICO Composite price takes into consideration the prices of Arabicas, which heavily skews the comparison. In section 8.4 the domestic price of coffee in Vietnam is modeled against the world price of Robustas to remove some of this bias.

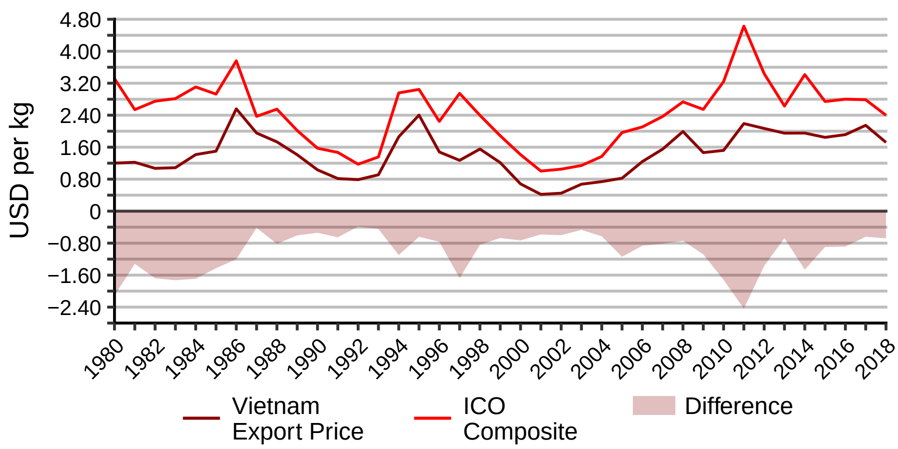

Figure 20. Export price of Vietnamese green coffee and ICO Composite price.

6.4.3 Consumption

Consumption in Vietnam has been growing at a pace in line with the growth of production and exports. Domestic consumption was around 5,000 tonnes in 1990, 20,000 tonnes in 2000, 70,000 tonnes in 2010 and is on course to reach 200,000 tonnes by 2020 (Fig. 21). Per capita

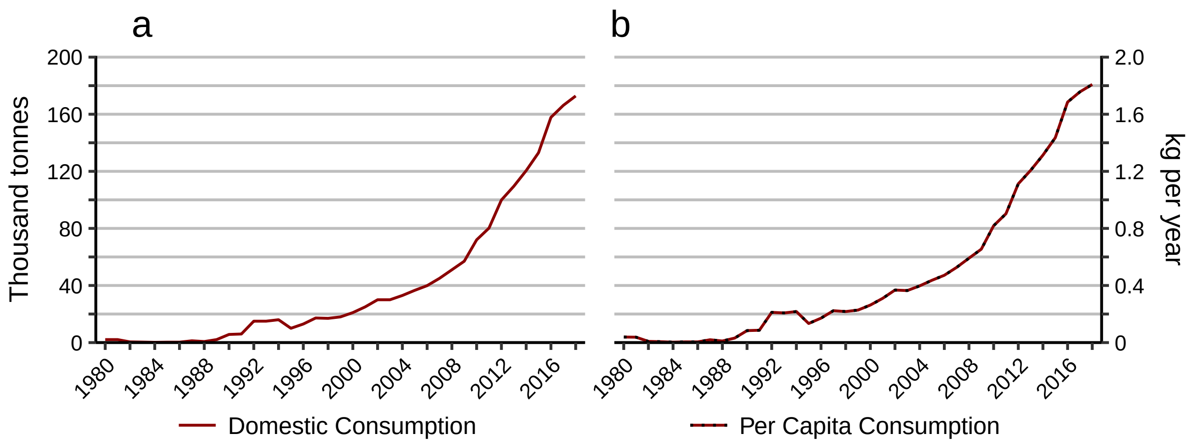

Figure 21. Vietnam domestic consumption and per capita coffee consumption.

consumption following the same growth has gone from 0.08 kg in 1990 to over 1.8 kg per person in 2018. The rising demand in consumption is driven by the development of the coffee industry, increasing domestic processing, and the rapidly expanding Vietnamese economy. Local coffee retailers are expanding retail outlets and marketing new products to consumers. As the standard of living increases, the citizenry have more money to spend on luxury commodities, which has caused a substantial increase in coffee consumption rates.

7 Comparative Analysis

The four largest coffee producers are responsible for more than 60% of the global production of green coffee. In this section, we compare the production, exports, and domestic consumption of coffee between these nations. This analysis provides a glimpse of the contributions that these producers make as well as the associated market dynamics of the global coffee trade. Recent developments of the industry have been more beneficial for some producers than others.

7.1 Production

7.1.1 Production Quantity

Production output of Brazil and Vietnam increased significantly, while Indonesia was able to double its production and Colombia remained relatively stable over time (Fig. 22). Brazil doubled its production between 1980 and 2018 and also decreased the variance caused by biennial crop harvests. Vietnam began as the lowest producer but became the second largest producer by 2018, with coffee production equivalent to the combined output of Colombia and Indonesia. Colombia briefly increased production after the lapse of the ICA in 1989 and briefly decreased production following the coffee crisis in the late 2000s, but has remained relatively constant at approximately 800,000 tonnes annually in recent years. This made Colombia the second largest coffee producer until being surpassed by Vietnam in 2000. Production in Indonesia showed stable growth, swelling from 300,000 tonnes in 1980 to more than 700,000 tonnes in 2018.

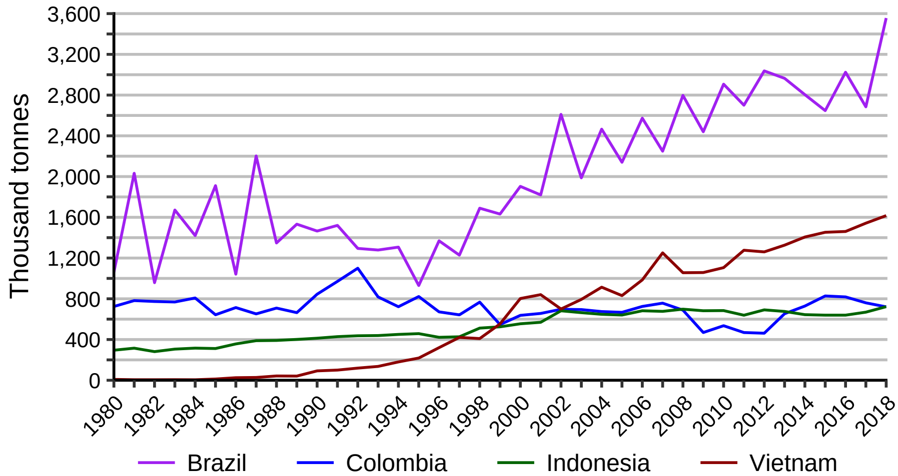

Figure 22. Total production output of the four largest coffee producers.

The compound annual growth rates of coffee production for different time periods can be seen in Table 7. Brazil and Indonesia both exhibited higher rates of growth than world coffee production, however Indonesia's growth has slowed in the most recent decade. Vietnam had explosive growth between 1980 and 2000 before slowing in recent years. With almost 15% annual growth between 1980 and 2018, Vietnam has far outpaced any of its competitors. Colombia is the only major producer that experienced negative growth, with production numbers decreasing from 1990 through 2010, followed by strong growth in recent years. With the exception of Colombia, the four major producers have outpaced the growth rate of the global coffee industry.

Table 7. Annual growth rate (%) of coffee production for different time periods.

	1980 – 1990	1990 – 2000	2000 – 2010	2010 – 2018	1980 – 2018
Brazil	3.28	2.65	4.33	2.55	3.23
Colombia	1.55	−2.78	−1.73	3.78	−0.01
Indonesia	3.42	3.00	2.12	0.68	2.39
Vietnam	27.04	24.18	3.26	4.86	14.84
World	2.28	2.15	1.23	2.47	2.01

7.1.2 Area Harvested

The area harvested for coffee has not followed trends similar to production. Brazil has more area dedicated to coffee production than the other producers, though this area has been in decline since the early 2000s. The harvested area of Colombia has been steadily decreasing since the 1980s. Colombia once had the second largest harvested area before the increased area in Indonesia surpassed it in the mid-1990s. Both Indonesia and Vietnam had very large increases in harvested area between 1999 and 2000, with Vietnam's harvested area almost doubling in size. Indonesia has been under slight decline since then, while Vietnam is slowly increasing. Although it is the country with the least amount of area dedicated to coffee agriculture, Vietnam has been the second largest coffee producer since 2000 due to its very high production yields.

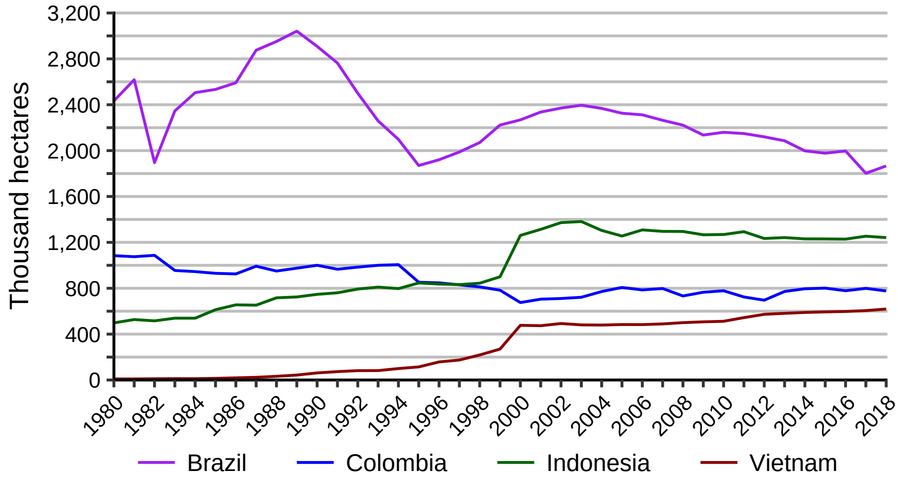

Figure 23. Area harvested for coffee production in the four largest producers.

The growth rates in Table 8 show that, globally, the area dedicated to coffee production has only slightly increased in the past 40 years. This can be explained by observing the negative growth rates in Brazil and Colombia, which were the two largest countries in terms of area harvested in the early 1980s. While the area harvested in Brazil varied over time, the decrease in Colombia was quite stable, ending with the two countries having very similar negative growth rates since 1980. The decreasing area harvested in Brazil and Colombia was offset by the substantial growth of the Indonesia and Vietnam harvested area, particularly in the late 1990s. The area harvested in Vietnam drastically increased between 1980 and 2000 before slowing, but has since started to increase. In fact, Vietnam is the only country in which the harvested area has increased in the past 8 years. Thanks to steady strong growth between 1980 and 2000, Indonesia had an overall annual growth rate of 2.43% from 1980 through 2018 despite stagnation and negative growth after 2000. Total coffee plantation area around the world has remained relatively stable as countries have shifted production between coffee and other cash crops like rubber or palm oil.

Table 8. Annual growth rate (%) of area harvested for coffee production.

	1980 – 1990	1990 – 2000	2000 – 2010	2010 – 2018	1980 – 2018
Brazil	1.80	−2.46	−0.49	−1.81	−0.70
Colombia	−0.80	−3.85	1.43	−0.03	−0.87
Indonesia	4.13	5.38	0.06	−0.27	2.43
Vietnam	20.99	22.66	0.71	2.40	11.71
World	1.03	−0.40	−0.19	0.08	0.13

7.1.3 Production Yield

Analyzing the production yields in Fig. 24 gives insight as to how Vietnam is able to produce vast quantities of coffee from a relatively small agricultural footprint. This is a result of the intensive farming that takes place there. Indonesia, in contrast, is composed of very small non-intensive farming operations, thus the yields are much lower. Colombia has been modernizing its production capability, but has had some setbacks with coffee rust (a type of fungus) in recent years which has reduced output yields. Brazil has been planting more high-yielding Robusta plants and also mechanizing cultivation as the economy improves. This has led to a steady increase in yield over the past four decades.

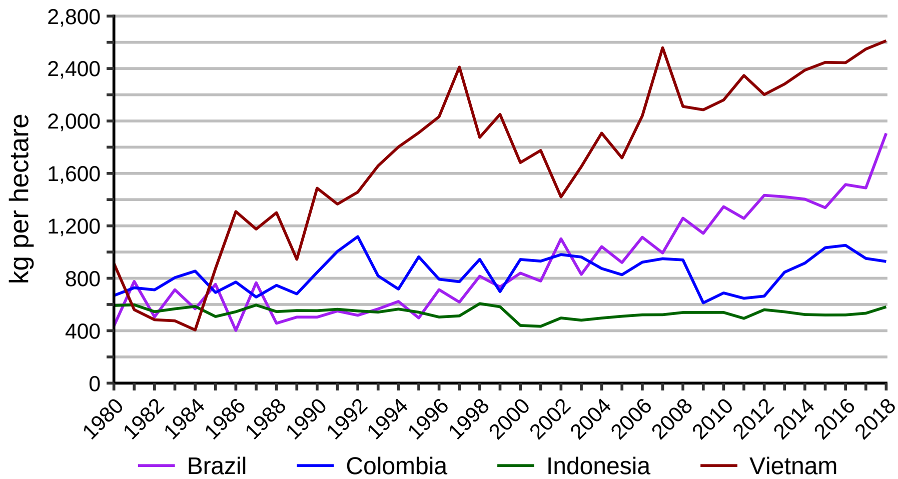

Figure 24. Production yields of the four largest coffee producers.

