PRICE TRANSMISSION OF VIETNAM'S ROBUSTA COFFEE

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Abstract

Coffee is important to Vietnam's economy in terms of export earnings and employment. As Vietnam carried out market reforms over the last three decades, its coffee sector has become increasingly market-driven and exposed to the fluctuations of the global market. The transmission of changes in global Robusta coffee prices to domestic farmgate prices is put under focus in this research as the knowledge of this will have important policy and welfare implications.

This research uses both linear and threshold vector error correction models to analyse price transmission as the cointegration-based approach recognises the nonstationarity of price series. The data used are daily export and farmgate prices of Robusta coffee, measured in USD per tonne, from June 1st, 2011 to December 31st, 2015. Export prices were collected in Ho Chi Minh city, the export hub for Vietnam, and farmgate prices in the largest coffee-producing province, Dak Lak.

The primary result of this research is that of a symmetric price transmission between export and farm levels for Vietnam's Robusta coffee. The two apparent asymmetries detected are considered minimal as the speed of daily adjustment is too high. In the linear model, export prices react faster to negative deviations from the long run equilibrium than to positive deviations. In the threshold model, farmgate prices respond faster to decreases than increases in export prices when the long run deviation exceeds a certain threshold. The research also confirms the importance of transaction costs and other price frictions that were mostly ignored in prior analyses for coffee. Most importantly, the finding of symmetric price transmission contradicts previous studies which found asymmetric price transmission for Robusta coffee in Vietnam and other producers in Africa. This dissimilarity may be attributable to characteristic differences of Vietnam's coffee sector, the use of high frequency data, and to the different time periods under investigation.

JEL Codes: C32, Q11, Q13, Q17
Keywords: asymmetric price transmission, Robusta coffee, Vietnam

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List of Acronyms

APT	Asymmetric Price Transmission
BIC	Bayesian Information Criterion
FAS	Foreign Agricultural Service
GSO	General Statistics Office Of Vietnam
ICA	International Coffee Agreement
ICO	International Coffee Organization
ITC	International Trade Centre
MARD	Ministry of Agriculture and Rural Development of Vietnam
OLS	Ordinary Least Squares
SUR	Seemingly Unrelated Regression
TVECM	Threshold Vector Error Correction Model
USDA	United States Department of Agriculture
VCCB	Vietnam Coffee Coordinating Board
VECM	Vector Error Correction Model
VICOFA	Vietnam Coffee and Cocoa Association

Chapter One: INTRODUCTION

Coffee is one of the principal crops for the agricultural sector of Vietnam in terms of production, international trade, and employment. Coffee production has nearly doubled since 2000 and amounted to approximately 1.64 million tonnes in 2014/15 (FAS, 2016c). The total area of coffee production in Vietnam has also trended upward over the last five years, reaching around 642,000 hectares in 2014/15 (GSO, 2016). In addition, coffee exports have increased in both value and volume (FAS, 2016b; ITC, 2016). The export value rose almost sevenfold while the export volume grew by one-half from 2000/01 to 2014/15. Whereas coffee prices trended upward over the first 10 years, the trend went in the opposite direction over the last five years. Of all tradable farm produce, coffee was the second largest contributor to Vietnam's agricultural export revenue in 2015. At this time, coffee exports were worth around US$2.7 billion and equivalent to some 16% of the total export value of agricultural commodities (MARD, 2016d). Lastly, the domestic coffee sector employed nearly 2.6 million workers in 2014 (Summers, 2014), which constituted approximately 4.8% of Vietnam's total workforce (World Bank, 2016).

Vietnam transitioned from a planned to a market economy three decades ago. This complete overhaul of the economic system has exerted knock-on effects on the coffee sector (AgroInfo, 2012). In the 1990s, the coffee sector benefited from these new economic policies. Some notable policies consisted of the permission of the importation of fertilisers by private businesses and the reduction of import duties on fertilisers to under 5%. This reduced production costs for coffee and enabled farmers to expand their coffee production, resulting in surplus production, which then led to the need for trading coffee more freely. The promulgation of the Law on Private Businesses in 1990 provided the legal base for the existence of the private sector in the economy. As a result, farmers could now sell coffee not only to state-owned enterprises, but also to private businesses, which were previously prohibited in the planned economy.

Since the 2000s Vietnam's government has carried out various policy reforms specific to the coffee sector to promote coffee exports (AgroInfo, 2012). Firstly, the government encouraged the participation of private businesses at a time when state-owned enterprises remained dominant, but inefficient in the coffee market. An export bonus scheme and also favourable credit were offered to domestic coffee exporters while the export ban was lifted for foreign-owned companies. Furthermore, state-owned enterprises were restructured to make them more efficient and to create a more level playing field for all economic participants. Finally, coffee farmers were granted financial incentives to enlarge their production. With these policy developments, the coffee sector has become more market-driven and export-oriented.

Price transmission denotes the way that a price change at one level is passed on to the price at another level in the marketing chain (Goodwin, 2006). Asymmetric price transmission (APT) can be simply defined as the different response, regarding magnitude, speed, and direction, of output prices to the increase or decrease in input prices (Assefa, Kuiper, & Meuwissen, 2014; Meyer & von Cramon-Taubadel, 2004). The literature has often classified APT as 'APT in magnitude' and 'APT in speed'. The former refers to the extent of price transmission among chain-wide agents while the latter denotes the pace of price transmission.

Insights into APT provide significant policy and welfare implications. For example, since policies are often formulated under the assumption of price transmission symmetry, the existence of APT could have some unintended consequences for coffee farmers (Mofya-Mukuka & Abdulai, 2013). The presence of APT also suggests that the market may not operate properly, which is synonymous with market inefficiency (Capps & Sherwell, 2007) and welfare losses to society (Bonnet & Villas-Boas, 2016; McLaren, 2015).

The aim of the above-mentioned policy reforms in Vietnam's coffee sector was to move the sector towards market-driven, having previously been state-regulated, so of particular interest is the extent and/or the speed of changes in international prices transmitted to domestic farmgate prices (Mofya-Mukuka & Abdulai, 2013).

The understanding of this price transmission could also deliver some policy implications for the Vietnam Coffee Coordinating Board (VCCB), whose objectives are both to maintain a market economy and to protect the welfare of coffee farmers. For the first objective, if the transmission between export and farmgate prices for Vietnam's Robusta coffee is symmetric, the policy reforms have made the domestic coffee sector more efficient and well-functioning. For the second objective, related to coffee farmers' welfare, the implication has become ambiguous. On the one hand, when the global coffee market booms, the presence of APT means that welfare gains for coffee farmers may not be as great as expected from economic reforms. Intermediaries such as domestic traders and exporters in the coffee supply chain may be the main beneficiaries. On the other hand, when global coffee prices slump, symmetric price transmission will have a negative impact for coffee farmers whilst APT may cushion the adverse effect of this downward trend.

Despite the importance of coffee for Vietnam's agricultural economy, there has been only one APT study of Vietnam's Robusta coffee in the literature to date, and this was carried out by Li and Saghaian (2013). In their study, the two authors used the linear error correction model to compare price transmission between Robusta coffee in Vietnam and Arabica coffee in Colombia. Although employing the same model specification is reasonable for the comparison of two coffee varieties, the linear error correction model may not accurately describe price transmission between export and farm levels, in which unobserved transaction costs could be involved. Furthermore, this study also ignored the test for APT resulting from different responses at one level to price increases and decreases at another level of the coffee supply chain.

In this research, testing for APT in speed will be undertaken for Vietnam's Robusta coffee. APT in speed refers to the different pace at which farmgate prices respond to increases or decreases in export prices (Fousekis, Katrakilidis, & Trachanas, 2016). Put simply, do price decreases at the export level get passed on to farmgate prices faster than corresponding price increases? In so doing, this research attempts to address limitations in Li and Saghaian's (2013) study by looking at both linearity and nonlinearity in the price transmission process

between export and farmgate prices. Also tested are the different responses of export prices to falling and rising farmgate prices and vice versa. Overall, this research aims to evaluate the linear and nonlinear transmission between export and farmgate prices for Vietnam's Robusta coffee using recent data, from mid-2011 until the end of 2015. Following this, some possible reasons for the findings of price transmission will be discussed. The results from the price transmission analysis may have some policy implications for the VCCB in protecting coffee farmers' welfare given the downward trend in global coffee prices during this period. Therefore, the two research questions in this research are stated as follows:

1. What is the nature of price transmission between the export and farmgate prices for Vietnam's Robusta coffee in both the short run and the long run?
2. What are the policy implications for the Vietnam Coffee Coordinating Board under the findings of the price transmission?

The thesis comprises six chapters and is organized as follows. Chapter Two provides detail of the world coffee market and Vietnam's coffee sector in terms of production, consumption, and international trade over the last 15 years. Chapter Three reviews the literature on APT, starting with its definition and importance in economic theory, and is followed by a summary of common APT types, the theoretical and empirical causes of APT, and approaches to detect and measure the extent of APT. The chapter closes with coverage of empirical findings from previous studies for a variety of farm produce. The linear and threshold vector error correction models to be used in the research are outlined in Chapter Four. Chapter Five details the price data used in the research, presents and interprets the results of the price transmission analysis for Vietnam's coffee sector, and discusses these findings in the context of previous studies both in Vietnam and elsewhere, for Robusta coffee producers. Chapter Six concludes the thesis by summarising the main findings, providing some policy implications for the VCCB, and suggesting extension for future research.

Chapter Two: OVERVIEW OF COFFEE SECTOR

As the nature of price transmission between the global and national coffee markets is a measure of their relationship, it is useful to have a concise description of them before one empirically evaluates their relationship. Such understanding offers a basic idea about the economic integration between the two markets and reiterates the need for the analysis taken in this research.

The purpose of this chapter is to examine the global and national coffee markets over the last 15 years. The first section provides an overview of the world coffee market in terms of production, consumption, and trade. This also presents the part that Vietnam has had in the global coffee market. The second section looks at Vietnam's coffee production, demonstrating the importance of this commodity in Vietnam's agricultural sector. Also described is the domestic coffee sector with regard to its production area, exports, consumption, and pertinent agricultural policies.

2.1. World coffee market

As the world coffee market has influenced the development of Vietnam's coffee sector, it is necessary to cover the current global trends in production, consumption, and trade over the last one and a half decades. This section also highlights the position of Vietnam in global production and trade of coffee beans in general and of Robusta coffee in particular.

2.1.1. Production

World coffee production experienced an overall upward trend from crop year 2000/01 to 2015/16 (Figure 1). The annual growth rate was about 1.8%. Production fluctuated over the first 10 years. For example, it rose from 7.2 million tonnes in 2007/08 to 7.8 million tonnes in 2008/09, and then fell to about 7.4 million tonnes in the following year. It has becoe more stable at over 8.5 million tonnes during the last six years of the period.

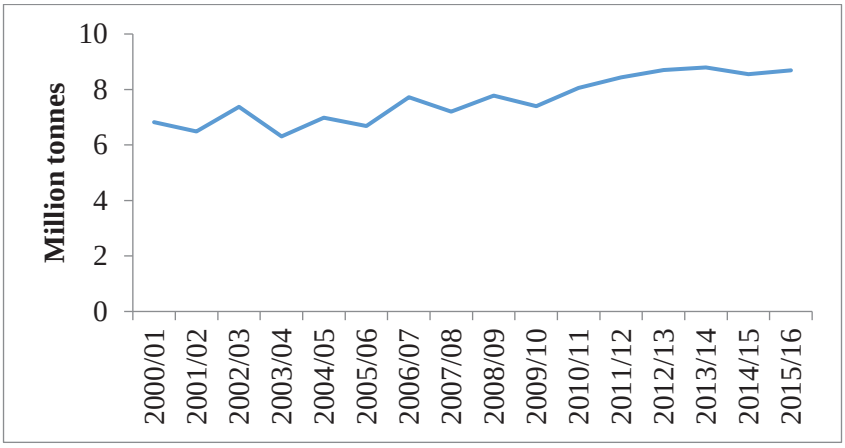

Figure 1: Global coffee production from 2000 to 2015

Source: (ICO, 2016f)

The pattern of production in the four largest coffee-producing countries was fairly distinctive (Figure 2). Brazil was the largest producer with total production fluctuating widely from around 1.9 to 2.6 million tonnes over the period. Vietnam ranked second and saw a more gradual growth in coffee production. Indonesia's coffee production was also on the rise, but at a lower rate, from about 0.4 million tonnes to nearly 0.75 million tonnes in 2015/16. Meanwhile, there was stability in Colombian coffee production from the beginning of the period till 2007/08. Its production then decreased over the next four years, moving the country to fourth position. From 2011/12 to 2015/16, there was a rapid increase of around 15% per year, making Colombia the third largest coffee producer at the end of the period.

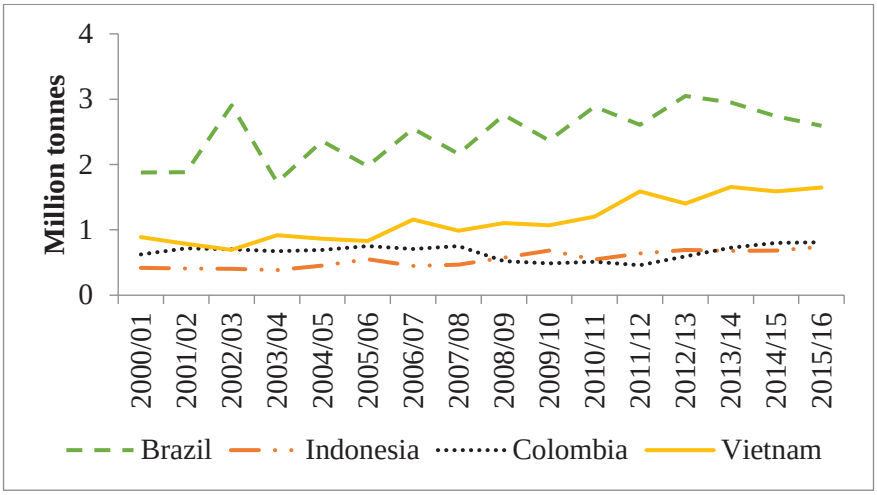

Figure 2: Coffee production in some major countries from 2000 to 2015

Source: (ICO, 2016f)

As shown in Figure 3, global coffee production was highly concentrated. The four largest producing countries, including Brazil, Vietnam, Colombia, and Indonesia, constituted nearly 70% of world production in crop year 2015/16. Brazil accounted for some 30%, followed by Vietnam with approximately 19%. The proportion of Colombia was 9.3% while Indonesia made up around 8.5% of global coffee production. The remaining share was spread over various countries whose proportions were fewer than 5% each.

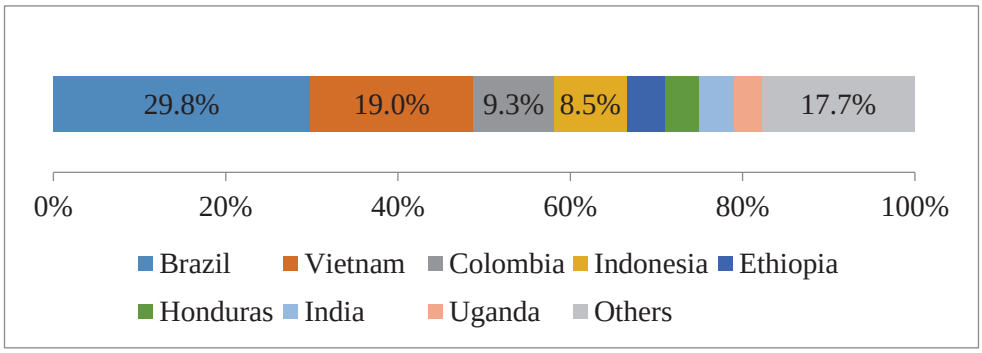

Figure 3: Coffee production by country in 2015/2016

Source: (ICO, 2016f)

The last aspect of global coffee production is related to the dispersion of major coffee cultivars. Arabia and Robusta are the two main coffee varieties. The former is of higher quality than the latter. Arabica coffee can be categorised into three sub-types consisting of Colombian Milds (CM), Other Milds (OM), and Brazilian Naturals (BN) according to their processing methods and places of production (Ponte, 2002). These types of coffee are produced in different parts of the world. In particular, Colombia, Kenya, and Tanzania are major CM producers whereas OM is mainly grown in Guatemala, Mexico, India, and Honduras. Brazil and Ethiopia are main suppliers of BN. Vietnam is dominant in the Robusta production followed by Cote d'Ivoire, Indonesia, and Uganda.

2.1.2. Consumption

Global coffee consumption gradually increased from 2000 to 2014 (ICO, 2016a, 2016b). The rate of increase in coffee consumption worldwide was faster than that of production while total consumption remained lower than total production in

absolute terms year-on-year. For instance, the consumption and production volumes were around 7.7 and 8.6 million tonnes respectively in 2014, indicating a surplus of nearly a million tonnes.

Note from Figure 4 that the consumption in three traditional markets (i.e. EU, the USA, and Japan) remained relatively unchanged over the period while Brazilian consumption rose by half. EU was the biggest consumer with about 2.5 million tonnes in 2014, followed by the US with nearly 1.5 million tonnes in the same year. Brazil was the only coffee producer which was also a considerable coffee consumer. Its consumption increased from 0.8 to 1.2 million tonnes between 2000 and 2014. Japan consumed about 0.45 million tonnes of coffee per year. In relative terms, these four economies accounted for approximately three quarters of global coffee consumption.

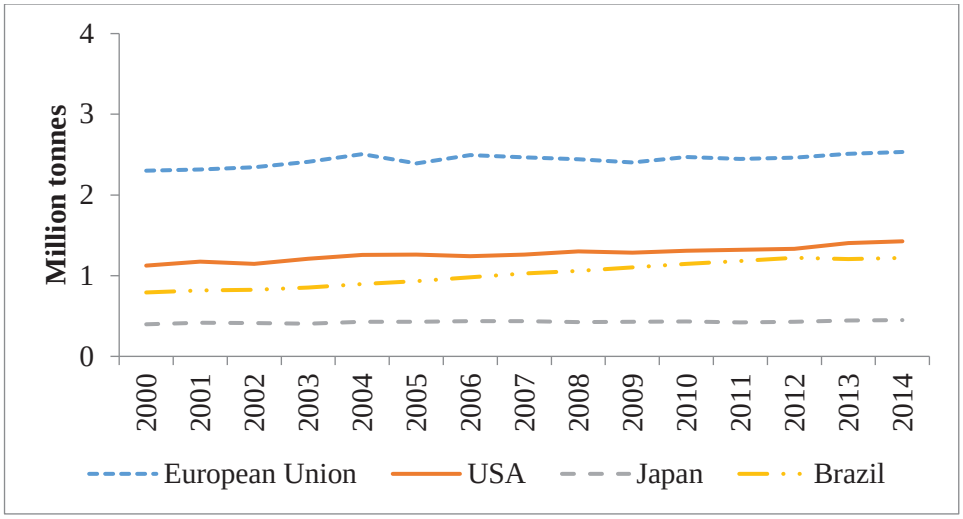

Figure 4: Coffee consumption in major consumers from 2000 to 2014
Source: (ICO, 2016a, 2016b)

2.1.3. Trade

Coffee is a highly traded agricultural commodity with more than 80% of that produced being traded internationally (ICO, 2016c, 2016f). As can be seen from Figure 5, the export and import volumes of coffee grew steadily from over five to around seven million tonnes with exports fluctuating more than imports. Another noticeable feature is that the import volume has exceeded the export volume since

2001. This could imply the entry of some new participants in the world coffee market whose exports were not officially recorded.

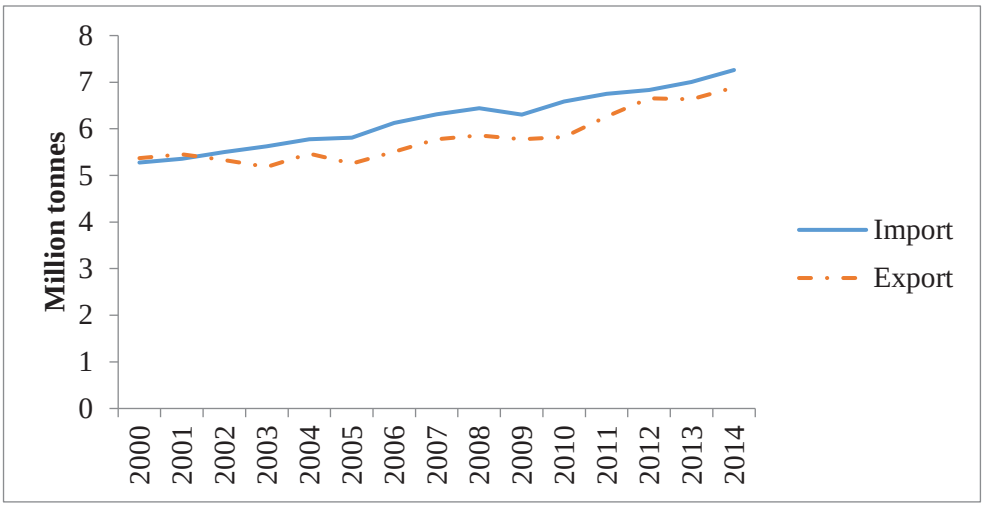

Figure 5: Volume of coffee exports and imports from 2000 to 2014
Source: (ICO, 2016c, 2016d)

The main coffee-growing countries: Brazil, Vietnam, Colombia, and Indonesia, acted as principal exporters. Likewise, EU countries, the US, and Japan were the main coffee importers. In addition, some of these importers also benefited from re-export activities. Notable examples included Germany, Belgium, Italy, and the US (ICO, 2016e).

World coffee production and consumption have been on the rise. Although rising at a higher rate than global production annually, global consumption has remained lower than world production in volume, for the whole period. Another characteristic of world production and consumption has been the high degree of concentration in just a few countries. With regard to world coffee trade, there has been a steady growth over the years. Vietnam has been the second largest producer and exporter of coffee over the last 15 years and has achieved dominance in the global market for Robusta coffee.

2.2. Coffee sector in Vietnam

This section details the coffee sector in Vietnam and the changing role of the government's influence in the sector. As one of the main agricultural products,

coffee is a strategic commodity for Vietnam. It has experienced growth in the production, export volume, and domestic consumption. The government has made some attempts to liberalise and promote the coffee sector to become more export-oriented while paying attention to the coffee farmers' welfare. Evidence shows that the development of Vietnam's coffee sector has been in line with the current trends in the global coffee market.