The growth rates found in Table 9 show that Brazil has had significant substantial growth in all periods, with an overall CAGR of 3.96% for the entire 1980 – 2018 period. At the other end of the spectrum is Indonesia, which saw negative growth during the first two decades, but growth in the two most recent periods nearly neutralized the negative growth. Colombian yields have also remained fairly constant over the long term. Vietnam has had very healthy growth in its production yield rates, with a CAGR of 2.80% over the past 39 years. World production has grown as cultivation methods have improved.

Table 9. Annual growth rate (%) of production yield for different periods.

	1980 – 1990	1990 – 2000	2000 – 2010	2010 – 2018	1980 – 2018
Brazil	1.45	5.24	4.84	4.44	3.96
Colombia	2.37	1.11	−3.11	3.81	0.87
Indonesia	−0.69	−2.26	2.06	0.96	−0.05
Vietnam	5.00	1.24	2.53	2.40	2.80
World	1.24	2.56	1.42	2.38	1.88

7.1.4 Global Production

The four major coffee producers were responsible for about 45% of global production prior to 1990. As production increased in Vietnam, the global share of coffee increased along with it. By 2018 Vietnam produces 16% of the global production, and the total share of global production from the four producers has increased to around 65%. Indonesia has maintained around a 7% share of the global production since 1980. The share of global coffee provided by Colombia has decreased from 15% in 1980 to only around 7% in 2018, due to the country's focus on quality over quantity. Brazil has increased its share of global coffee production from about 25% in the 1980s to around 35% in the 2010s. As the global demand for coffee rises, these four countries will continue to expand their production capabilities.

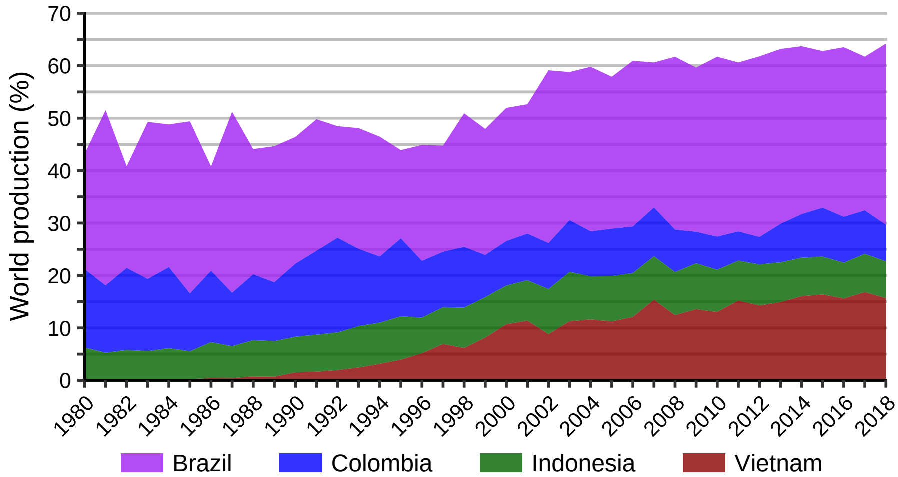

Figure 25. Four countries are responsible for 60% of global coffee production.

7.2 Exports

7.2.1 Export Quantity

Coffee exports have been increasing to meet rising demands as coffee popularity increases around the world (Fig. 26). Between the mid-1990s to until 2011, the growth of exports from Brazil and Vietnam grew along a similar trajectory. Increased exports from Vietnam in 2012 combined with a decline in Brazilian exports meant that the two countries exported the same quantity of around 1.5 million tonnes. Exports in Colombia showed slight decline and were surpassed by Indonesia at a few points from 2009 to 2013. Currently, Colombia exports less than half of what Vietnam does at 710,000 tonnes to Vietnam's 1.6 million tonnes. Indonesia is the fourth largest exporter,

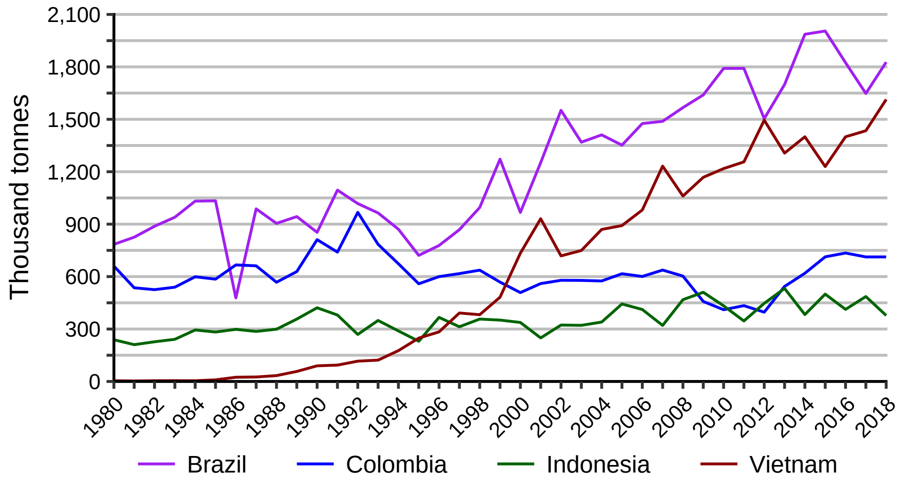

Figure 26. Total export quantity output of the four largest coffee producers.

and has seen little growth in the export market over the past decades. Indonesia exported 375,000 tonnes in 2018, which was around one-fifth of Brazilian exports (1.8 million tonnes).

The compound annual growth rate of export quantity was quite different between the countries, as seen in Table 10. Vietnam exploded onto the coffee market scene, with a CAGR of 36.4% between 1980 and 1990. Growth continued throughout the 1990s and began to slow after 2000. For the entire 1980 – 2018 period, Vietnam experienced 17.09% annual growth in its coffee exports. This high growth is because the Vietnamese coffee market was pretty much non-existent before 1980, whereas the other three producers had well-established coffee markets. Brazil experienced the second largest growth, with a CAGR of 2.25% from 1980 through 2018. There was a period of high growth between 2000 and 2010, but this was followed by a period of low growth (0.25%). Colombian exports experienced growth in the 1980s, followed by two decades of negative growth. Exports have recovered since 2010, making the CAGR of Colombia in the 1980 – 2018 period a stagnant 0.20%. Indonesia experienced unstable growth from 1980 to 2018 with a CAGR of 1.21%, although this was slightly less than the world CAGR of 1.94%.

Table 10. Annual growth rate (%) of the quantity of coffee exported.

	1980 – 1990	1990 – 2000	2000 – 2010	2010 – 2018	1980 – 2018
Brazil	0.84	1.26	6.36	0.25	2.25
Colombia	2.09	−4.57	−2.12	7.14	0.20
Indonesia	5.86	−2.20	2.51	−1.69	1.21
Vietnam	36.40	23.41	5.20	3.58	17.09
World	2.79	1.28	1.81	1.85	1.94

7.2.2 Export Value

The differences between Arabica and Robusta producers are very evident in Fig. 27. Brazil and Colombia enjoy much higher export values than Vietnam and Indonesia, but at the cost of more volatility. The Brazilian coffee market shot from 1.2 billion USD in 2002 to a peak of 8 billion USD in 2011, but has since fallen to below 4.5 billion USD. The value of Colombian exports was

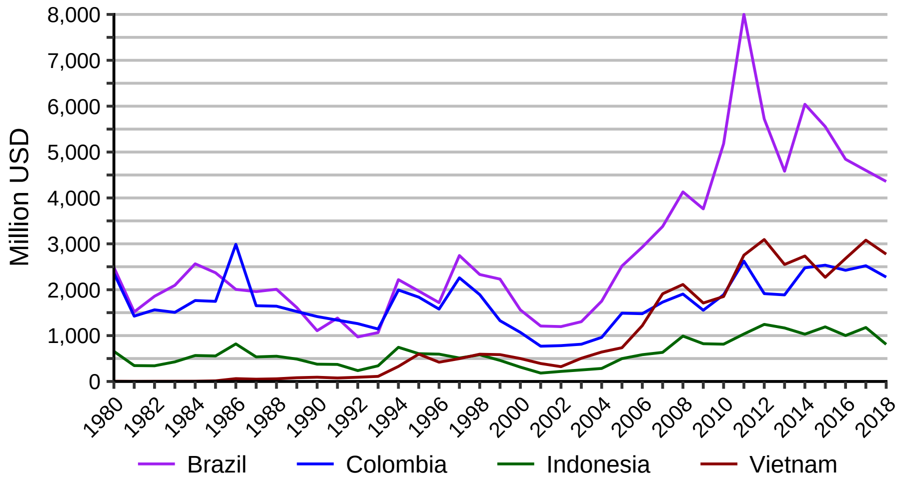

Figure 27. Total value of exported coffee in the four largest producers.

about equal with Brazil until around 1997 when Brazil began to increase production. Following the period of low prices associated with the coffee crisis of the early 2000s, Brazil experienced strong export value growth, whereas the Colombian value returned to pre-crisis levels. Both Vietnamese and Indonesian export values are much lower than the two Arabica producers, but much more stable. Some experts have implicated Vietnam in the coffee crisis by flooding the market with a high quantity of inexpensive beans. The negative effect experienced by other producers was not nearly as strong in Vietnam. After the crisis, the increased exportation of coffee resulted in Vietnam being the second largest exporter, both in terms of quantity and value.

The compound annual growth rates that are computed for export value are very similar to the export quantity. Table 11 shows that Vietnam experienced rapid growth as its coffee industry developed. In the 2000 – 2010 period, all producers experienced strong growth as they recovered from the coffee crisis.

Table 11. Annual growth rate (%) of export value for different periods.

	1980 – 1990	1990 – 2000	2000 – 2010	2010 – 2018	1980 – 2018
Brazil	−7.78	3.49	12.76	−2.14	1.49
Colombia	−4.99	−2.76	5.86	2.35	−0.10
Indonesia	−5.40	−1.86	10.04	−0.05	0.55
Vietnam	34.34	18.37	13.99	5.19	18.20
World	−5.31	1.91	7.80	0.81	1.22

7.2.3 Export Price

The export prices of the four countries all exhibit the same trends as they are all influenced by the forces of the global market. Colombia is known for its high-quality coffee, and it commands the highest price of the four producers (Fig. 28). Brazil, the other Arabica exporting nation, also receives considerably higher prices for its green coffee exports. Indonesia exports a higher quality Robusta, giving it a slight edge over the price of Vietnamese exports. However, at the peak of global prices in 2011 Indonesia's export price of 3.00 USD per kilogram was only worth

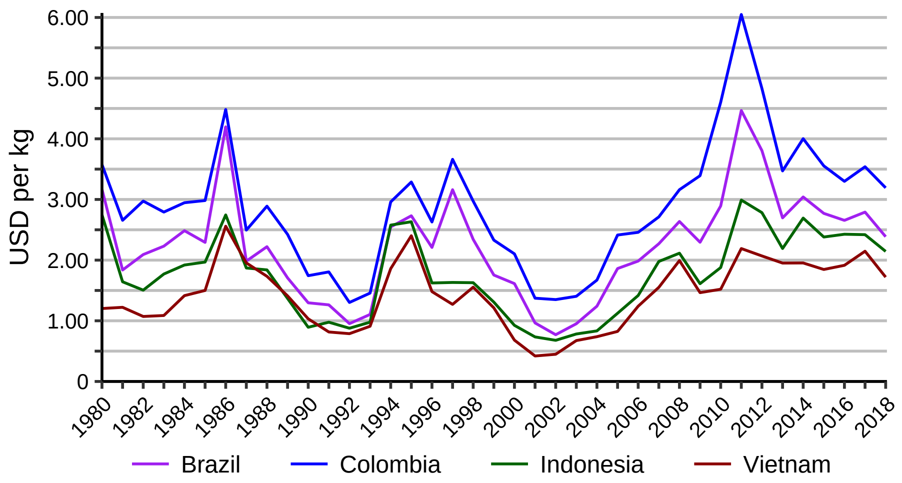

Figure 28. Calculated average annual export prices.

two-thirds of Brazil's ($4.50), and half of the Colombian price ($6.00). Vietnam's place in the global coffee market is producing low-quality, inexpensive beans in mass quantities. The price that these beans receive reflects this, as the export price is lower than the other producers' prices.