2.2.1. Importance of coffee in Vietnam's tradable commodities

Coffee is one of six major commodities for export in Vietnam (MARD, 2011, 2013, 2014, 2015, 2016d; SEARCA, 2014). Note from Figure 6 that rice was the most valued export commodity in 2001, and coffee ranked second with an export revenue of nearly US$0.4 billion. Coffee's export value increased gradually over the following six years and exceeded rice's export value in 2006 and 2007. After that, coffee was overtaken by rice in terms of export value for most of the remaining period, except in 2014. The other four major agricultural products (i.e. rubber, cashew nut, pepper, and cassava) remained less valuable than coffee in terms of export revenue for most of the period.

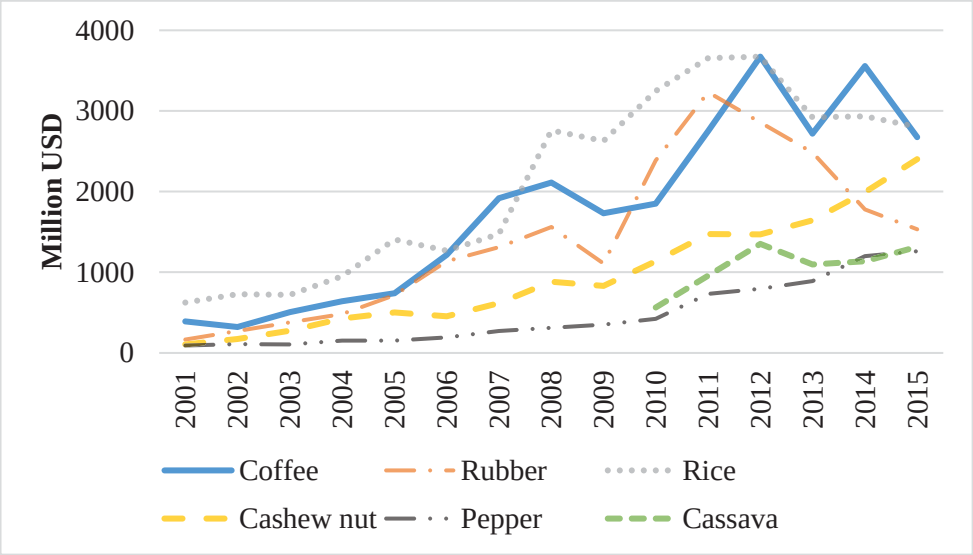

Figure 6: Export values of the main agricultural products from 2001 to 2015

Source: (MARD, 2011, 2013, 2014, 2015, 2016d; SEARCA, 2014)

Note: Data for cassava have only been available since 2010.

In relative terms, coffee accounted for some 16% of total agricultural export earnings in 2015 (Figure 7). This was slightly lower than the share of rice (nearly 17%) and higher than that of cashew nuts (about 14.5%). The proportions of rubber, pepper, and cassava were all fewer than 10%. Other agricultural products constituted about 30%, showing the diversity of tradable commodities in Vietnam's agricultural economy.

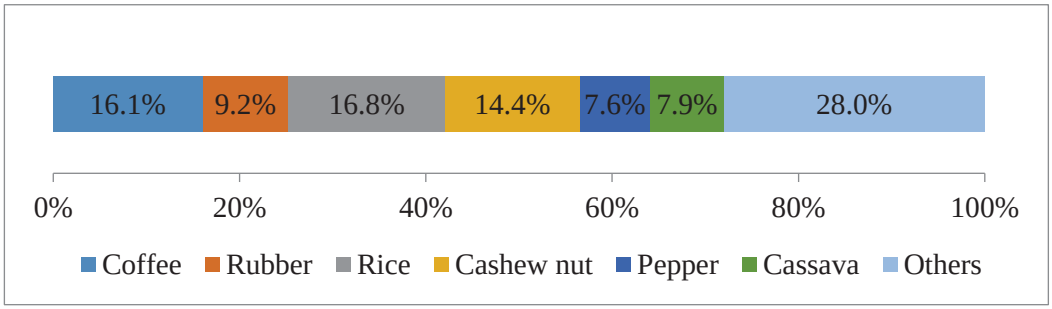

Figure 7: Proportion of export earnings of some major farm produce in 2015
Source: (MARD, 2016d)

2.2.2. Production

Land planted in coffee in Vietnam increased over the period from 2008/09 to 2014/15. Total production area was about 531,000 hectares in 2008/09 and then there was a rapid expansion in coffee production between 2010/11 and 2012/13 (GSO, 2016). This mirrored high prices in the world coffee market during this time period stimulating farmers' coffee production. At the end of the period, the production area was about 642,000 hectares.

As shown in Figure 8, there was an overall upward trend in coffee production from 2000/01 to 2014/15. At the beginning of the period, the production volume was nearly 0.9 million tonnes. It fluctuated over the next years, reaching a peak of approximately 1.8 million tonnes in 2013/14. Total coffee production then fell by around 8% in the following crop year. In addition, total production was higher than total exports (by volume) for most of the period.

Figure 8: Production and export volume of coffee from 2000/01 to 2014/15

Source: (FAS, 2016b, 2016c)

Coffee is grown mainly in the Central Highlands of Vietnam. Four coffee-producing provinces there accounted for over 85% of total production area and 90% of total production volume in 2014 (Figure 9). The province of Dak Lak was the largest producer, making up almost a third of total production area and production volume, and Lam Dong province constituted about a quarter of total production.

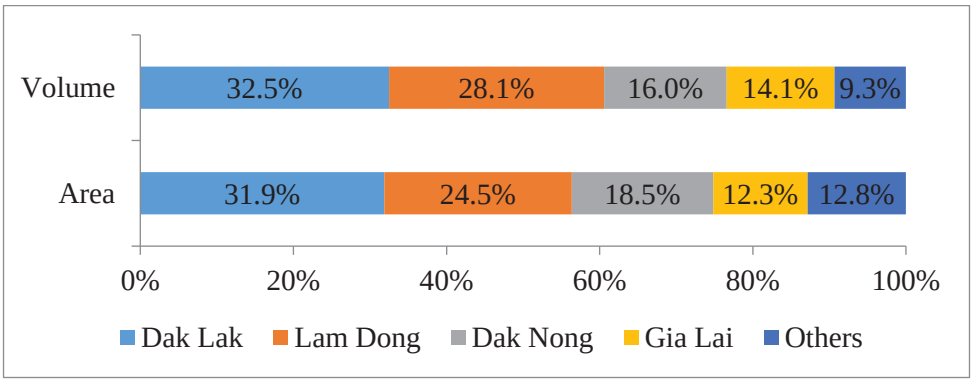

Figure 9: Coffee production area by provinces in 2014

Source: (MARD, 2016b, 2016c)

2.2.3. Exports

Figure 10 shows the export value of coffee between 2000/01 and 2014/15. The export value of coffee began at around US$0.4 billion and then exceeded US$1 billion in the following five years. There was a decrease in export value from

2007/08 to 2009/10. After that, it rocketed to a peak of nearly US$3.7 billion in 2011/12 and fell sharply by approximately US$1 billion in the following crop year. Since the export volume remained comparably high (around 1.5 million tonnes), the decline in export earnings in 2012/13 was mainly due to falling coffee prices. A similar pattern was seen in the last two years in which coffee export earnings surged to some US$3.6 billion in 2013/14 and then plummeted to about US$2.7 billion in 2014/15. However, the decrease at the end of the period was largely due to the decline in export volume from 1.7 to 1.3 million tonnes.

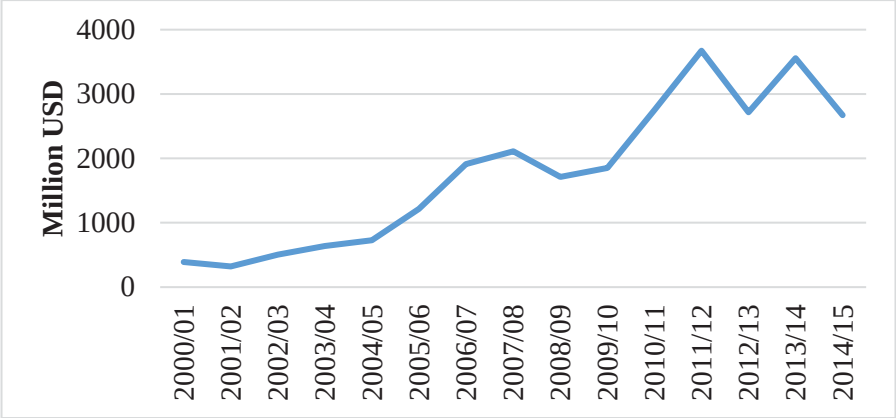

Figure 10: Export value of coffee from 2000/01 to 2014/15

Source: (ITC, 2016; MARD, 2011, 2013, 2014, 2015, 2016d)

As can be seen from Figure 11, the destination of Vietnam's coffee exports was quite diverse. The six biggest importers made up less than 50% of total export value of Vietnam's coffee. Germany imported the most at about 14% (equivalent to around US$500 million). The US was the second most important market, importing about 9.3% of Vietnam's export coffee.

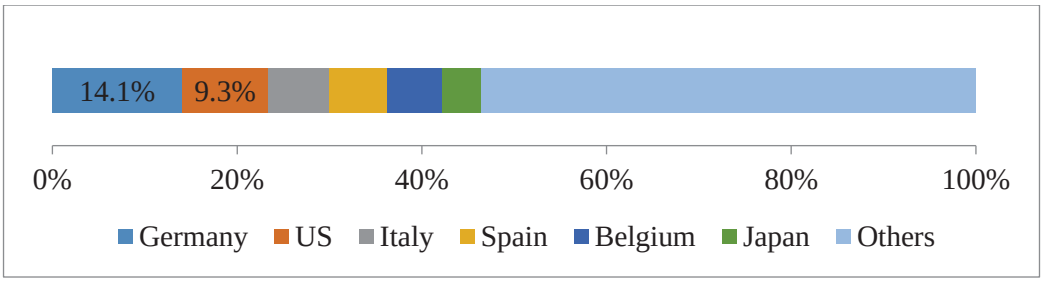

Figure 11: Proportions of main importers in terms of value in 2014

Source: (ITC, 2016)

2.2.4. Domestic market

The domestic consumption of coffee was on the rise from 2000/01 to 2014/15 (Figure 12). At the beginning of the period, total consumption was about 25,000 tonnes. It gradually increased to about 50,000 tonnes in the next seven years. The remaining period witnessed a more rapid growth in coffee consumption, reaching about 130,000 tonnes in 2014/15. However, this domestic consumption was only 8% of total coffee production for the year.