When looking at the compound annual growth rates in Table 12, the decade ending in 1990 was a period of strong negative growth as the dynamics of the global market changed with disagreements over the ICA. The decade spanning from 1990 to 2000 was characterized by price increases in the first half followed by a sharp decrease that returned prices to earlier levels (Fig. 28). This decrease affected Vietnam more than the other producers, resulting in a negative CAGR of -4.08% during this period. Between 2000 and 2010 there was another period of rapid growth in export prices. This was followed by a strong decline in Arabica prices after 2011. Overall, the past four decades of coffee export prices have been quite dynamic, with 2018 prices being slightly lower than 1980 prices, save for Vietnam, which experienced a CAGR of 0.95%.

Table 12. Annual growth rate (%) of export price for different periods.

	1980 – 1990	1990 – 2000	2000 – 2010	2010 – 2018	1980 – 2018
Brazil	−8.55	2.21	6.02	−2.38	−0.74
Colombia	−6.93	1.89	8.15	−4.47	−0.30
Indonesia	−10.63	0.35	7.34	1.67	−0.65
Vietnam	−1.51	−4.08	8.36	1.56	0.95
World	−7.88	0.62	5.88	−1.02	−0.71

7.2.4 Yield Value

The yield value represents the export price multiplied by the production yield and gives an indication about how much value can be extracted from an area under coffee cultivation. This value is highly influenced by the world market, as well as production efficiency and the type of coffee harvested. The values in Fig. 29 show that Brazil, Colombia, and Vietnam all have similar yield values despite differences in coffee type, cultivation methods and climate. Vietnam has increased its yield value through the use of irrigation and fertilizers which produces extremely

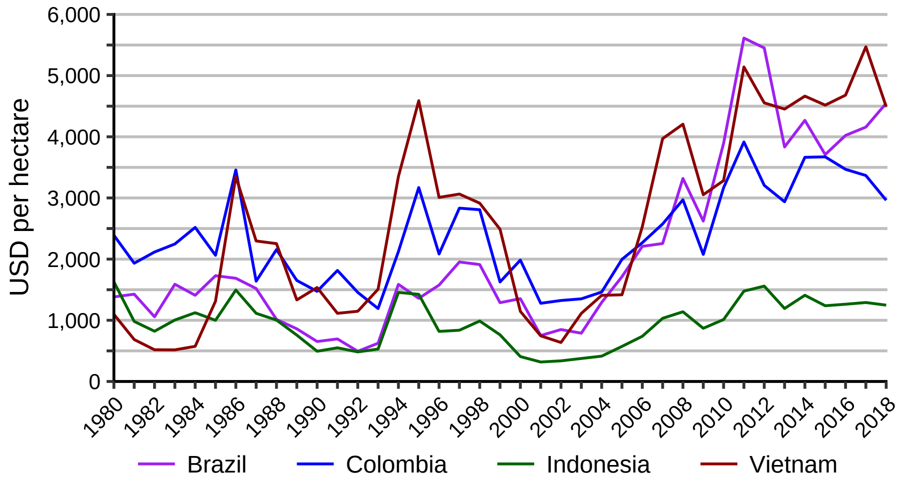

Figure 29. Export value per hectare of coffee production.

high yields from a small area. Colombia, on the other hand, has focused more on growing higher quality beans and using processing methods which increase the value. Although these methods reduce the production yields, the increased values offset the loss. Brazil has increased the value of plantation area by implementing modern mechanized farming methods. The use of machinery increases production yields without a heavy loss in value. Indonesia is lagging behind the others in terms of yield values. With many farmers in Indonesia switching to other crops, the investment into the coffee industry and growing practices has not been able to keep up with the competitors.

7.2.5 Global Exports

It is not surprising that the four largest coffee producers are also the four largest exporters of green coffee. While the overall structure of exports is comparable to production, there are slight differences caused by the domestic consumption of these countries (Fig. 26). Brazil and Indonesia reserve around one third of their production for domestic consumption, whereas Colombia and Vietnam export approximately 90% of their total production. This results in variations between the global shares of coffee production and exports. Currently, Brazil produces around 35%

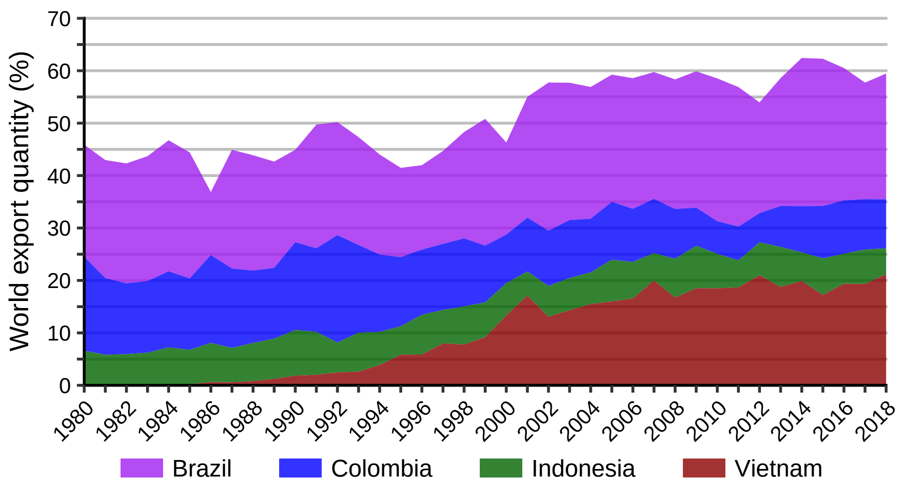

Figure 30. Share of global coffee exports.

of coffee in the world but is only responsible for 24% of global exports. On the other hand, Colombia produces around 7% of the world's coffee, yet accounts for 9% of total exports. 21% of global exports come from Vietnam, which only produces 16% of the world's coffee. And finally, Indonesia produces a 7% share of total global production, but only accounts for 5% of total exports. As we can see, domestic consumption in these countries can have a significant impact on the amount of coffee that is exported. As consumer demand and roasting/processing abilities increase in these countries, domestic consumption will also increase, which will affect the supply of coffee being sold on the world market.

7.3 Consumption

7.3.1 Per Capita Consumption

The population and size differences between the countries make direct comparison of consumption figures problematic, therefore the annual per capita consumption of the four producers will be analyzed. While Colombia and Brazil both consumed about 4 kilograms per capita in 1980, these numbers declined until 1990. For Brazil, this was when consumption began trending upward, and now at 6.4 kg per year, it is one of the highest per capita consumers of coffee in the world. Consumption in Colombia continued its decline well into the 2000s and only in the past few years has consumption begun to increase. Now at 2 kg per year, per capita consumption in Colombia is only half of what it was in 1980. Indonesia's consumption remained around 0.5 kg from 1980 through 2010. In recent years, a strong retail market and rising popularity of pre-prepared coffee has increased per capita consumption to 0.8 kg annually. Consumption in Vietnam has followed a similar trend to its coffee production, if not with a slight lag. In the twenty-five years from 1980 to 2005, per capita consumption rose from near 0 to 0.5 kg. In the following ten years, consumption increased to 1.5 kg and is set to continue increasing well into the future. If consumption in these nations continues to increase, the world supply of coffee may be disrupted as the coffee grown in these countries is diverted from the international market to meet domestic demands.

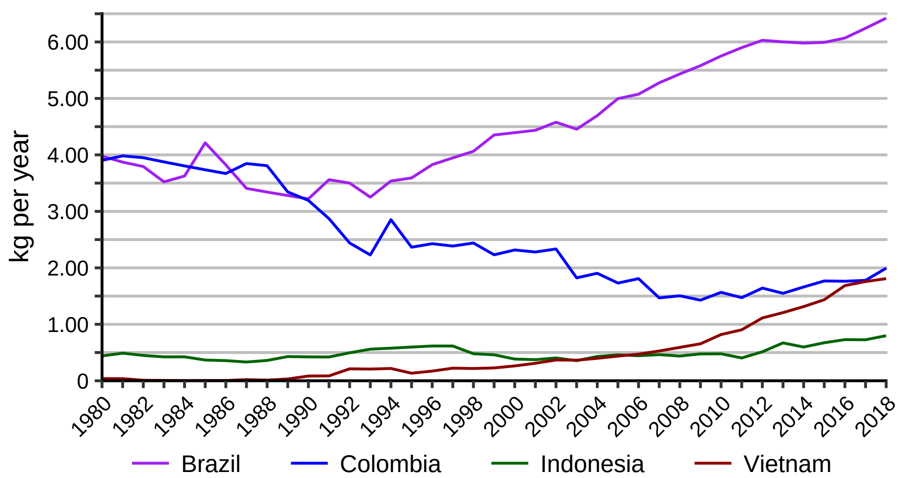

Figure 31. Per capita coffee consumption of the four largest coffee producers.

8 Empirical Model

The specification, estimation, and results of the empirical models are presented in the following sections. Each country has the relationship between the domestic price and the world market price of the variety of coffee that is produced in the country.

8.1 Brazil

The majority of coffee produced in Brazil is Arabica and is post-harvest processed using dry methods, which produces lower quality 'Brazilian Naturals'. Due to this, the domestic price of coffee in Brazil (DPB) is modeled against the world price of Brazilian Naturals (BNP).

8.1.1 Stationarity

Stationarity tests of the Brazilian price data imply that the time series are non-stationary at levels. The level series show evidence of trend stationarity, while the first differences appear to be stationary with both ADF and KPSS tests. Plots of the log level and log differenced time series are available in the Appendix.

ADF Test

The results of the augmented Dickey-Fuller tests are shown in Table 13. The first column shows that the null hypothesis is rejected when testing with constant and trend. The second column shows that the null hypothesis fails to be rejected, implying there is a unit root within the data. The last two columns are the differenced time series and the null hypothesis of a unit root is rejected at a highly significant level. These tests imply that the series are trend stationary and that the first differences are stationary. We will use the KPSS test to confirm these findings.

Table 13. Results of augmented Dickey-Fuller tests on Brazil time series.

	Level		First Difference	
	Constant with trend	Constant no trend	Constant no trend	No constant no trend
Domestic Price				
DPB	[5] -4.73^{***}	[1] -1.80	[1] -4.15^{***}	[1] -4.17^{***}
World Price				
BNP	[6] -3.85^{**}	[1] -1.48	[1] -5.31^{***}	[1] -5.33^{***}

(Number in brackets is lag selected according to AIC)
Significance codes: $^{*}p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$

KPSS Test

To ensure that the results of the ADF tests above are accurate, we perform KPSS tests on the data. The KPSS results in Table 14 confirm the findings of the ADF tests. When tested with a constant and trend the null hypothesis of trend stationarity fails to be rejected. Additionally, when the level data is tested with a constant, the null hypothesis is rejected at the 5% level. The first difference of the data fails to reject the null, suggesting stationarity. While the time series appear to be trend stationary, the first differences are stationary, therefore we will treat the data as integrated of order one, or I(1), and proceed with the Johansen tests of cointegration.

Table 14. Results of KPSS tests on Brazil time series.

	Level		First Difference
	Constant with trend	Constant no trend	Constant no trend
Domestic Price			
DPB	[8] 0.071	[7] 0.603**	[7] 0.146
World Price			
BNP	[8] 0.056	[7] 0.639**	[4] 0.142

(Number in brackets is lag selected by Newey-West)
Significance codes: $^{*}p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$

8.1.2 Lag Selection

We test several unrestricted VAR models to determine the optimal lag of our model. We compare the AIC, HQ and BIC selection criteria to find the optimal lag. All three criteria confirm an optimal lag order of one ($p = 1$) as shown in Table 15. To test for long-run relationships, a Johansen cointegration test is performed on the time series. If cointegration exists between variables, a VEC model is suitable for modeling the relationship.

Table 15. A lag order of one is selected for the Brazil model.

	Number of lags											
Criteria	1	2	3	4	5	6	7	8	9	10	11	12
AIC	−13.14*	−13.10	−13.08	−13.02	−13.00	−12.94	−12.94	−12.89	−12.86	−12.79	−12.76	−12.71
HQ	−13.08*	−13.00	−12.93	−12.83	−12.76	−12.66	−12.62	−12.52	−12.45	−12.33	−12.27	−12.17
BIC	−12.98*	−12.84	−12.70	−12.54	−12.41	−12.25	−12.14	−11.98	−11.85	−11.67	−11.53	−11.37

* indicates optimal lag

8.1.3 Causality

We test the Brazil time series for Granger causality using the Toda & Yamamoto (1995) procedure. Table 16 shows the results of these tests. We find evidence of a one-way causal relationship. The Wald tests imply that the domestic price of coffee in Brazil does not Granger cause the world price of Brazilian Naturals. Alternately, it is implied that the domestic coffee price is Granger caused by the world price of Brazilian Naturals.

Table 16. Granger causality between Brazil time series.

Null hypothesis	χ^2	df	p-value
Brazil Coffee does not Granger cause Brazilian Naturals	1.625	1	0.202
Brazilian Naturals does not Granger cause Brazil Coffee	67.223	1	0.000***

Significance codes: $^{*}p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$

8.1.4 Cointegration

A Johansen cointegration test will tell us if our time series are cointegrated. Table 17 shows both the trace and maximum eigenvalue results of a model with one lag. When examining the results of the trace statistic, the null hypothesis of $r = 0$ is rejected while the null $r \leq 1$ fails to be rejected. The maximum eigenvalue test confirms these results. The Johansen cointegration test shows that our time series have a cointegration rank of one ($r = 1$).

Table 17. Johansen cointegration test of the Brazil model.

Hypothesis				
Null	Alternative	Test Statistic	Critical Value	p-value
Trace Statistic				
$r = 0$	$r > 0$	46.384	20.262	0.000***
$r \leq 1$	$r > 1$	5.385	9.165	0.253
Maximum Eigenvalue				
$r = 0$	$r = 1$	40.998	15.892	0.000***
$r = 1$	$r = 2$	5.385	9.165	0.252

Significance codes: $^{*}p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$

8.1.5 VECM Estimation

We specify a VECM with one cointegrating vector ($r = 1$) and zero lags of differences ($p - 1$). The VEC model is specified according to Equation 11, with the constant restricted to the error correction term. The left side of Table 18 shows the error correction equation and implies that BNP has a significant long-run effect on DPB. This long-run relationship is positive, meaning that the prices move in the same direction. The right side of the table shows the error correction model and the coefficients of the ECT are negative and significant, indicating the speed of adjustment toward long-run equilibrium. ΔDPB responds to system changes faster than ΔBNP.

Table 18. Vector error correction model of Brazil time series.

ECT			ΔDPB	ΔBNP
DPB(-1)	1.0000	ECT	−0.3296***	−0.1837***
BNP(-1)	−0.9169***		(0.0228)	(0.0642)
Constant	−0.0015			
		R-squared	0.6639	0.0713
		Adj. R-squared	0.6607	0.0624

Standard error in parenthesis.
Significance codes: $^{*}p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$

8.1.6 VECM Diagnostics

The Brazil model diagnostics in Table 19 show that residuals of the model are not serially correlated. The null hypothesis of no serial correlation fails to be rejected in both the Portmanteau and Breusch-Godfrey tests. The normality tests show us that the residuals are not normally distributed. The ARCH test rejects the null hypothesis of no ARCH effects, implying that there is autoregressive conditional heteroskedasticity present.

Table 19. Diagnostics of the Brazil VEC model.

Test	χ^2	df	p-value
Autocorrelation			
Portmanteau	22.575	22	0.426
Breusch-Godfrey	28.846	24	0.226
Normality			
Skewness	15.680	2	0.000***
Kurtosis	18.209	2	0.000***
Jarque-Bera	33.890	4	0.000***
Heteroskedasticity			
ARCH test	68.053	45	0.015**

Significance codes: $^{*}p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$

8.2 Colombia

The Colombia model is specified in this section. The majority of coffee produced in Colombia is high-value, washed Arabica, also known as Colombian Milds. The domestic price of coffee in Colombia (DPC) is modeled against the world price of Colombian Milds (CMP). The long-run relationship between these variables is investigated.

8.2.1 Stationarity

The stationarity tests imply that the time series are non-stationary at levels, but stationary at first differences. Plots of the log level and log differenced time series are available in the Appendix.

ADF Test

The augmented Dickey-Fuller test results in Table 20 show that the null hypothesis of a unit root is not rejected when levels are only tested with a constant. DPC is trend stationary at the 10% significance level. The null hypothesis of a unit root is strongly rejected when the first differences of the time series are tested. We will compare these results with the KPSS tests.

Table 20. Results of augmented Dickey-Fuller tests on Colombia time series.

	Level		First Difference	
	Constant with trend	Constant no trend	Constant no trend	No constant no trend
Domestic Price				
DPC	[7] -3.42^{*}	[1] -1.00	[1] -6.98^{***}	[2] -4.90^{***}
World Price				
CMP	[2] -2.85	[1] -1.27	[1] -5.76^{***}	[1] -5.75^{***}

(Number in brackets is lag selected according to AIC)
Significance codes: $^{*}p<0.10$; $^{**}p<0.05$; $^{***}p<0.01$

KPSS Test

The KPSS test results provide a slightly different outcome (Table 21). The first column shows the null hypothesis of trend stationarity fails to be rejected. When levels are tested with a constant and no trend, the null hypothesis of stationarity is strongly rejected. Furthermore, the null hypothesis of stationarity is not rejected when the test is applied to the first differences. From the KPSS tests we can conclude that our data is non-stationary at level and stationary when differenced. We will assume both series are I(1) and use the Johansen procedure to test for cointegration.

Table 21. Results of KPSS tests on Colombia time series.

	Level		First Difference
	Constant with trend	Constant no trend	Constant no trend
Domestic Price			
DPC	[8] 0.094	[9] 0.790***	[1] 0.159
World Price			
CMP	[8] 0.085	[9] 0.784***	[1] 0.079

(Number in brackets is lag selected by Newey-West)
Significance codes: $^{*}p<0.10$; $^{**}p<0.05$; $^{***}p<0.01$

8.2.2 Lag Selection

Table 22 shows the lag selection criteria of several unrestricted VAR models. An optimal lag order of one ($p = 1$) is identified according to the AIC, BIC and HQ selection criteria. We will conduct a Johansen cointegration test on a model with a lag order of one. If the data series are found to be cointegrated, we will specify a VEC model with zero lags of differences ($p - 1$).

Table 22. A lag order of one is selected for the Colombia model.

	Number of lags											
Criteria	1	2	3	4	5	6	7	8	9	10	11	12
AIC	-12.22^*	-12.19	-12.22	-12.16	-12.11	-12.04	-11.99	-11.93	-11.89	-11.88	-11.83	-11.87
HQ	-12.16^*	-12.08	-12.06	-11.97	-11.87	-11.75	-11.66	-11.56	-11.48	-11.43	-11.33	-11.33
BIC	-12.06^*	-11.92	-11.84	-11.68	-11.52	-11.34	-11.19	-11.02	-10.87	-10.76	-10.60	-10.53

* indicates optimal lag

8.2.3 Causality

To test for Granger causality, we must specify a VAR(2) for the Colombia time series as the optimal lag order was one. We then apply a Wald test to the coefficients of lag 1 for each equation to determine if Granger causality exists. The result of the first Wald test in Table 23 shows that the Colombian domestic price does not Granger cause the world price of Colombian Milds. The second Wald test rejects the null, indicating that the world price of Colombian Milds Granger causes the domestic price in Colombia.

Table 23. Granger causality between Colombia time series.

Null hypothesis	χ^2	df	p-value
Colombia Coffee does not Granger cause Colombian Milds	0.022	1	0.881
Colombian Milds does not Granger cause Colombia Coffee	21.107	1	0.000^{***}

Significance codes: $^*p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$

8.2.4 Cointegration

We carry out the Johansen test with a specified lag order of one as previously determined. As Table 24 shows, the null hypothesis of $r = 0$ is rejected by both the trace statistic and maximum eigenvalue. Additionally, the null hypothesis of a rank equal to one fails to be rejected by both tests. The Johansen tests tell us that there is one cointegrating vector ($r = 1$) in our data, therefore a VECM is the appropriate model to use.

Table 24. Johansen cointegration test of the Colombia model.

Hypothesis				
Null	Alternative	Test Statistic	Critical Value	p-value
Trace Statistic				
$r = 0$	$r > 0$	45.014	20.262	0.000^{***}
$r \leq 1$	$r > 1$	2.623	9.165	0.658
Maximum Eigenvalue				
$r = 0$	$r = 1$	42.391	15.892	0.000^{***}
$r = 1$	$r = 2$	2.623	9.165	0.657

Significance codes: $^*p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$

8.2.5 VECM Estimation

The Johansen test identified a cointegrating rank of one and an optimal lag order of one was selected. Thus, we specify the VEC model with one error correction term and zero lags of differences. Table 25 shows the results of the estimation. In the ECT equation on the left side, the CMP coefficient shows a positive long-run effect on the domestic price. This relationship and the constant are significant at the 1% level. The results of the error correction model estimates on the right side show that the ECT coefficients are negative and significant, indicating the speed of adjustment toward the long-run equilibrium. The ΔDPC coefficient is larger than the ΔCMP, implying that the domestic price has a faster adjustment speed than the world price.

Table 25. Vector error correction model of Colombia time series.

ECT			ΔDPC	ΔCMP
DPC(-1)	1.0000	ECT	-0.3402^{***}	-0.1142^{*}
CMP(-1)	-0.8757^{***}		(0.0401)	(0.0653)
Constant	-0.2102^{***}			
		R-squared	0.4029	0.0265
		Adj. R-squared	0.3972	0.0172

Standard error in parenthesis.
Significance codes: $^{*}p<0.10$; $^{**}p<0.05$; $^{***}p<0.01$

8.2.6 VECM Diagnostics

The results of the Colombia VEC model diagnostics in Table 26 show that the residuals of the model are not serially correlated. The Portmanteau and Breusch-Godfrey tests fail to reject the null hypothesis of no autocorrelation. The null hypotheses are rejected in all three normality tests, indicating that the model residuals are not normally distributed. The null hypothesis is also rejected by the ARCH test, implying that there is autoregressive conditional heteroskedasticity in the residuals of the model.

Table 26. Diagnostics of the Colombia VEC model.

Test	χ^2	df	p-value
Autocorrelation			
Portmanteau	22.446	22	0.434
Breusch-Godfrey	26.593	24	0.324
Normality			
Skewness	19.907	2	0.000^{***}
Kurtosis	152.969	2	0.000^{***}
Jarque-Bera	172.876	4	0.000^{***}
Heteroskedasticity			
ARCH test	79.558	45	0.001^{***}

Significance codes: $^{*}p<0.10$; $^{**}p<0.05$; $^{***}p<0.01$

8.3 Indonesia

We specify the empirical model of Indonesia in this section. Coffee production in Indonesia primarily consists of the Robusta variety. For that reason, the domestic price of Robusta coffee in Indonesia (DPI) is modeled against the world price of Robustas (ROB).

8.3.1 Stationarity

The stationarity tests of the Indonesia data are inconclusive, therefore we decide to treat the variables as I(1). Graphs of time series are available in the Appendix for consultation.

ADF Test

The augmented Dickey-Fuller test results in Table 27 imply that the domestic price series is trend stationary. However, when tested with a constant and no trend DPI rejects the null of a unit root. The world price fails to reject the null when tested with a constant and trend, but rejects the null of a unit root when tested with only a constant at the 10% level. The null hypotheses are strongly rejected when the data series are differenced. From the ADF tests we can conclude that the domestic price is trend stationary.

Table 27. Results of augmented Dickey-Fuller tests on Indonesia time series.

	Level		First Difference	
	Constant with trend	Constant no trend	Constant no trend	No constant no trend
Domestic Price				
DPI	[3] -3.78^{**}	[1] -2.98^{**}	[1] -5.90^{***}	[1] -5.92^{***}
World Price				
ROB	[1] -3.09	[1] -2.84^{*}	[1] -5.96^{***}	[1] -5.99^{***}

(Number in brackets is lag selected according to AIC)
Significance codes: $^{*}p<0.10$; $^{**}p<0.05$; $^{***}p<0.01$

KPSS Test

We try to corroborate the results of the ADF tests with KPSS tests. Table 28 shows the level series fail to reject the null hypothesis of trend stationarity when tested with a constant and trend. When we test the series with only a constant, we fail to reject the null of stationarity. Similarly, the first differences of the time series also fail to reject the null of stationarity. The results of the KPSS tests imply that the data is trend stationary while first differences are stationary. We will treat the data as I(1) and continue with the Johansen tests.

Table 28. Results of KPSS tests on Indonesia time series.

	Level		First Difference
	Constant with trend	Constant no trend	Constant no trend
Domestic Price			
DPI	[8] 0.079	[8] 0.097	[5] 0.197
World Price			
ROB	[8] 0.092	[8]0.122	[5] 0.222

(Number in brackets is lag selected by Newey-West)
Significance codes: $^{*}p<0.10$; $^{**}p<0.05$; $^{***}p<0.01$

8.3.2 Lag Selection

We compare unrestricted VAR models of varying lag orders to determine the optimal lag to use in our model. All three selection criteria in Table 29 show that the optimal lag order is two. We will use $p = 2$ for our Johansen cointegration tests.