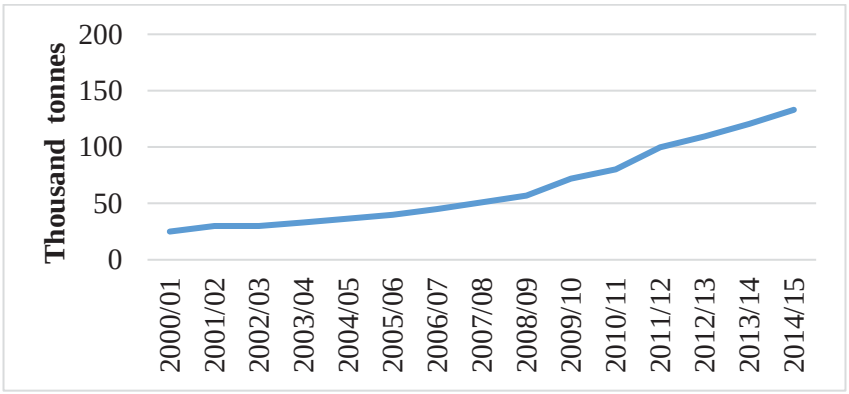

Figure 12: Domestic consumption of coffee from 2000/01 to 2014/15

Source: (FAS, 2016a)

As export has played an important role in Vietnam's coffee sector, focus is also needed on the key players in the domestic coffee exporting business. Figure 13 illustrates the share of the 10 biggest exporters in terms of coffee volume in 2013/14. It is evident that Vietnam's coffee sector is not characterised by market power. These 10 firms constituted less than half of the market share. The most powerful domestic exporter was Intimex Group with 18% of the total market share. Louis VN accounted for only 7% with the next three major firms having about 5% of market share each.

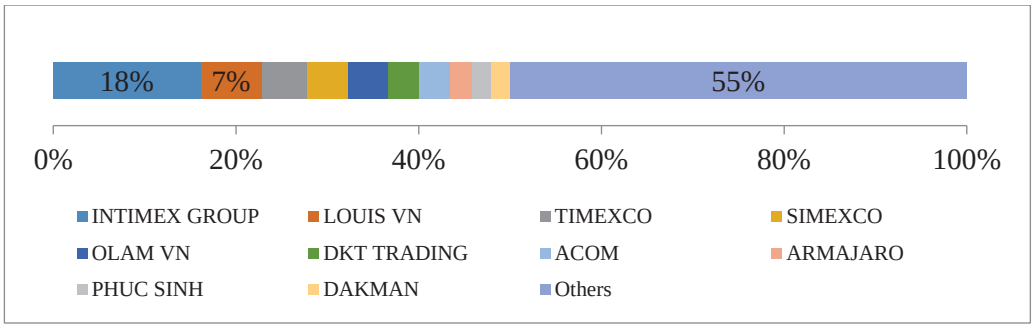

Figure 13: Ten biggest domestic coffee exporters (by volume) in 2013/14

Source: (Vu, 2015)

2.2.5. Vietnam's coffee organisations

The first domestic organisation in Vietnam's coffee sector is the Vietnam Coffee and Cocoa Association (VICOFA) established in 1990. The VICOFA represents enterprises, research centres, and governmental agencies but not coffee farmers. The main objective of the organisation is to protect the benefits of businesses by advising governmental agencies of its members' concerns. Accordingly, many policies have focused on the interest of coffee processors and exporters ahead of farmers (Pham, 2014; Vu, 2016). For example, the government offered a 36-month-extension for loan terms to exporters, refunded value-added taxes to exporters, and granted coffee processors direct payments to purchase machines and to build processing facilities.

Since the crop year 2011/12, coffee export value has become more fluctuated, and coffee prices have been on the decline (MARD, 2016a). These raised concerns about the welfare of coffee farmers in the supply chain. To partly deal with this, the government founded the Vietnam Coffee Coordinating Board (VCCB) in 2013 (Vu, 2015). The VCCB has representatives of all chain-wide agents in the coffee sector, including local and foreign businesses, relevant state agencies, and farmers from Dak Lak and Lam Dong which are the two largest coffee-producing provinces. The organisation aims to coordinate and work in the interests of all agents in the coffee chain. Therefore, the VCCB is anticipated to take into account the welfare of farmers besides businesses when formulating and implementing policies in the coffee sector.

Currently, the VCCB has been in charge of three major development programmes in Vietnam's coffee sector (Vu, 2015). The first was the development plan for the domestic coffee sector introduced in 2012. In response to the oversupply of coffee worldwide, one of its main objectives was to reduce the coffee production area to 500,000 hectares by 2020 and to 480,000 hectares by 2030. However, this target was not met as the coffee production area kept increasing over the years, and thus the target was amended in two years later in the second development programme aiming to maintain around 600,000 hectares by 2020. Lastly, the third

programme, also introduced in 2014, focused on replanting about 120,000 hectares of old coffee trees in the Central Highlands between 2014 and 2020.

In summary, international trade is vital to Vietnam's coffee sector and more so because total production has increased over years while total domestic consumption has remained low. At the same time, the domestic exporters are part of a relatively competitive market in which none have had the dominant market share and so remain price takers. Also, since the interest of coffee farmers has been neglected, the VCCB took the responsibility for implementing existing development programmes in the coffee sector, paying particular attention to coffee farmers' welfare.

The focus of this chapter was the global coffee market, rising in both consumption and production. Vietnam is a significant global exporter of coffee and its coffee sector is valuable to the national economy in terms of export earnings. The next chapter will survey the literature on APT in the agricultural sector, examining both the methods used and the outcomes observed. This will provide insights into the relationship among different markets.

Chapter Three: LITERATURE REVIEW

The purpose of this chapter is to discuss the literature on APT in agriculture with regard to theoretical underpinnings, econometric models, and empirical results. The first section gives an overview of APT and its importance in agricultural economics. The second section classifies APT according to several common criteria and the third examines both theoretical and empirical reasons for APT. The fourth section illustrates the development in the methodological strand of APT studies. The fifth and final section summarises main findings from empirical work for a variety of agricultural goods.

3.1. Introduction to asymmetric price transmission

Studies of price linkages along the chain refer to price transmission and price volatility transmission. The former has been more frequently investigated by agricultural economists with two comprehensive surveys of the literature by Meyer and von Cramon-Taubadel (2004) and Frey and Manera (2007). The transmission of prices in levels deals with the relationship between the conditional mean prices (Natcher & Weaver, 1999), the portion of prices that can be predicted by market fundamentals like historical prices, market structure, and supply and demand conditions. The nature of price transmission is more applicable to policies on welfare and income distribution for many agents in the marketing chain (Bonnet & Villas-Boas, 2016). For instance, consumers may not gain from a reduction in farm prices due to the incomplete price transmission from farm to retail markets. Alternatively, producers possibly do not benefit from a price rise at downstream industries. Indeed, participants in the middle of the chain such as traders, processors, and retailers could be the main beneficiaries of these price movements.

Price volatility transmission involves the relationship between the conditional variance of prices, whose property is “unpredictable and unanticipated” (Assefa, Meuwissen, & Oude Lansink, 2015, p. 1). Simply put, it describes the transmission of uncertainty in a price series to another. The investigations of price volatility transmission are significant and useful for risk management policies. If

price volatility is not conveyed among chain-wide actors, measures to stabilise prices at one level will not necessarily lead to stability of prices at other levels (Serra, 2011). In addition, relevant actors could make their hedging decisions dependent on the magnitude and direction of transmission of price volatility (Assefa et al., 2015). They could also take advantage of new risk management approaches in other markets, which are linked to their market, to protect themselves from instability in their own market.

Price transmission refers to how a price at one level (referred to as output price, p^{out}) responds to a price change at another level (referred to as input price, p^{in}) in the marketing chain (Goodwin, 2006). The different response of p^{out}, in terms of the magnitude, speed, and direction, conditional on the increase or decrease in p^{in}, is construed as asymmetric price transmission (APT) (Assefa et al., 2014; Meyer & von Cramon-Taubadel, 2004). It should also be noted that there are numerous types of APT based on several criteria (as dealt with in the next section).

The investigation of APT's existence across separate markets and throughout supply chains has been of great significance in agricultural economics. Firstly, APT indicates a gap in economic theories. Standard market theory considers it as an exception, while many empirical studies in the current literature have shown its prevalence (see for instance Aguiar & Santana, 2002; Goodwin & Harper, 2000; Peltzman, 2000). Secondly, APT may lead to different impacts from policies, which are often formulated under the condition of price transmission symmetry (Mofya-Mukuka & Abdulai, 2013). For example, a state procurement programme that aims to increase farm prices in times of a downward trend may be less beneficial to farmers if the price increase at the wholesale level is not transmitted correspondingly to prices at the farm level. Thirdly, the degree of price transmission has long been a crucial indicator of the overall functioning of the market (Goodwin, 2006). APT may theoretically imply the exercise of market power, leading to market inefficiency (Capps & Sherwell, 2007) and welfare losses to society as a whole (Bonnet & Villas-Boas, 2016; McLaren, 2015). Lastly, since prices also serve as an instrument for conveying information along the supply chain, APT may exaggerate the problem of asymmetric information (as cited in Falkowski, 2010). This inadequate or improper information about real

market conditions such as supply, demand, and potential shocks could negatively affect the consumption and production decisions by chain-wide agents.

3.2. Types of APT

There are several criteria to classify APT. These classifications overlap somewhat because asymmetry in the context of price transmission does have ambiguous meanings. One of the most common criteria is between short run (SR) and long run (LR) asymmetries (Frey & Manera, 2007). Asymmetry in the SR refers to the degree of variation in p^{out} in response to increases or decreases in p^{in} in several lagged points of time. From a LR viewpoint, the adjustment towards a LR equilibrium level is dissimilar for positive and negative shocks to p^{in} with regard to speed of adjustment, reaction times, or the number of recovery periods.

Another criterion is related to the magnitude and speed of price transmission. The extent and speed of the change in p^{out} in reaction to a change in p^{in} are dependent on the nature of such change in p^{in}, i.e. rise or fall, at a specific time point. By way of illustration, consider p_1^{in} and p_1^{out} for a particular product in period 1. In the next period, these prices are p_2^{in} and p_2^{out}. Accordingly, $\Delta p^{in} = p_2^{in} - p_1^{in}$ is the change in p^{in}, and $\Delta p^{out} = p_2^{out} - p_1^{out}$ the change in p^{out}. Let Δp^{in+} and Δp^{out+} denote positive price changes and Δp^{in-} and Δp^{out-} negative price changes. If Δp^{in+} equals Δp^{in-}, Δp^{in+} (Δp^{in-}) and Δp^{out+} (Δp^{out-}) are positively related, and Δp^{out+} is either greater or less than Δp^{out-}, then APT exists. If the difference between Δp^{out+} and Δp^{out-} persists permanently, this indicates APT in magnitude. If this difference is eliminated within some periods, this suggests APT in speed. If only part of such difference is adjusted after several periods, this implies APT with respect to both magnitude and speed (Meyer & von Cramon-Taubadel, 2004).

The third criterion is positive or negative APT proposed by Peltzman (2000) and subsequently generalised by Meyer and von Cramon-Taubadel (2004). Positive APT means that p^{out} adjusts more completely and/or quickly to a change in p^{in} that contracts margins than a change in p^{in} that improves margins. Negative APT describes the situation in which p^{out} reacts more wholly and/or swiftly to a change

in p^{in} that stretches margins, compared to an equivalent change in p^{in} that squeezes margins.