Table 29. A lag order of two is selected for the Indonesia model.

	Number of lags											
Criteria	1	2	3	4	5	6	7	8	9	10	11	12
AIC	−14.68	−14.89*	−14.87	−14.87	−14.80	−14.75	−14.74	−14.68	−14.62	−14.57	−14.49	−14.48
HQ	−14.61	−14.79*	−14.72	−14.67	−14.57	−14.47	−14.41	−14.32	−14.21	−14.11	−13.99	−13.94
BIC	−14.52	−14.63*	−14.49	−14.39	−14.22	−14.06	−13.93	−13.78	−13.61	−13.44	−13.26	−13.14

* indicates optimal lag

8.3.3 Causality

We analyze potential Granger causality using the Toda & Yamamoto (1995) procedure. As we are treating the time series as I(1) and the optimal lag order was two, a VAR(3) is specified. We apply a Wald test to the coefficients of lag 1 and lag 2 for each equation to determine if Granger causality exists. Table 30 shows the results of these tests. The null hypothesis of Granger non-causality fails to be rejected in the first test; however, the null is rejected in the second test. This implies the domestic price in Indonesia does not Granger cause the world price of Robustas. Conversely, the world price of Robustas Granger causes the domestic price in Indonesia.

Table 30. Granger causality between Indonesia time series.

Null hypothesis	χ^2	df	p-value
Indonesia Coffee does not Granger cause Robustas	2.527	1	0.283
Robustas does not Granger cause Indonesia Coffee	12.617	1	0.002***

Significance codes: $^{*}p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$

8.3.4 Cointegration

We specify the Johansen cointegration test to include a restricted constant and a lag order of two. The results of the Johansen tests in Table 31 show that both the trace statistic and maximum eigenvalue tests reject the null hypotheses of a cointegration rank of zero ($r = 0$). The null hypotheses of $r \leq 1$ and $r = 1$ fail to be rejected, implying our data has a cointegration rank of one ($r = 1$).

Table 31. Johansen cointegration test of the Indonesia model.

Hypothesis				
Null	Alternative	Test Statistic	Critical Value	p-value
Trace Statistic				
$r = 0$	$r > 0$	24.603	20.262	0.010**
$r \leq 1$	$r > 1$	7.263	9.165	0.116
Maximum Eigenvalue				
$r = 0$	$r = 1$	17.339	15.892	0.027**
$r = 1$	$r = 2$	7.263	9.165	0.116

Significance codes: $^{*}p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$

8.3.5 VECM Estimation

We specify a VEC model with a restricted constant, a single cointegrating vector and one lag of differences. Table 32 shows the results of the model estimation. We can see in the error correction term that the world price of Robustas has a significant positive long-run effect on the domestic price of Robustas in Indonesia. The error correction model on the right shows us that the coefficient of the ECT in the domestic price (ΔDPI) equation is significant, while the coefficient of the world price (ΔROB) is insignificant. This indicates that the domestic price adjusts toward long-run equilibrium, however, the world price does not. The significance of the ΔROB(-1) coefficient shows short-run causality between the variables, implying the world price of Robustas causes the domestic price in the short run. There are no significant coefficients in the world price equation, which tells us that the domestic price of coffee in Indonesia has no significant effect on the world price of Robusta coffee.

Table 32. Vector error correction model of Indonesia time series.

ECT			ΔDPI	ΔROB
DPI(-1)	1.0000	ECT	-0.4209^{**}	-0.2129
ROB(-1)	-1.0257^{***}		(0.2054)	(0.1862)
Constant	0.1202^{***}	ΔDPI(-1)	-0.4583	-0.1739
			(0.3033)	(0.2749)
		ΔROB(-1)	0.8954^{**}	0.4201
			(0.3529)	(0.3198)
		R-squared	0.1758	0.0696
		Adj. R-squared	0.1678	0.0606

Standard error in parenthesis.
Significance codes: $^{*}p<0.10$; $^{**}p<0.05$; $^{***}p<0.01$

8.3.6 VECM Diagnostics

Table 33 shows the results of the Indonesia VECM diagnostics tests. Both the Portmanteau and Breusch-Godfrey tests fail to reject the null hypothesis of no serial correlation. This indicates that the residuals of the model are not serially correlated. Furthermore, the normality tests show that the residuals are not normally distributed, since the null hypotheses are rejected in all three tests. The ARCH test rejects the null hypothesis of no ARCH effects, indicating that there are ARCH effects present in the residuals of the model.

Table 33. Diagnostics of the Indonesia VEC model.

Test	χ^2	df	p-value
Autocorrelation			
Portmanteau	16.464	18	0.560
Breusch-Godfrey	28.872	24	0.225
Normality			
Skewness	13.556	2	0.001^{***}
Kurtosis	123.424	2	0.000^{***}
Jarque-Bera	136.980	4	0.000^{***}
Heteroskedasticity			
ARCH test	67.254	45	0.017^{**}

Significance codes: $^{*}p<0.10$; $^{**}p<0.05$; $^{***}p<0.01$

8.4 Vietnam

The model of the Vietnam time series is specified in this section. Vietnam is the largest producer of Robusta in the world and more than 90% of Vietnam's exports are Robusta beans. The long-run relationship between the domestic price of coffee in Vietnam (DPV) and the world price of Robustas (ROB) is examined with the following model.

8.4.1 Stationarity

The stationarity tests help to determine the order of integration of the time series. Plots of the time series are also available in the Appendix for visual assessment.

ADF Test

We apply ADF tests to the data series and Table 34 contains the results. The first column shows that DPV rejects the null, implying trend stationary data, while ROB fails to reject the null. The second column shows that when tested with only a constant, DPV strongly rejects the null of a unit root and ROB rejects the null at the 10% significance level. The last two columns show that the first differences of the data reject the null of a unit root, implying stationarity. The ADF tests determine DPV to be trend stationary and both series are stationary at first differences.

Table 34. Results of augmented Dickey-Fuller tests on Vietnam time series.

	Level		First Difference	
	Constant with trend	Constant no trend	Constant no trend	No constant no trend
Domestic Price				
DPV	[2] -3.76^{**}	[2] -3.57^{***}	[1] -5.60^{***}	[1] -5.61^{***}
World Price				
ROB	[1] -3.09	[1] -2.84^{*}	[1] -5.96^{***}	[1] -5.99^{***}

(Number in brackets is lag selected according to AIC)
Significance codes: $^{*}p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$

KPSS Test

We apply KPSS tests to compare with the results of the ADF tests. Table 35 shows that the null hypothesis of trend stationarity fails to be rejected by both series. When tested with only a constant, the null hypothesis also fails to be rejected by the level data and the differenced data. The KPSS tests imply that the time series are trend stationary, but stationary at first differences. We make the assumption that the data is I(1) and will continue with Johansen tests of cointegration.

Table 35. Results of KPSS tests on Vietnam time series.

	Level		First Difference
	Constant with trend	Constant no trend	Constant no trend
Domestic Price			
DPV	[8] 0.094	[8]0.115	[5] 0.139
World Price			
ROB	[8] 0.092	[8]0.122	[5] 0.222

(Number in brackets is lag selected by Newey-West)
Significance codes: $^{*}p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$

8.4.2 Lag Selection

To determine the optimal lag, we analyze several unrestricted VAR models with different lag orders. Table 36 shows that the three selection criteria identify a lag order of one as the optimal lag. We will specify our model with $p = 1$ as determined by the selection criteria.

Table 36. A lag order of one is selected for the Vietnam model.

	Number of lags											
Criteria	1	2	3	4	5	6	7	8	9	10	11	12
AIC	-13.14^{*}	-13.11	-13.11	-13.04	-12.97	-12.91	-12.88	-12.86	-12.81	-12.84	-12.79	-12.77
HQ	-13.08^{*}	-13.00	-12.96	-12.84	-12.73	-12.63	-12.56	-12.49	-12.40	-12.39	-12.29	-12.23
BIC	-12.98^{*}	-12.84	-12.74	-12.56	-12.38	-12.22	-12.08	-11.95	-11.80	-11.72	-11.56	-11.44

* indicates optimal lag

8.4.3 Causality

The Toda & Yamamoto (1995) procedure for testing Granger causality reveals a one-way causal relationship between the time series. As the optimal lag order was one, we specify a VAR(2) of the data and apply Wald tests to the coefficients of the first lags. Table 37 shows that the null hypothesis of 'Vietnam coffee does not Granger cause Robustas' fails to be rejected, while the null of 'Robustas does not Granger cause Vietnam coffee' is rejected. This implies that the world price of Robustas Granger causes the domestic price of coffee in Vietnam, but that the reverse relationship is not true.

Table 37. Granger causality between Vietnam time series.

Null hypothesis	χ^2	df	p-value
Vietnam Coffee does not Granger cause Robustas	2.579	1	0.108
Robustas does not Granger cause Vietnam Coffee	20.720	1	0.000^{***}

Significance codes: $^{*}p<0.10$; $^{**}p<0.05$; $^{***}p<0.01$

8.4.4 Cointegration

We conduct a Johansen cointegration test with a restricted constant and lag order of one. The results in Table 38 show that the null hypothesis of $r = 0$ is rejected at the 5% significance level in both tests. The null hypotheses of $r \leq 1$ and $r = 1$ are rejected at the 10% significance level; however, since these hypotheses fail to be rejected at the 5% significance level, we conclude there is one cointegrating vector between the Vietnam time series.

Table 38. Johansen cointegration test of the Vietnam model.

Hypothesis				
Null	Alternative	Test Statistic	Critical Value	p-value
Trace Statistic				
$r=0$	$r>0$	24.069	20.262	0.013^{**}
$r\leq 1$	$r>1$	7.909	9.165	0.087^{*}
Maximum Eigenvalue				
$r=0$	$r=1$	16.161	15.892	0.043^{**}
$r=1$	$r=2$	7.909	9.165	0.087^{*}

Significance codes: $^{*}p<0.10$; $^{**}p<0.05$; $^{***}p<0.01$

8.4.5 VECM Estimation

As our time series are cointegrated, we estimate a VECM with $r = 1$ and zero lags of differences $(p - 1)$. Table 39 contains the results of the estimation and the error correction term shows the long-run equilibrium between the variables. The error correction term on the left side of the table shows that ROB has a positive long-run relationship with DPV. On the right side of the table, the ECT coefficients in both equations are negative and significant, showing the speed at which the variables adjust toward the long-run equilibrium. The significance of the ECT coefficients tells us that both the domestic and world market prices adjust toward the long-run equilibrium. The speed of adjustment of ΔDPV is almost twice that of the ΔROB. This implies that although the domestic price has an influence on the world price of Robustas, the world market exerts a much larger influence on the domestic price of coffee in Vietnam.

Table 39. Vector error correction model of Vietnam time series.

ECT			ΔDPV	ΔROB
DPV(-1)	1.0000	ECT	-0.4743^{***}	-0.2620^{***}
ROB(-1)	-1.0058^{***}		(0.0807)	(0.0766)
Constant	0.1460^{***}			
		R-squared	0.2450	0.0990
		Adj. R-squared	0.2378	0.0905

Standard error in parenthesis.
Significance codes: $^{*}p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$

8.4.6 VECM Diagnostics

Diagnostics of the Vietnam VEC model show that the residuals are not serially correlated (Table 40). The Portmanteau test as well as the Breusch-Godfrey test do not reject the null hypothesis of no serial correlation. The Jarque-Bera test rejects the null of normality, indicating that the residuals are not normally distributed. The skewness test fails to reject the null, implying there is no skewness in the residuals; however, the kurtosis test rejects the null hypothesis of kurtosis consistent with normality. Additionally, the ARCH test fails to reject the null, implying that there are no ARCH effects in the residuals of the model.

Table 40. Diagnostics of the Vietnam VEC model.

Test	χ^2	df	p-value
Autocorrelation			
Portmanteau	18.962	22	0.648
Breusch-Godfrey	20.475	24	0.669
Normality			
Skewness	3.901	2	0.142
Kurtosis	10.481	2	0.005^{***}
Jarque-Bera	14.382	4	0.006^{***}
Heteroskedasticity			
ARCH test	54.462	45	0.158

Significance codes: $^{*}p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$

8.5 Empirical Summary

In this section we provide a summary of the empirical models. The tabulated results of the four countries are presented together so that comparisons can be made.