The next classification is vertical and spatial APT (Meyer & von Cramon-Taubadel, 2004). Vertical APT deals with the transmission among agents in the supply chain. For instance, many vertical APT studies investigate price transmission between farm, wholesale, and retail levels. Spatial APT is related to the relationship between prices of a particular product at different places, for example, wheat prices in the US and Australia (von Cramon-Taubadel & Loy, 1996). Additionally, vertical and spatial APT can be further categorised according to magnitude and/or speed, and positive or negative nature.

The above list is not an exhaustive collection of asymmetries in price transmission. The current literature has named some other types of APT. Frey and Manera (2007) proposed a new classification system, distinguishing eight types of asymmetries (e.g. contemporaneous impacts and distributed lag effects) in order to be able to test the suitability of econometric models for each type of asymmetry. Han and Ahn (2015) discerned APT according to the high or low levels of p^{in} rather than p^{in} increases or decreases in conventional studies. Besides the traditional time-domain, APT was also identified in the frequency-domain and classified based on high- or low-frequency cycles (Miller & Hayenga, 2001). However, this research will not review these asymmetries in detail because the main focus here is on APT in the SR and the LR with respect to their positive and negative nature in the traditional time-domain.

3.3. Reasons for APT

Theoretical and empirical causes of APT are described in this section. On the theoretical side, the characteristics of demand and supply curves, the market power of buyers and sellers, and their interactions could result in APT. The degree of market power and the returns to scale of a particular industry together could also contribute to APT. Consumption inertia could also be a source of asymmetry. Meanwhile, empirical work emphasises two major causes: market power and adjustment costs (Meyer & von Cramon-Taubadel, 2004). APT could also be

attributable to government policies and asymmetric information. These empirical explanations are outlined for the vertical and horizontal supply chains separately.

3.3.1. Theoretical explanations

The interest in APT is predicated on the factual perception that downstream industries in the supply chain possess some characteristics that lead to incomplete price transmission. Some theoretical justifications are laid out in the literature of some branches of economics apart from agricultural economics. For example, macroeconomics literature attributes the inadequate price adjustment at the retail level to menu costs (as cited in McCorriston, Morgan, & Rayner, 2001). This assumes the stickiness of price in the SR, but full adjustment in the LR. Studies in public economics focus on oligopolistic behaviour while from international economics the issue of exchange rate pass-through is often used to justify the presence of APT.

From agricultural economics, the current literature has been less informative with only a handful of theoretical studies on reasons for APT. The initial focus has been on the demand of consumers. Bailey and Brorsen (1989) ascribed asymmetry to a kinked demand curve. The kink in the demand curve of a firm could be caused by a situation in which all competitors follow either its increased or decreased pricing practices. Later, Azzam (1999) proved that the farm-retail APT resulted from the optimizing behaviour of spatially competitive retailers for the condition of concave spatial demand of customers. The fierce retail competition did not guarantee the improvement in transmission of falling farm prices. Azzam (1999) also implied that repricing costs might cause rigid retail prices when farm prices experienced a downward trend.

The next attempts to explain APT were directed to the market power of agents in the supply chain. Bunte and Peerlings (2003) considered both oligopoly power of retailers over consumers and oligopsony power of retailers over growers. The authors deduced that the oligopolistic behaviour could lead to APT in the retail-consumer chain while the oligopsonistic behaviour could result in APT between growers and retailers. The model by Bunte and Peerlings (2003) was then

modified to add wholesalers to the farm-retail chain (Weldegebriel, 2004). Weldegebriel (2004) assumed the oligopsony power of wholesalers over farmers and the oligopoly power of retailers over consumers in the industry characterised by variable input proportions. If both forms of market power were present together, they may neutralise each other, leaving no APT in the farm-retail chain. For example, price increases at the farm level were transmitted more slowly to the wholesale level whereas price increases at the retail level were passed on faster to consumers. In this case, the exercise of oligopoly and oligopsony power did not necessarily lead to APT between farm and retail levels.

Later still, Xia (2009) investigated price transmission in the same framework of a three-level supply chain and attached significance to the supply condition. The Xia's (2009) study showed that strictly convex farm supply curvature and buyer power of wholesalers/processors at the farm level were largely responsible for the higher transmission of farm price rises to retail prices than farm price falls. The results related to the demand condition at the retail level were in contrast to the findings of Azzam (1999) and in accordance with those of Weldegebriel (2004). The impact of strictly concave consumer demand on the farm-retail price transmission was undetermined and appeared to be trivial when buyer power was played out in the farm market, and seller power in the retail market. Specifically, in the farm-wholesale price transmission with wholesalers' market power, the strict concavity of consumer demand led to negative APT. In the retail-consumer price transmission with retailers' market power, the strict concavity of consumer demand gave rise to positive APT. These two opposite effects could offset each other in the farm-retail chain. In short, the Xia's (2009) study shed light on the occurrence of APT by developing a theoretical framework that incorporate market's conditions including farmers' supply, consumers' demand, wholesalers' power, and retailers' power.

The nature of farm-retail price transmission was shown to be influenced by the interaction between market power and returns to scale of an agri-food industry. Given constant returns to scale or constant marginal costs, market power decreased the magnitude of price transmission (McCorriston, Morgan, & Rayner, 1998). In an industry characterised by decreasing returns to scale, market power

had a more dwindling impact on price transmission (McCorriston et al., 2001). In contrast, the increasing returns to scale could counteract the market power's dampening effect. Under some special circumstances subject to the demand curve, this decreased marginal cost condition could lead to a greater price transmission, compared to the competitive market with constant marginal costs. In other words, APT should not be explained only by market power without considering returns to scale of an industry.

The marginal cost function of large intermediaries affected price transmission from global to domestic markets for agricultural products (McLaren, 2015). If the firms have adequately convex marginal cost functions, domestic prices will react more proportionately to world price decreases than to world price increases. The McLaren (2015) study reiterated the role of marginal cost functions or returns to scale in price transmission.

Finally, consumption inertia was put forward to in part clarify the faster pass-through of rising prices than falling prices in the wholesale-retail chain (Xia & Li, 2010). Consumption inertia can be defined as the gradual reaction to retail price changes by consumers in their level of consumption. Retailers with market power over consumers were more inclined to promptly raise their retail prices in response to wholesale price increases because consumers would not substantially reduce their consumption level in the SR. Retailers also tended not to cut their retail prices quickly when wholesale prices fell for the same reason. Therefore, consumer's behaviour could explain APT in the wholesale-retail chain.

3.3.2. Explanations for vertical APT

Some reasons for vertical APT have been proposed in the empirical literature (Meyer & von Cramon-Taubadel, 2004). One of the main explanations is the exercise of a firm's market power. For instance, processors and retailers could capitalise on the imperfectly competitive market to transmit increases in p^{in} received by farmers to p^{out} paid by consumers more rapidly and fully than the corresponding decreases in p^{in} (positive APT). In addition, oligopolistic firms could establish an unspoken collusion to enjoy higher profits (Balke, Brown, &

Yücel, 1998). These firms more quickly increased or more slowly decreased p^{out} to maintain such tacit agreement, which could cause positive APT.

Empirical investigations of the impact of market power on APT provided mixed results because of using mainly price data and some proxies that did not adequately capture the exercise of market power. Peltzman (2000) found differing impacts of market power from two metrics: the number of competitors and market concentration. Asymmetry increased as the number of firms or market concentration decreased, which signalled high and low levels of market power, respectively. Additionally, Bettendorf and Verboven (2000) also noticed a marginal contribution of market power to incomplete price transmission of coffee beans in the Netherlands.

The second most important reason for APT is adjustment costs incurred to firms when they alter the "quantities and/or prices of inputs and/or outputs" (Meyer & von Cramon-Taubadel, 2004, p. 589). The effects of adjustment costs could be negative. Firstly, beef packers in the US tended to raise bids faster in undersupply and to lower bids more slowly in oversupply because of the competition in the beef packing market and their substantial fixed investment (negative APT) (Bailey & Brorsen, 1989). Another case for negative APT could be related to product storability. Retailers of perishable products hesitated to raise retail prices when wholesale/farm prices increased for fear of unsold spoiled products (Ward, 1982). Meanwhile, retailers were willing to decrease retail prices accordingly when wholesale/farm prices fell in order to accelerate the sales of perishable goods. The reason of product perishability for negative APT, however, was challenged by Aguiar and Santana (2002) when they found positive APT for fresh tomatoes and onions in Brazil.

Adjustment costs could lead to positive APT. Peltzman (2000) argued that firms had to bear some additional costs, including search costs and price premia, to employ new inputs. As a result, they became more reluctant to decrease p^{out} with a view to increasing sales and production during the period of falling p^{in}. Positive APT may also arise from menu costs, a special case of adjustment costs, in times of inflation and nominal p^{in} shocks (Ball & Mankiw, 1994). Besides, adjustment

costs related to inventory management may explain positive APT (Reagan & Weitzman, 1982). Specifically, firms could temporarily shrink their production and increase inventory rather than decrease p^{out} to cope with low demand. They also tended to raise prices instead of expand production in periods of high demand. A further illustration of positive APT is when a positive shock to p^{in} increases p^{out}, resulting in a decline of a firm's sales. This may then lower a firm's inventory target level, leaving the firm with an impression of rising production costs. In response, the firm could transmit p^{in} increases more thoroughly to p^{out} (Abbassi, Tamini, & Gervais, 2012).

Government interventions may be another source of APT. Price support in agriculture could give rise to positive APT (Kinnucan & Forker, 1987). It is widely believed that a reduction in farm prices will be more likely to trigger government's support to reverse this shock, whereas an increase in farm price will be left as it is. This would affect retailers' behaviour, making them more reluctant to decrease retail prices in times of falling farm prices, but less reluctant to increase retail prices when farm prices rise. The quota system, on the other hand, might bring about the opposite impact, negative APT (Serra & Goodwin, 2003). In this situation, retail prices could fall while farm prices rise, given that competing firms wanted to enhance their access to quota and to increase retail market share. Furthermore, policies in biofuel industries, in some circumstances, may lessen the magnitude of price adjustments in corn and food markets. This may take place as long as agricultural markets were connected to biofuels, regardless of market power in agricultural downstream industries (Drabik, Ciaian, & Pokrivčák, 2016).

The presence of APT may also be due to input substitution, temporary entrants, and asymmetric information. When farm prices increased, downstream industries could use agricultural input substitutes and avoid raising p^{out} (Bunte & Peerlings, 2003). APT between farm and export levels possibly resulted from the emergence of small occasional traders (Fafchamps & Hill, 2008). Temporary traders moved around the countryside and procured coffee directly from farmers when there was a surge in export prices. In so doing, these temporary traders briefly entered the supply chain, interrupting the usual chain between farmers and permanent

wholesalers/ exporters. These new entrants exploited farmers' lack of information to buy coffee at prices that inadequately increased with export prices, but they sold to permanent wholesalers/exporters at correspondingly rising prices. Lastly, asymmetric information obtained by large competing firms could lead to APT (Bailey & Brorsen, 1989). For instance, some firms could have a better source of market insights and accordingly alter their pricing strategies differently, or postpone the decreased price reporting.

3.3.3. Explanations for spatial APT

Most of the justifications for vertical APT can be valid for spatial APT (Bailey & Brorsen, 1989). They include market power, adjustment costs, government policies, and asymmetric information. In the spatial context, p^{in} and p^{out} denote prices for the same product in separate places rather than prices at different levels of a supply chain. Therefore, the reasons for spatial APT would differ those for vertical APT in representation.