8.5.1 Granger Causality

Following the Toda & Yamamoto (1995) procedure, we tested for Granger causality between the variables. Table 41 shows the results of those tests. We find that the world prices Granger cause the domestic coffee prices in each country. The world price of Brazilian Naturals Granger causes the domestic price of coffee in Brazil, the majority of which is naturally dried Arabica. Similarly, the world price of Colombian Milds Granger causes the domestic price of coffee in Colombia as the coffee produced there is washed Arabica. The world price of Robustas Granger causes the domestic prices of both Indonesia and Vietnam. The production of these two countries predominantly consists of Robustas. These one-way Granger causalities imply that world market prices determine domestic coffee prices. However, the evidence provided by the Johansen model is stronger and more elaborate than the VAR Granger causality tests.

Table 41. Summary of Granger causality analyses.

	Domestic Price		World Price
Brazil	DPB	⟸	BNP
Colombia	DPC	⟸	CMP
Indonesia	DPI	⟸	ROB
Vietnam	DPV	⟸	ROB

8.5.2 Long-run Equilibrium

In Table 42 we have compiled the error correction terms of each VEC model. Johansen (2005) states that coefficients of a cointegrating relation can be considered long-run elasticities if the variables are measured in logarithms. We can consider this a long-run relationship, or equilibrium, between the domestic and world market prices. Following this, the long-run multiplier of the world price can be interpreted as the magnitude of price transmission. This value corresponds to the percentage of an increase or decrease in the world price which is transmitted to the domestic price. From this we can see that changes in the world price will result in similar changes in the domestic price. In the long-run equilibriums of Brazil and Colombia, the coefficients of the world price are -0.9169 and -0.8757 respectively. The world price coefficients in the long-run equations of Indonesia (-1.0257) and Vietnam (-1.0058) are slightly larger. We surmise this difference can be explained by the fact that Brazil and Colombia predominantly produce Arabicas, while Indonesia and Vietnam production is of the Robusta variety. From this, we can infer that a change in the global price of Arabica coffees would result in a slightly smaller change in the domestic prices found in Brazil and Colombia. This is in contrast to a change in the global Robustas price which would result in a slightly larger change in the domestic coffee prices of Indonesia and Vietnam. We provide possible explanations for these magnitude differences in the discussion.

Table 42. Summary of long-run relationships found in the error correction terms.

			Domestic Price		World Price	Constant
Brazil	ECT	=	DPB	−	0.9169 BNP	− 0.0015
Colombia	ECT	=	DPC	−	0.8757 CMP	− 0.2102
Indonesia	ECT	=	DPI	−	1.0257 ROB	+ 0.1202
Vietnam	ECT	=	DPV	−	1.0058 ROB	+ 0.1460

8.5.3 ECT Coefficients

The vector error correction models show the convergence speed at which the variables return to the long-run equilibrium. The ECT coefficients in Table 43 show the percentage of the previous period's deviation from the long-run equilibrium that is corrected in the current period. This value can be thought of as the speed of price transmission, or the speed at which the prices respond to increases or decreases to the long-run equilibrium. From the table we can see that the domestic prices have larger coefficients than the world prices. This indicates that domestic coffee prices adjust to changes in the long-run equilibriums at a faster speed than the world prices.

When considering Arabica type coffees, the domestic price of Brazil (DPB) has an adjustment speed of 33%, while the adjustment speed of the domestic price in Colombia (DPC) is 34%. The domestic prices of the Robusta producing countries have slightly faster adjustment speeds. We find that the adjustment speed of the Indonesia price (DPI) is 42.1%, while Vietnam (DPV) has the fastest adjustment speed at 47.4%. The adjustment speeds of world prices are approximately half of their domestic price counterparts. BNP (18.4%) has a faster speed of adjustment than CMP (11.4%). Like domestic prices, the ECT coefficients in the world price equations are larger for the Robusta producing countries. The adjustment speed of the world price (ROB) in the Indonesia equation is 21.3%, which is slightly lower than that of Vietnam (26.2%).

The significance of the coefficients also provides us information that world prices have a larger influence on domestic prices than vice versa. Both Brazil and Vietnam are highly significant in influencing world prices, while Colombia is to a lesser degree. Conversely, the domestic price in Indonesia has an insignificant effect on the world price of Robustas. We discuss these findings in further detail in the following section.

Table 43. Summary of the VECM adjustment coefficients.

	ECT Adjustment Coefficients	
	Domestic Price	World Price
Brazil	ΔDPB -0.3296^{***}	ΔBNP -0.1837^{***}
Colombia	ΔDPC -0.3402^{***}	ΔCMP -0.1142^{*}
Indonesia	ΔDPI -0.4209^{**}	ΔROB -0.2129
Vietnam	ΔDPV -0.4743^{***}	ΔROB -0.2620^{***}

Significance codes: $^{*}p<0.10$; $^{**}p<0.05$; $^{***}p<0.01$

9 Discussion

In this study, we apply vector error correction models to identify market integration and price transmission between the global coffee market and the four leading coffee producers. We place emphasis on the long-run relationship and speed of adjustment of the coffee prices in these countries. These are described as the magnitude and speed of price transmission respectively. Coffee production in each country is tailored to the local climatic conditions and processing capabilities available; therefore, the variety, quality, and quantity of coffee produced vary greatly. Furthermore, the different coffee varieties (Arabica and Robusta) are subject to a price hierarchy based on consumer tastes and preferences. We analyze the coffee industries of these four producers to provide insight into how this may affect market integration and price transmission.

We first examine the individual coffee producers by analyzing the production, export and consumption of coffee. We are able to evaluate the development of the national coffee sectors over the past four decades. The data shows that Brazil is the largest coffee producer, supplying the world with a large quantity of naturally dried Arabica coffee. Colombia also produces Arabica coffee, although in much smaller quantities of high-value washed Arabica. Indonesia and Vietnam both produce lower valued Robusta coffee, with Vietnam benefiting from very high production yields. We also examine the export quantity and value of each country and find that the Arabica producing countries receive a much better price for their exports. The higher price of Arabica comes at the expense of lower production yields.

Following the individual investigations, we conduct a comparative analysis of the four producers. Brazil produces almost as much coffee as the other three countries combined. Altogether, the four countries account for 60% of the world's coffee production. Brazil has the largest landmass and is able to dedicate much more land area to coffee plantations. Interestingly enough, Vietnam is the second largest producer but has the smallest harvested area. This is possible because the production yields of Vietnam are much higher than the other countries. While Colombia only exports half the quantity of coffee as Vietnam, their export values are nearly equal. This is due to the fact that Colombia produces a small quantity of high value Arabica and Vietnam produces a large quantity of low value Robusta. The methods used in Arabica processing result in product differentiation, leading to a larger range in price than Robusta. The price of Arabica coffee is substantially higher than Robusta, but also much more volatile.

The final step in our study is the application of VEC models to capture the price transmission that occurs between the domestic and world markets. As mentioned in the introduction, the multinational coffee roasters are responsible for asymmetric price transmission as most of the coffee value is generated during the processes of roasting, branding, advertising and distribution (World Bank, 2004). However, as this study is focusing on the trade of green coffee, we analyze the price link before value is added by roasters and large coffee distributors. It is for this reason we are able to assume symmetric price transmission between local and global markets.

Our empirical models show that the domestic and world coffee prices are cointegrated and that a long-run equilibrium between the prices exists. This is expected behavior and suggests that domestic and world prices move together over time, which is also known as market integration. Moreover, these long-run relationships can also be interpreted as the magnitude of the respective price transmissions. Lower-value Robusta coffees from Indonesia and Vietnam are integrated to a higher degree than the more valuable Arabica coffees grown in Brazil and Colombia. Robusta producing countries exhibit near perfect market integration, transmitting approximately 100% of the change in global prices. The Arabica producing countries of Brazil and Colombia transmit 91.7% and 87.6% of world price changes respectively. Our findings show that the Robusta producing countries display more market integration and a higher magnitude of price transmission than the Arabica producing countries. This is probably due to product differentiation in Arabica coffee caused by the wet and dry processing methods, which leads to higher price volatility. Robustas, on the other hand, are only processed using the dry method producing a more uniform product, which allows for a higher degree of market integration.

Our Granger causality tests determine one-way causality between world and domestic prices. This implies that the global coffee market determines the domestic price, or that the domestic price responds to changes in the world price. This is somewhat expected, as coffee traders and exporters balance their stocks of green coffee with the global market to achieve the best price. However, the stronger and more elaborate Johansen procedure gives evidence that the domestic markets also affect the world prices to a smaller degree. The VEC models show us that the domestic coffee prices of the four countries respond to changes in the world price, which is to be expected as the global market forces are much larger. Additionally, Brazil and Vietnam, the two largest coffee producers, have domestic markets that have a significant influence on the world price of the respective coffees produced in each nation. It is thought that the mass quantities of coffee produced by these countries alter the world market prices. The domestic market in Colombia also has a significant effect on the world price of washed Arabica. Although Colombia is the third largest coffee producer, we believe this effect is caused by the quality of Colombian coffee rather than the quantity produced. Colombia is the source of the highest priced Arabica coffee, and as a result, sets the standard for high-value Arabicas. Indonesia, while a major player in the global coffee market, does not have a significant influence on the world market prices. We believe that this can be explained by the fact that Indonesia produces a modest amount of average value Robusta coffee. The Robusta market is not as developed as the Arabica market, therefore there is not as much product differentiation as in Arabicas. The volume of coffee produced in Indonesia is not nearly as influential as the mass quantities produced in Vietnam. The impact of Vietnamese coffee production has been felt across both Robusta and Arabica markets as seen in the comparative analysis.

The VEC models also show that the speed of adjustment varies between countries and coffee types. The error correction mechanism can also be interpreted as the speed of price transmission, or how fast the prices respond to changes in the long-run equilibrium. The domestic prices of

Arabica producing countries respond to disequilibrium at a lower rate than the Robusta producing countries. Brazil has the slowest domestic price response to shocks at 33%. 'Brazilian Naturals' is the designated term for air dried Arabica coffee, which is the most widely produced coffee type in the world at just over half of total production (ICO, 2019b). Brazil is the largest producer of Brazilian Naturals, but also produces large quantities of lower quality washed Arabicas known as 'Other Milds'. The diversification of the Brazilian market can explain the slow response to changes in the world price of Brazilian Naturals. The response of the domestic price in Colombia is only slightly faster than Brazil at 34%. Colombia produces the vast majority of 'Colombian Milds', but the price of Colombian Milds and the prices of lower quality Other Milds and Brazilian Naturals are intrinsically linked as they are all of the Arabica variety of coffee. As a result, the domestic prices in Colombia respond to changes in the global Arabica prices at a lower rate than the Robusta producing countries. Unlike Arabicas, which are traded under different varieties and varying grades, Robusta beans are traded as one variety of varying grades. The speed of adjustment for the Indonesia domestic price is 42.1%, while the Vietnam adjustment speed is 47.4%. This discrepancy is likely the result of the different production ratios of Arabica and Robusta in each country. Vietnam's production is 95% Robusta and Indonesia is only 80% Robusta. This may play a role in the speed of price transmission as Indonesia cannot be as well integrated as Vietnam. Vietnam also produces half of all Robusta coffee in the world, which means there is a very strong link between the domestic and world markets. As a result, the Vietnam domestic price adjusts to changes in the world market price at a higher rate than Indonesia, and much faster than the domestic prices found in the Arabica producing countries.

When examining how the domestic prices influence world prices, we find that the relationships are not nearly as pronounced. As previously mentioned, our Granger causality tests determine one-way causality from world prices to domestic prices; however, the VEC models indicate a two-way relationship between the domestic and world prices. As these countries are the four largest coffee producers, it is intuitive that their domestic prices may have an influence on the world market prices. We find that the adjustment speeds of the world prices are approximately half the speed of their domestic counterparts, which indicates that the world prices respond to disequilibrium more slowly than domestic prices. As with the domestic prices, the adjustment speeds of the Arabica world prices are slower than that of the Robusta world price. The adjustment speed of the Robusta world price to the Vietnamese coffee market is the fastest at 26.2%. This can be accounted for by the high degree of market integration that is observed. The world price of Brazilian Naturals has an adjustment speed of 18.4% to the Brazilian domestic price. Brazil is the largest coffee producer in the world, however, the more complex market of Arabicas does not allow for the same level of influence that Vietnam exerts on Robustas. The adjustment speed of Colombian Milds to the domestic price in Colombia is the lowest at only 11.4%. The Colombian market sets the standard for high-quality Arabica, but does not produce nearly the quantity of Brazil. Although the world price of Robusta has an adjustment speed of 21.3% to the Indonesia domestic price, it is not statistically significant. Indonesia does not produce a large enough volume to influence the world coffee market through quantity like Brazil or Vietnam. Additionally, an undiversified market prevents Indonesia from influencing the world price of Robustas with high-quality coffee like Colombia does to global Arabica prices. Although we speculate that Indonesia affects the world coffee market, our modeled data does not support this.