Market power in the spatial context could have mixed impacts on APT. A firm with local market power, by definition, has no competitors within a particular distance. It does not have to worry about the harmful pricing behaviour of its competitors when stretching its margins. It, therefore, is able to transmit an increase in p^{in} in a faster and/or greater manner with respect to p^{out}, than a corresponding decrease in p^{in}. Local customers keep buying its products with rising prices because of location convenience (Vavra & Goodwin, 2005) and their expectation that the loss from this price increase is not worth searching for cheaper goods in other places (McLaren, 2015). This spatial market power leads to positive APT. In contrast, if firms with local market power in a larger region vie for market share (Meyer & von Cramon-Taubadel, 2004), they will rapidly respond to a price decrease by their competitors, but diminish, delay, or even halt their reaction to a price increase. This gives rise to negative APT.

Spatial APT could take place if transportation costs vary according to the direction of transaction (Meyer & von Cramon-Taubadel, 2004). For instance, suppose the infrastructure or natural characteristics for transportation of a

particular product from place A to place B are more favourable than those from place A to place C. This might cause spatial APT for this product between place B and place C.

Spatial APT could also be attributed to government policies. An example occurred for wheat markets in Brazil and Argentina (Balcombe, Bailey, & Brooks, 2007). Their participation in Mercosur, a free trade agreement among some South American countries, led Brazil towards importing wheat from Argentina and strengthened the price leadership role of Argentina. A further case was price transmission of corn between South Africa and Zambia when there was an acute shortage of corn in Zambia (Myers & Jayne, 2012). The Zambian government usually amplified imports and sold corn at subsidised prices. Such governmental intervention probably discouraged firms from participating in the corn supply chain and disrupted price transmission between the two countries.

The last cause is asymmetric information between the central and peripheral markets (Abdulai, 2000). Rising wholesale prices for corn in the central market were transmitted more promptly to peripheral markets than falling prices. The peripheral markets that had closer proximity and higher trade intensity with the central market also displayed a greater price transmission. By contrast, prices in the central market seemed less sensitive to price changes in peripheral markets.

3.4. Methods for empirical investigations

Given the importance of APT in agricultural economics, various econometric methods have been developed to ascertain APT and to measure its extent. Until now, there have been two attempts to classify APT methods (Frey & Manera, 2007; Meyer & von Cramon-Taubadel, 2004). Frey and Manera's (2007) study aimed to match APT types with appropriate models. It specified five groups of APT methods, comprising the autoregressive distributed lag model, the partial adjustment model, the error correction model (ECM), the regime switching model, and their multivariate extensions. Meanwhile, the study by Meyer and von Cramon-Taubadel (2004) differentiated pre-cointegration and cointegration-based models according to the treatment of these models for nonstationary properties of

price series. This research investigates APT types discussed in Meyer and von Cramon-Taubadel's (2004) study and, therefore, it will follow this classification of common APT methods for consistency and brevity.

3.4.1. Pre-cointegration approaches

First of all, it is necessary to define some notation for ease of comparison among methods. Consider p_t^{out} and p_t^{in} [notation used in (Meyer & von Cramon-Taubadel, 2004)] are output price and input price in period *t*. The equation for linear and symmetric price transmission from p_t^{in} to p_t^{out} is as follows:

$$p_t^{out} = \alpha + \beta p_t^{in} + \mu_t \quad (1)$$

where t = 1, 2, ..., T;

μ_t is a residual from OLS regression.

Preliminary work on APT was undertaken by Farrell (1952) who investigated the irreversibility feature of the demand function of several consumption goods. Tweeten and Quance (1969) then focused on the irreversible supply function in the agricultural sector. The two authors developed a two-equation system with each equation referring to periods of price decreases or increases. They used a dummy variable to combine two equations into a single one. Their technique can be translated into the APT perspective. The two-equation system is:

$$\begin{aligned} p_t^{out} &= \alpha + \beta^{+} p_t^{in+} + \mu_t \\ p_t^{out} &= \alpha + \beta^{-} p_t^{in-} + \mu_t \end{aligned} \quad (2)$$

where $p_t^{in+} = p_t^{in}$ if $p_t^{in} > p_{t-1}^{in}$;

$p_t^{in-} = p_t^{in}$ if $p_t^{in} < p_{t-1}^{in}$.

The two equations in (2) are combined for estimation.

$$p_t^{out} = \alpha + \beta^{+} D_t^{+} p_t^{in} + \beta^{-} D_t^{-} p_t^{in} + \mu_t \quad (3)$$

where D_t^{+} = 1 if $p_t^{in} \geq p_{t-1}^{in}$ and D_t^{+} = 0 otherwise;

D_t^{-} = 1 if $p_t^{in} < p_{t-1}^{in}$ and D_t^{-} = 0 otherwise.

If the null hypothesis of equal coefficients for increased and decreased prices (H_0: $\beta^{+} = \beta^{-}$ in equation (3)) is rejected, there is enough evidence of APT.

The approach by Tweeten and Quance (1969) considered the period-to-period changes and could result in biased estimates. Wolffram (1971) subsequently took cumulative changes into account to avoid the bias from estimating equation (3). Equation (4) includes sums of all positive and negative changes in p_t^{in}. The hypothesis test for asymmetry remains unchanged. If H_0: $\beta^+ = \beta^-$ in equation (4) is rejected, APT is present.

$$p_t^{out} = \alpha + \beta^+(p_0^{in} + \sum_{t=1}^{T} D_t^+ \Delta p_t^{in}) + \beta^-(p_0^{in} + \sum_{t=1}^{T} D_t^- \Delta p_t^{in}) + \mu_t \qquad (4)$$

where p_0^{in} is the first observation of p_t^{in};

D_t^+ = 1 if $\Delta p_t^{in} \geq 0$ and D_t^+ = 0 otherwise;

D_t^- = 1 if $\Delta p_t^{in} < 0$ and D_t^- = 0 otherwise;

$\Delta p_t^{in} = p_t^{in} - p_{t-1}^{in}$.

Later Houck (1977) improved equation (4) to make the estimation more convenient. This specification considered the differential between p^{out} in period *t* (p_t^{out}) and its first observation (p_0^{out}) as the dependent variable. The test for $\beta^+ = \beta^-$ in equation (5) will substantiate or repudiate the asymmetry.

$$p_t^{out*} = \alpha t + \beta^+ \sum_{t=1}^{T} D_t^+ \Delta p_t^{in} + \beta^- \sum_{t=1}^{T} D_t^- \Delta p_t^{in} + \mu_t \qquad (5)$$

where $p_t^{out*} = p_t^{out} - p_0^{out}$.

Since the above studies only explored asymmetric effects of prices on demand and supply functions, Ward (1982) was considered the pioneer in examining APT when focusing on the transmission among retail, wholesale, and shipping-point prices. Ward (1982) allowed the effect of previous changes in p_t^{in} on the current differential output price (p_t^{out*}) by fitting some lags of independent variables into equation (5) to obtain:

$$p_t^{out*} = \alpha t + \sum_{j=1}^{P}(\beta_j^+ \sum_{t=1}^{T} D_t^+ \Delta p_{t-j+1}^{in}) + \sum_{j=1}^{N}(\beta_j^- \sum_{t=1}^{T} D_t^- \Delta p_{t-j+1}^{in}) + \mu_t \qquad (6)$$

where P and N are the numbers of lags;

D_t^+ = 1 if $\Delta p_{t-j+1}^{in} \geq 0$ and D_t^+ = 0 otherwise;

D_t^- = 1 if $\Delta p_{t-j+1}^{in} < 0$ and D_t^- = 0 otherwise;

$\Delta p_{t-j+1}^{in} = p_{t-j+1}^{in} - p_{t-j}^{in}$.

This specification is consistent with the models discussed in this literature review, therefore the final equation in Ward's (1982) study, which used Young's (1980) framework and had some reparameterisation, is not described. The null hypotheses of period-to-period and cumulative symmetries would be $\beta_j^+ = \beta_j^-$ and $\sum_{j=1}^{P} \beta_j^+ = \sum_{j=1}^{N} \beta_j^-$, respectively.

Following a different approach to Wolffram's (1971) study, Balke et al. (1998) modified the model by Tweeten and Quance (1969) (equation (3)) and included lagged values of independent variables. The equation is expressed as:

$$p_t^{out} = \alpha + \sum_{j=1}^{P} \beta_j p_{t-j+1}^{in} + \sum_{j=1}^{P} \beta_j^+ D_t^+ p_{t-j+1}^{in} + \mu_t \qquad (7)$$

where D_t^+ = 1 if $p_{t-j+1}^{in} > p_{t-j}^{in}$ and D_t^+ = 0 otherwise;

P is the number of lags.

Equation (7) leads to a different hypothesis test although some reparameterisation could transform it into a new equation with a similar hypothesis test to that of equation (3). In equation (7), the hypothesis tests for symmetric price transmission would be $\beta_j^+ = 0$ and $\sum_{j=1}^{P} \beta_j^+ = 0$.

Another effort to adjust equation (3) was made by Karrenbrock (1991) with the model described as:

$$\Delta p_t^{out} = \alpha + \sum_{j=1}^{P} \beta_j^+ D_t^+ \Delta p_{t-j+1}^{in} + \sum_{j=1}^{N} \beta_j^- D_t^- \Delta p_{t-j+1}^{in} + \mu_t \qquad (8)$$

where $\Delta p_t^{out} = p_t^{out} - p_{t-1}^{out}$.

This specification allowed the test for asymmetry in period-to-period and cumulative changes in p_t^{in}. The null hypotheses became analogous to those of Ward's (1982) model ($\beta_j^+ = \beta_j^-$ and $\sum_{j=1}^{P} \beta_j^+ = \sum_{j=1}^{N} \beta_j^-$).

3.4.2. Cointegration-based methods

The models discussed in section 3.4.1 do not take into consideration the properties of price series. If price series are nonstationary, their regression models will more

likely be spurious. In this context, an alternative approach with cointegration, which implies a LR relationship between two price series, offers a more accurate method to test for APT.

The cointegration-based method was first employed by von Cramon-Taubadel and Loy (1996). The authors used Engle and Granger's (1987) two-step procedure to test for cointegration of two price series. If they are cointegrated, lagged residuals (μ_{t-1} in equation (1)), aka error correction terms (ECT_{t-1}), and lagged differences of the dependent variable will be incorporated in the model. The vector error correction model (VECM) for the relationship between the two price series is:

$$\Delta p_t^{out} = \alpha + \sum_{j=1}^{K} \beta_j \Delta p_{t-j+1}^{in} + \delta ECT_{t-1} + \sum_{j=1}^{L} \gamma_j \Delta p_{t-j}^{out} + \omega_t \qquad (9)$$

where ECT_{t-1} is the lagged residual from equation (1);

K and L are lag lengths;

ω_t is white noise error terms.

Using the partitioning technique to test for APT, equation (9) becomes:

$$\Delta p_t^{out} = \alpha + \sum_{j=1}^{P} \beta_j^{+} D_t^{+} \Delta p_{t-j+1}^{in} + \sum_{j=1}^{N} \beta_j^{-} D_t^{-} \Delta p_{t-j+1}^{in} + \delta^{+} ECT_{t-1}^{+} + \delta^{-} ECT_{t-1}^{-} + \sum_{j=1}^{L} \gamma_j \Delta p_{t-j}^{out} + \omega_t \qquad (10)$$

where D_t^{+} = 1 if $\Delta p_{t-j+1}^{in} \geq 0$ and D_t^{+} = 0 otherwise;

D_t^{-} = 1 if $\Delta p_{t-j+1}^{in} < 0$ and D_t^{-} = 0 otherwise;

$ECT_{t-1}^{+} = ECT_{t-1}$ if $ECT_{t-1} \geq 0$ and ECT_{t-1}^{+} = 0 otherwise;

$ECT_{t-1}^{-} = ECT_{t-1}$ if $ECT_{t-1} < 0$ and ECT_{t-1}^{-}= 0 otherwise.

This specification enabled the test for APT of various types. The alternative hypothesis of $\delta^{+} \neq \delta^{-}$ denoted a LR asymmetry. The hypothesis tests for SR asymmetries in period-to-period and cumulative variation remained akin to those of Ward's (1982) model ($\beta_j^{+} = \beta_j^{-}$ and $\sum_{j=1}^{P} \beta_j^{+} = \sum_{j=1}^{N} \beta_j^{-}$).

There is a concern pertinent to this approach. The model in equation (10) assumes a symmetric LR relationship (symmetric cointegration) between the two price series (reflected in equation (1)). If this is not the case, the test for APT based on

this assumption may be misleading (Abdulai, 2002). As a solution, Enders and Granger (1998) proposed two models: Threshold Autoregressive (TAR) and Momentum-TAR (M-TAR), in order to test for asymmetric cointegration. The subsequent estimation of the VECM and hypothesis test would be the same as the above procedure for symmetric cointegration.

Additionally, Manning (1991) used the Stock and Watson's (1993) method to estimate the VECM. The technique required one step rather than the two in the Engle and Granger's (1987) approach. Fortunately, the results from the two methods were similar in the Manning (1991) study, whilst the debate on their robustness and power remained unsettled (Frey & Manera, 2007). The VECM using the Stock and Watson's (1993) method can be written as:

$$\Delta p_t^{out} = \alpha + \alpha^{+} D_t^{+} + \sum_{j=1}^{P} \beta_j \Delta p_{t-j+1}^{in} + \sum_{j=1}^{P} \beta_j^{+} D_t^{+} \Delta p_{t-j+1}^{in} + \sum_{j=1}^{L} \gamma_j \Delta p_{t-j}^{out} + c_1 p_{t-1}^{out} - c_2 p_{t-1}^{in} + \omega_t \quad (11)$$

where $D_t^{+} = 1$ if $p_{t-j+1}^{in} > p_{t-j}^{in}$ and $D_t^{+} = 0$ otherwise.

The hypothesis tests, similar to those for equation (7), would be $\beta_j^{+} = 0$ and $\sum_{j=1}^{P} \beta_j^{+} = 0$. In equation (11), the implied LR relationship that was similar to the first step in the Engle and Granger's (1987) method was derived as:

$$p_t^{out} = -\frac{\alpha}{c_1} - \frac{c_2}{c_1} p_t^{in} + \mu_t \quad (12)$$

Model (10) and (11) are based on the assumption that any deviation from a LR equilibrium will be corrected by the same amount in each period. In other words, price transmission is deemed to be linear. However, the involvement of transaction costs and other price frictions could make it nonlinear (Meyer, 2004; Vavra & Goodwin, 2005). There are two prevalent specifications to deal with the nonlinearity in price transmission, namely threshold and polynomial models.

The threshold approach seems intuitively attractive because threshold variables need to exceed some certain values before the correction process takes place. The choice of threshold variables varied, from an outside-model variable (Powers,

1995), to a function of input price differences (Godby, Lintner, Stengos, & Wandschneider, 2000), to an unobserved state variable (Radchenko, 2005), and to the widely used *ECT* (e.g. Alemu & Worako, 2011; Ben-Kaabia & Gil, 2007; Wondemu, 2015; Worako, van Schalkwyk, Alemu, & Ayele, 2013).

The number of thresholds is also a critical issue. Most empirical studies assumed one or two thresholds. Hansen and Seo (2002) developed a two-regime threshold VECM (TVECM) with one threshold, which can be consistently expressed as:

$$\Delta p_t^{out} = \begin{cases} \alpha_1 + \sum_{j=1}^{K} \beta_{1j} \Delta p_{t-j+1}^{in} + \delta_1 ECT_{t-1} + \sum_{j=1}^{L} \gamma_{1j} \Delta p_{t-j}^{out} + \omega_t \; if \; ECT_{t-1} \leq \theta \\ \alpha_2 + \sum_{j=1}^{K} \beta_{2j} \Delta p_{t-j+1}^{in} + \delta_2 ECT_{t-1} + \sum_{j=1}^{L} \gamma_{2j} \Delta p_{t-j}^{out} + \omega_t \; if \; ECT_{t-1} > \theta \end{cases} \quad (13)$$

where ECT_{t-1} is the threshold variable;

θ is the threshold.

Even though the delay of threshold variables (d in ECT_{t-d}) is usually assumed to be one, it is conceivable to find a more significant delay. Note from model (13) that if the deviation from a LR equilibrium is less than or equal to θ, the price transmission process will occur in regime 1. If the LR deviation is greater than θ, it will be corrected in a different manner in regime 2. The hypothesis tests for APT in model (13) would be $\beta_{1j} = \beta_{2j}$, and $\sum_{j=1}^{K} \beta_{1j} = \sum_{j=1}^{K} \beta_{2j}$. In addition, it is possible to split Δp_{t-j+1}^{in} into positive and negative terms with a view to verifying SR asymmetries.

A variant of model (13) is a three-regime TVECM with one threshold. This specification would acknowledge the possibility of a 'band of non-adjustment' $(-\theta; \theta)$ for smaller deviations from the LR equilibrium (Meyer, 2004, p. 329). In this situation, only deviations outside this band will be subject to elimination. Hence, while the hypothesis tests for model (14) are similar to those for model (13), model (14) is more economically significant than model (13).

$$\Delta p_t^{out}$$
$$= \begin{cases} \alpha_1 + \sum_{j=1}^{K} \beta_{1j} \Delta p_{t-j+1}^{in} + \delta_1 ECT_{t-1} + \sum_{j=1}^{L} \gamma_{1j} \Delta p_{t-j}^{out} + \omega_t \; if \; |ECT_{t-1}| \leq \theta \\ \alpha_2 + \sum_{j=1}^{K} \beta_{2j} \Delta p_{t-j+1}^{in} + \delta_2 ECT_{t-1} + \sum_{j=1}^{L} \gamma_{2j} \Delta p_{t-j}^{out} + \omega_t \; if \; |ECT_{t-1}| > \theta \end{cases} \quad (14)$$

However, there is not any evidence that lower and upper thresholds are always equal. This leads to a more generalised model: the three-regime TVECM with two thresholds (Goodwin & Holt, 1999). This model (15) is specified as:

$$\Delta p_t^{out}$$
$$= \begin{cases} \alpha_1 + \sum_{j=1}^{K} \beta_{1j} \Delta p_{t-j+1}^{in} + \delta_1 ECT_{t-1} + \sum_{j=1}^{L} \gamma_{1j} \Delta p_{t-j}^{out} + \omega_t \; if \; ECT_{t-1} < \theta_1 \\ \alpha_2 + \sum_{j=1}^{K} \beta_{2j} \Delta p_{t-j+1}^{in} + \delta_2 ECT_{t-1} + \sum_{j=1}^{L} \gamma_{2j} \Delta p_{t-j}^{out} + \omega_t \; if \; \theta_1 \leq ECT_{t-1} \leq \theta_2 \\ \alpha_3 + \sum_{j=1}^{K} \beta_{3j} \Delta p_{t-j+1}^{in} + \delta_3 ECT_{t-1} + \sum_{j=1}^{L} \gamma_{3j} \Delta p_{t-j}^{out} + \omega_t \; if \; ECT_{t-1} > \theta_2 \end{cases} \quad (15)$$

The 'band of non-adjustment' is within $(\theta_1; \theta_2)$. The test of equal coefficients across three regimes would confirm or refute the null hypothesis of symmetry ($\beta_{1j} = \beta_{2j} = \beta_{3j}$, and $\sum_{j=1}^{K} \beta_{1j} = \sum_{j=1}^{K} \beta_{2j} = \sum_{j=1}^{K} \beta_{3j}$). Similarly, for the above threshold models, it is possible to use the partitioning technique to test a richer set of SR asymmetries.

Model (15) can be called the Equilibrium-TVECM (EQ-TVECM), which implies the correction process towards an equilibrium point within the 'band of non-adjustment' (Lo & Zivot, 2001). A variant of model (15) is the BAND-TVECM in which if ECT_{t-1} lies in the lower and upper regimes, the process adjusts to the middle regime $(\theta_1; \theta_2)$. The middle regime is characterised by a random walk model. The hypothesis test of asymmetry is somewhat similar to that for the EQ-TVECM. The equation for BAND-TVECM (16) is as follows:

$$\Delta p_t^{out} = \begin{cases} \alpha_1 + \sum_{j=1}^{K} \beta_{1j} \Delta p_{t-j+1}^{in} + \delta_1 ECT_{t-1} + \sum_{j=1}^{L} \gamma_{1j} \Delta p_{t-j}^{out} + \omega_t & if\ ECT_{t-1} < \theta_1 \\ \omega_t & if\ \theta_1 \leq ECT_{t-1} \leq \theta_2 \\ \alpha_3 + \sum_{j=1}^{K} \beta_{3j} \Delta p_{t-j+1}^{in} + \delta_3 ECT_{t-1} + \sum_{j=1}^{L} \gamma_{3j} \Delta p_{t-j}^{out} + \omega_t & if\ ECT_{t-1} > \theta_2 \end{cases} \quad (16)$$

The above-mentioned TVECMs can describe nonlinear price transmission, but they suppose a sudden switch of regimes at threshold points. Some studies showed that a gradual regime switch is more reasonable (Mainardi, 2001; Meyer & von Cramon-Taubadel, 2004). One approach to this perspective is to apply a polynomial model with *ECT*. In this regard, the models for quadratic and cubic VECMs are often utilised. If δ_2 is statistically different from 0, model (17) confirms the nonlinear price transmission process. The hypothesis test for APT would be $\beta_j^+ \neq \beta_j^-$ and $\sum_{j=1}^{P} \beta_j^+ \neq \sum_{j=1}^{N} \beta_j^-$. Likewise, there is enough evidence for nonlinearity in price transmission if δ_3 in equation (18) is statistically different from 0. The hypothesis test to detect SR asymmetries would be $\beta_j^+ \neq \beta_j^-$ and $\sum_{j=1}^{P} \beta_j^+ \neq \sum_{j=1}^{N} \beta_j^-$. However, there are no theoretical grounds for the choice of two, three, or higher order polynomials. The preference is predicated more on the data itself and the practitioners.

$$\Delta p_t^{out} = \alpha + \sum_{j=1}^{P} \beta_j^+ D_t^+ \Delta p_{t-j+1}^{in} + \sum_{j=1}^{N} \beta_j^- D_t^- \Delta p_{t-j+1}^{in} + \sum_{j=1}^{L} \gamma_j \Delta p_{t-j}^{out} + \delta_1 ECT_{t-1} + \delta_2 ECT_{t-1}^2 + \omega_t \quad (17)$$

$$\Delta p_t^{out} = \alpha + \sum_{j=1}^{P} \beta_j^+ D_t^+ \Delta p_{t-j+1}^{in} + \sum_{j=1}^{N} \beta_j^- D_t^- \Delta p_{t-j+1}^{in} + \sum_{j=1}^{L} \gamma_j \Delta p_{t-j}^{out} + \delta_1 ECT_{t-1} + \delta_2 ECT_{t-1}^2 + \delta_3 ECT_{t-1}^3 + \omega_t \quad (18)$$

There are a number of variants to empirically test for APT, in addition to the models discussed in section 3.4. Many studies dealt with the transmission of three price series for farm, wholesale, and retail levels (e.g. Goodwin & Harper, 2000; Goodwin & Holt, 1999; Griffith & Piggott, 1994; Miller & Hayenga, 2001). Some papers included the market power variable in the model investigating price

transmission (Falkowski, 2010; Peltzman, 2000). In some studies, a couple of identification variables such as exchange rates, precipitation, temperature, cloud cover, catastrophic events, and consumer price index were fitted to the model of price transmission (Gomez & Koerner, 2009; McLaren, 2015). Other authors formulated price equations from demand or supply functions to allow for demand and supply shifts in the analysis of price transmission (Han & Ahn, 2015). Lastly, it should also be noted that there are some complex developments in the methodological aspect of APT studies (Bonnet & Villas-Boas, 2016; Musumba & Gupta, 2013).