While we are able to analyze the dynamics of the four leading coffee producers, as well as their economic impacts on the global coffee market, this research is not without its limitations. As coffee is an annual crop, production values are only available at yearly intervals. The coffee growing cycle has a fairly significant impact on the amount of coffee available for export. Different harvest times and processing durations also factor into availability of coffee stocks, which in turn has an effect on the coffee trade. Data availability at the monthly interval may have also introduced error in our empirical models. As the domestic prices are collected from varying outlets, the direct comparison between the coffee producing countries is not entirely accurate. These price series are collected at different points along the production chain, therefore the price transmission between world and domestic prices may not be directly comparable between countries. Unfortunately, this obstacle is not easily overcome as the data was not collected by a single agency or at a single point in the supply chain. Another limitation of this research is the assumption of symmetric price transmission. Although we assumed symmetric price transmission between domestic and world prices, literature suggests that this transmission is asymmetrically occurring at differing speeds. Our own results also show a difference between transmission speeds. While meeting the needs of this study, future research should consider asymmetric price transmission using threshold VECMs or other methods to better evaluate the relationships between the domestic and world coffee prices.

10 Conclusion

From our analysis of the coffee industry we have identified the production strategies utilized by the four leading coffee producers. Colombia relies on maintaining a reputation of high-quality coffees which command a high price point. These higher-quality coffees are the result of hand-selecting premium quality beans which are produced in low quantity. Vietnam is on the other end of the spectrum, striving to produce a large quantity of cheap coffee. Higher yields resulting from large nutrient inputs and intensive cultivation practices produce vast quantities of low-quality Robusta coffee. The low prices paid for Robustas make it an attractive alternative to the pricier Arabicas when used in products where quality is not as important. This has resulted in several roasters producing 'blended' coffees, which is a mixture of Arabica and Robusta to lower costs. Robustas are also used in several new products featuring coffee flavoring and extracts that are being developed and introduced by beverage companies. Interestingly enough, while Brazil is historically an Arabica producing country, we found evidence that Brazil is expanding its production toward Robustas to capture some of this quickly emerging market. While already dominating the Arabica market, modern farming methods and automated harvesting have also allowed Brazil to compete with Vietnam over control of the Robusta market. Indonesia, on the other hand, has shown difficulty in keeping up with the developments of the coffee trade in recent decades. Although expanding plantation area has increased production, the lack of modern techniques and organizational structure has prevented production yields from increasing. This means that Indonesia, historically the premier Robusta producer, has been replaced by Robustas grown in Vietnam and Brazil. This has caused a small increase in Arabica production and a shift toward specialty Robusta coffees, both of which bring higher prices. As we have seen, each of the four countries utilize production strategies constrained by their climatic conditions, land availability, and technical limitations. These strategies have been developed and implemented in response to the dynamic changes of the global coffee market.

We applied vector error correction models to investigate the relationship between domestic and world coffee prices. Our research has shown that the market for Arabicas is much more complex than Robustas. In the coffee trade, Arabica coffee is classified into three main types and then graded by quality. Robusta coffee, on the other hand, is only traded under different grades of quality. This results in the price of Arabica coffees being higher than Robustas, but also much more volatile. The empirical models show that the Robusta producing countries displayed more market integration than the Arabica producers. The Robusta producing countries have a higher magnitude of price transmission as indicated by the long-run equilibriums. Robusta producers also experienced faster price transmission speeds than Arabica producers. The world market price had a much stronger influence on domestic prices, since adjustments occurred in the domestic prices much faster than the world prices. Vietnam appears to have a larger impact on the world price of Robustas than Brazil has on the world price of Arabicas. Colombia also appears to have an influence on the world price of Arabicas; however, the Indonesia domestic price does not significantly influence the world price of Robustas.

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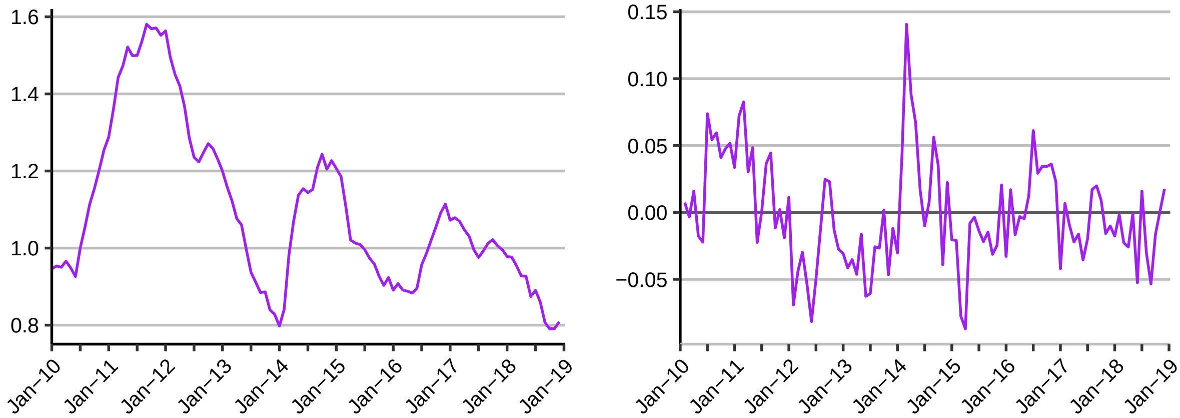
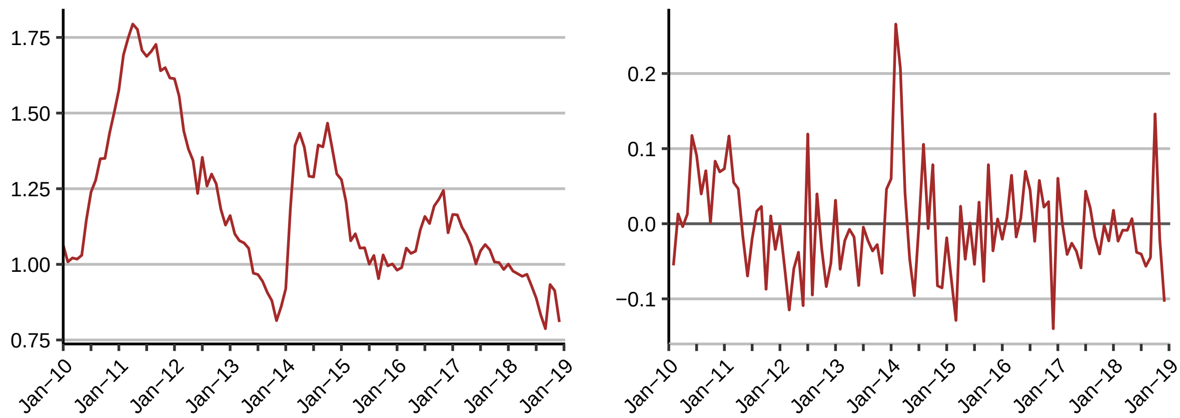
Appendix

Brazil monthly price time series



(a) Log level data **(b)** Log difference data

Figure A.1. Domestic price of coffee in Brazil (DPB).



(a) Log level data **(b)** Log difference data

Figure A.2. World Brazilian Naturals price (BNP).

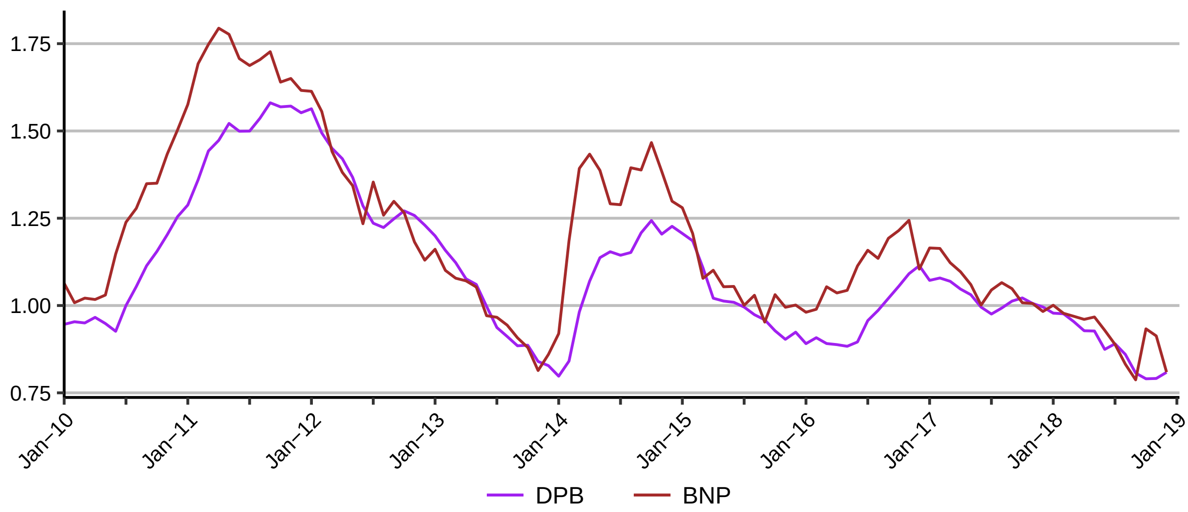


Figure A.3. The Brazil time series show signs of cointegration.

Appendix

Colombia monthly price time series

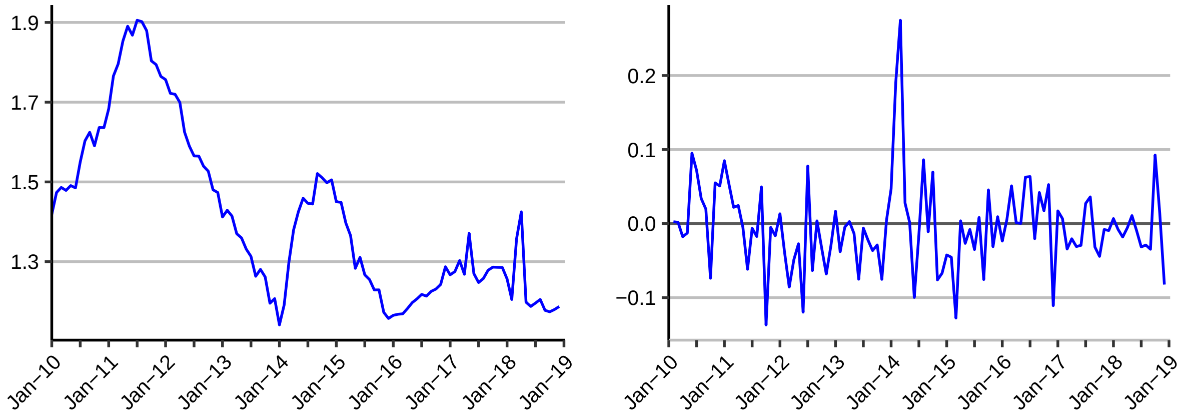


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Figure A.4. Domestic price of coffee in Colombia (DPC).

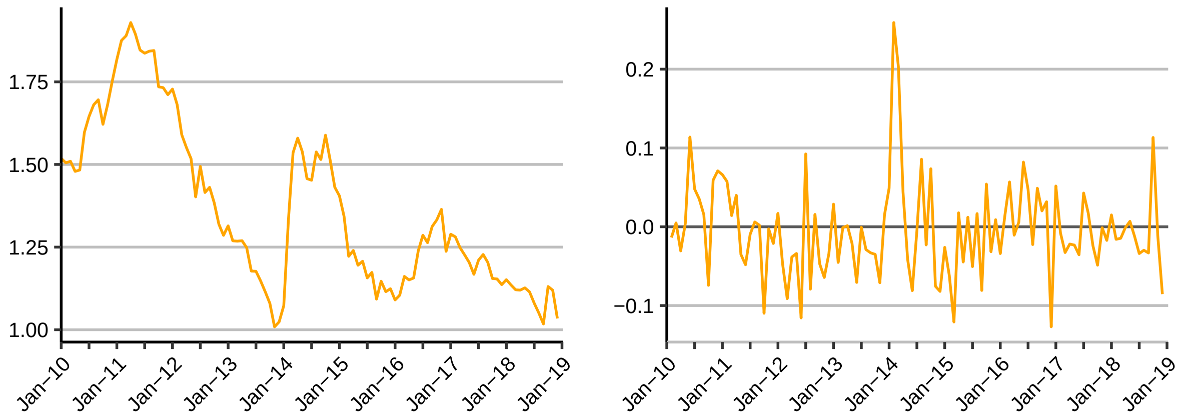

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Figure A.5. World Colombian Milds price (CMP).

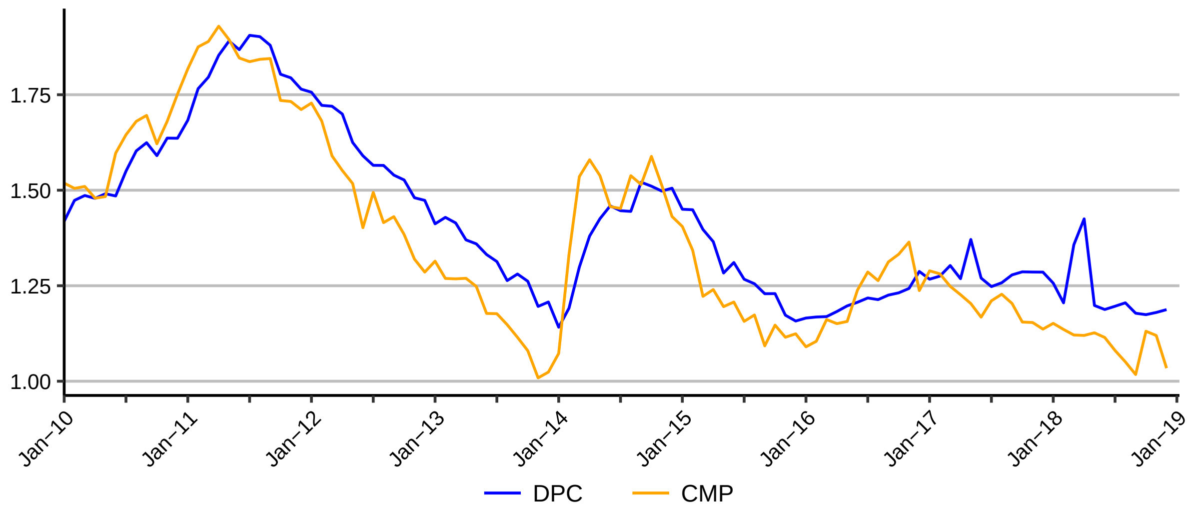

Figure A.6. The Colombia time series show signs of cointegration.

Appendix

Indonesia monthly price time series

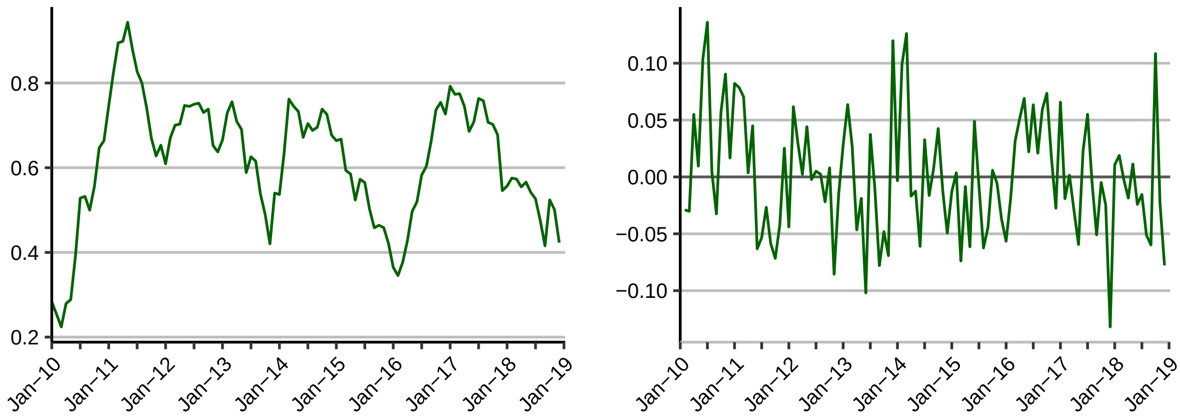

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Figure A.7. Domestic price of coffee in Indonesia (DPI).

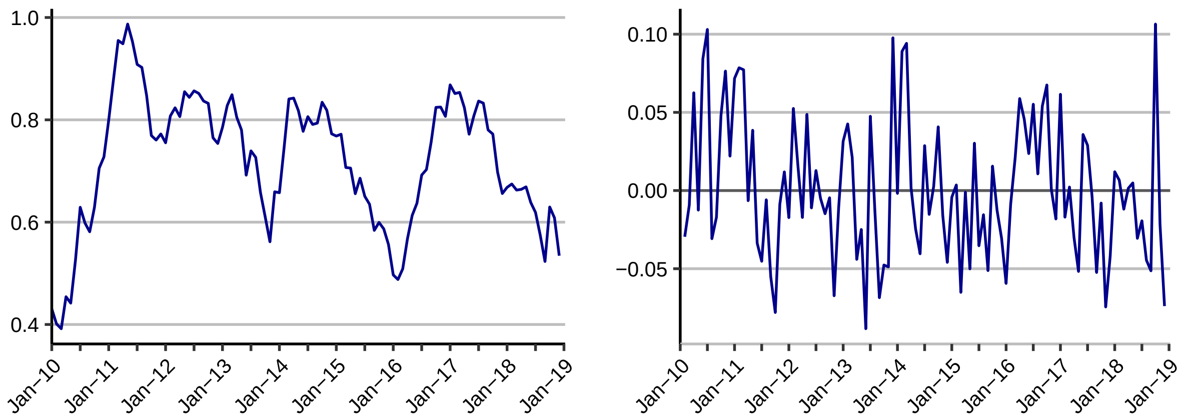

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Figure A.8. World Robustas price (ROB).

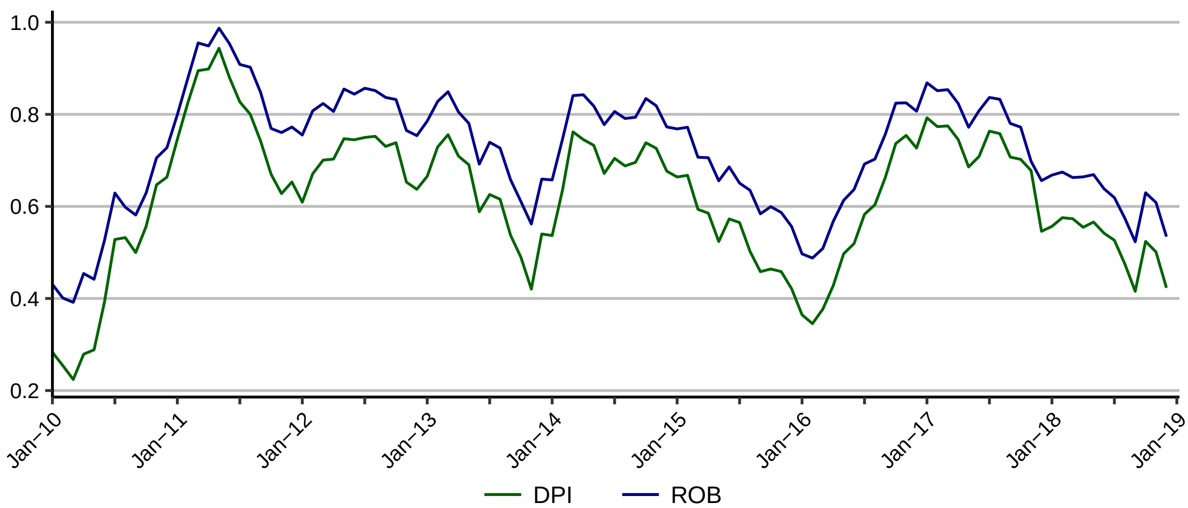
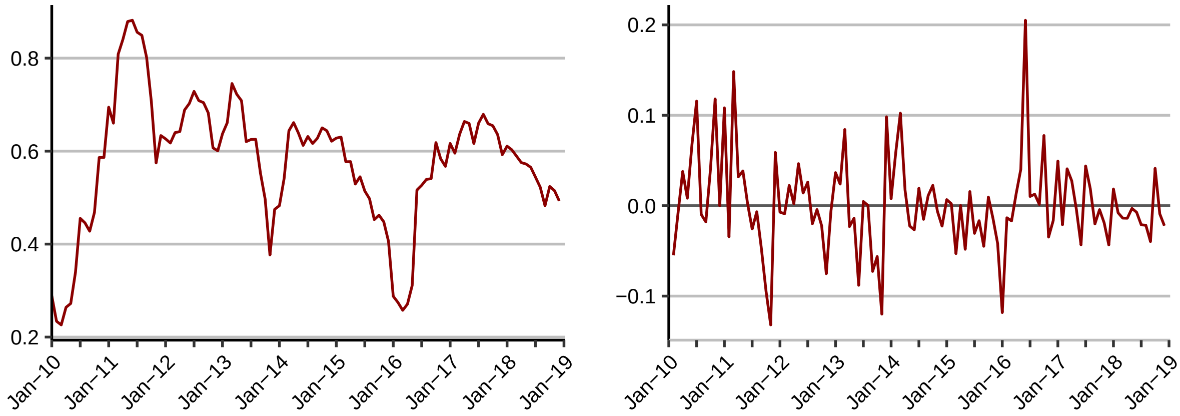


Figure A.9. The Indonesia time series show signs of cointegration.

Appendix

Vietnam monthly price time series



(a) Log level data **(b)** Log difference data

Figure A.10. Domestic price of coffee in Vietnam (DPV).

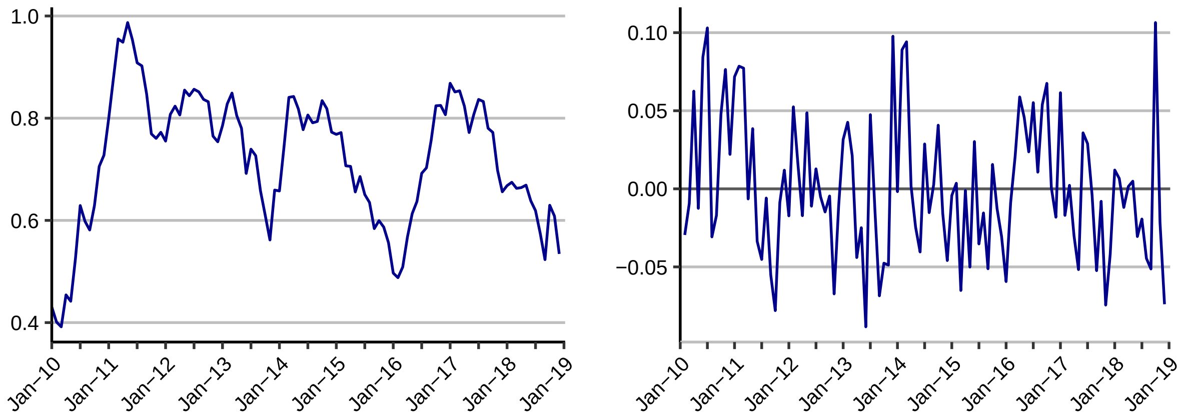


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Figure A.11. World Robustas price (ROB).

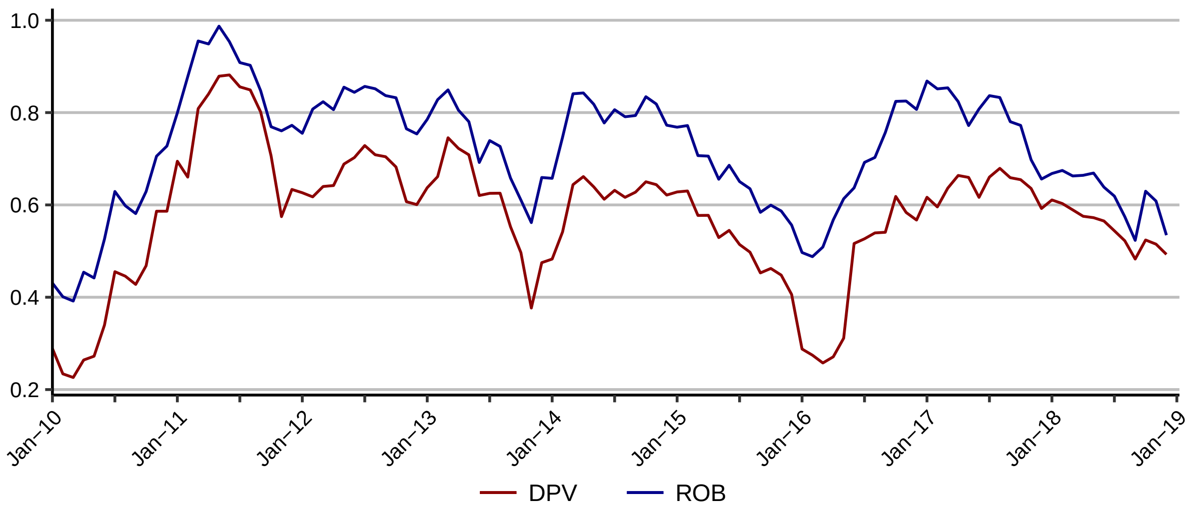

Figure A.12. The Vietnam time series show signs of cointegration.