In summary, a wide range of empirical tests in the existing literature emphasize that APT has been usually method-driven with insufficient theoretical basis and economic elucidation (Meyer & von Cramon-Taubadel, 2004). Furthermore, each technique has its own advantages and disadvantages in detecting various sorts of APT. It is not true that the pre-cointegration methods are no longer applicable to APT studies. The appropriateness is mainly reliant on the properties of price series data. Finally, despite striving to cover various methods, this section is not a comprehensive collection of APT tests in the current literature.

3.5. Empirical results of APT studies

In agricultural economics, a considerable amount of literature has been published on APT. This section reviews previous studies for various agricultural products, including grain, meat, dairy, vegetables, fruits, seafood, and coffee. The background and findings of these empirical works are discussed in the following subsections. Studies for the vertical chain are presented prior to studies for the horizontal chain, and studies showing APT are reported first.

3.5.1. APT studies in the grain sector

In the grain sector, the number of APT studies seems evenly distributed across the vertical and horizontal chains. The findings of asymmetry are more frequent, especially for corn and rice.

For the vertical chain, Nakajima (2011) found APT between domestic and export prices of soybeans in the US, using monthly data from 1967 to 2010. This long time period also enabled the discovery of different asymmetries in several subsamples. The paper recognised positive APT from 1967 to 1977 and from 1989 to the latter half of the 1990s. APT was neutral or negative from 1978 to 1988 and became negative from the late 1990s onwards. The findings of different APT could be due to the decline of the US's market power worldwide when Brazil and Argentina emerged as major wheat exporters.

A vertical study by Han and Ahn (2015) provided evidence of APT in the Korean wheat market. The authors estimated the transmission of monthly prices of imported wheat and domestic wheat flour in Korea from 1993 to 2014. To account for a price surge in 2008, a subsample (from 1993 to 2008) was also analysed. Both estimations validated the finding that higher p^{in} led to a stronger price transmission to p^{out}. In particular, the whole sample was divided into three regimes in terms of the p^{in} level. The price transmission impact in regime 3, which had the highest wheat prices, was greater than that in regime 2, and that in regime 2 was larger than that in regime 1.

In the rice market, APT was present in the wholesale-retail chain and between the world and domestic markets. In an analysis in Sri Lanka, weekly wholesale and retail prices from 2005 to 2011 were employed (Korale Gedara, Ratnasiri, & Bandara, 2016). Rising prices at the wholesale level were transmitted much faster to prices at the retail level than falling prices from March 2010 onwards. This may have been caused by the price ceiling policy, which tightened retailers' margins during the period of retail price hike. As a consequence, retailers became more reluctant to decrease retail prices when wholesale prices were on the decline after March 2010. In a similar vein, price transmission between wholesale and retail levels was positively asymmetric in Bangladesh (Alam et al., 2016) with wholesalers playing the price leadership role. In addition, positive APT was also present in the transmission of world prices to domestic prices in Benin and Mali (Fiamohe, Alia, Bamba, Diagne, & Amovin-Assagba, 2015).

A further study for rice shifted its focus to the farm-mill chain, which was usually neglected in the vertical context (Sung Chul, Zapata, Salassi, & Gauthier, 2004). The authors relied on monthly prices between 1987/88 and 2001/02 and noticed only one positive LR APT in a major rice-producing state in the US. The results for the other three major states were indicative of symmetric price transmission.

For the horizontal price chain, one of the first investigations that found APT for corn and soybeans was undertaken between four markets in North Carolina (Goodwin & Piggott, 2001). Using daily prices from 1992 to 1999, Goodwin and Piggott (2001) also ascertained the significance of thresholds in the transmission process. In the models with thresholds, the adjustment for deviations from a LR equilibrium was much faster than that in models where thresholds were disregarded. Hence, this study highlighted the role of transaction costs, whose data were often not available, in price transmission, albeit in a restrictive manner.

In another study for wheat and corn, APT was found between Brazil, Argentina, and the US from 1986 to 2000 (Balcombe et al., 2007). The estimation was indicative of asymmetric adjustments in the Brazil-Argentina price pair for wheat and in the Brazil-US price pair for corn. A possible reason for APT in the Brazil-Argentina price pair is that the Mercosur, a free trade agreement among some South American countries, reinforced Brazil's inclination to import wheat from Argentina and consequently intensified the dominant role of Argentina in price transmission between the two countries. The asymmetry in the Brazil-US price pair is less interpretable. It may result from the small proportion of the traded corn from the US to Brazilian total consumption of corn.

Esposti and Listorti (2013) analysed price transmission across commodities and markets for durum wheat and corn in five markets (i.e. three in Italy, one in Canada, and one in the US). They used weekly spot prices from 2006 to 2010 which covered three stages of a price bubble period: boom, slump, and gradual recovery. They found that price transmission between commodities was much weaker than between locations. In the cross-market case, shocks in the international market were somewhat buffered in the domestic central market before being channelled to domestic secondary markets. This made price

transmission asymmetric for durum wheat and corn during periods of market bubble.

The results of spatial APT for corn were relatively consistent in some African countries. Abdulai (2000) found APT in three local corn markets in Ghana, using monthly wholesale prices from 1980 to 1997. The study offered evidence of faster transmission of price increases than price decreases from the central market to the two peripheral markets. Of the two secondary markets, the one which was more closely connected to the central market had the higher degree of price transmission. Later, APT was discovered between South African and Zambian corn markets (Myers & Jayne, 2012).

For wheat, a study was carried out between the US and other markets, including Argentina, Australia, Canada, and the EU from 1980 to 1990 (von Cramon-Taubadel & Loy, 1996). Little evidence of APT was found across these markets. Recently, a spatial analysis among five major wheat exporters also supported this result of symmetric price transmission (Goychuk & Meyers, 2014). The study detected three co-integrated price pairs, i.e. Russia-France, Russia-US, and Ukraine-France, from 2004 to 2010. It suggested that the absence of APT could result from the high competition in the global wheat market where no country could exert market power to their advantage.

There were also some results of symmetric price transmission in the grain sector. Balcombe et al. (2007) did not find enough evidence of APT between Brazil and the US for wheat and between Brazil and Argentina for corn. The reason for the Brazil-US case could be the Mercosur, which diverted the imports of wheat from the US to Argentina. The failure to find asymmetry in the Brazil-Argentina price pair might result from the trivial role of the regional trade of corn in Brazilian corn market. Another study in three corn markets in Ethiopia provided little evidence of spatial APT (Wondemu, 2015). However, this conclusion needed to be treated with caution as the study used only about 60 observed prices for a 5-year period (2008-2012). The few observations and short time span could have biased the finding.

3.5.2. APT studies in the meat sector

In the meat sector, the majority of APT studies focus on the vertical chain. The findings of symmetry and asymmetry are almost equal in number.

APT was found for the vertical chain of pork in Europe. A cointegration-based analysis was carried out for price transmission between farm and wholesale levels in northern Germany (von Cramon-Taubadel, 1998). The result attested that from 1990 to 1993, wholesalers passed on weekly price increases more rapidly to producers than price decreases. Another study undertaken in the Swiss pork market produced a similar result (Abdulai, 2002). Retail prices were more responsive to increases than decreases in farm prices for the 1988-1997 period. Price transmission was also shown to be from farm to retail levels without any evidence of it in the reverse direction.

Griffith and Piggott (1994) found some APT in Australian meat markets. The authors used monthly data for auction (comparable to farm prices), wholesale and retail prices for beef and lamb between 1971 and 1988. They estimated three equations representing farm-wholesale, farm-retail, and wholesale-retail relationships for each product. Positive APT was detected in three cases: farm-retail and wholesale-retail for beef, and wholesale-retail for lamb. More surprisingly, negative APT was present in the farm-wholesale lamb chain, suggesting favourable conditions for farmers.

Another analysis showed varied results of APT in the lamb market in Spain between 1996 and 2002 (Ben-Kaabia & Gil, 2007). It confirmed the LR symmetric transmission between farm and retail prices. However, in the SR, price transmission was asymmetric and subject to different situations. In a situation of too low margins, negative supply shocks at the farm level and negative demand shocks at the retail level were transmitted faster than the positive shocks, leading to positive APT and benefiting retailers. In a situation of too high margins, demand and supply shocks led to different scenarios. Supply shocks caused

positive APT while responses to negative and positive demand shocks were symmetric.

The broiler market in the US was largely characterised by APT. Bernard and Willett (1996) investigated the 1983-1992 period and identified the causal pricing role of wholesalers. Positive APT existed in the wholesale-farm chain in which rising wholesale prices were passed on less completely to farm prices than falling wholesale prices. In contrast, price transmission for the wholesale-retail chain was more symmetric. Only one in four sample regions exhibited positive APT between wholesale and retail levels. However, a study for a more recent period (from 1990 to 2011) verified the wholesale-retail APT in the US broiler market (Kuiper & Oude Lansink, 2013). The results also suggested that wholesalers and retailers enjoyed a certain advantage over each other for some time. Specifically, wholesalers possessed a stronger bargaining power over retailers following changes in the wholesale-retail margin in the last 10 months. Such changes worked in favour of retailers after 21 months.

Further applications into the US pork market reported different findings. Goodwin and Harper (2000) used weekly prices at three levels: farm, wholesale, and retail from 1987 to 1999. They found negligible asymmetries, which was contradictory to that of previous studies in German and Swiss pork markets (Abdulai, 2002; von Cramon-Taubadel, 1998). They also showed that price transmission ran from farm to retail levels, which was consistent with the findings in Abdulai's (2002) and von Cramon-Taubadel's (1998) studies. Later, Miller and Hayenga (2001) studied price transmission between farm, wholesale, and retail levels in the US pork market, using weekly data for the 1981-1995 period. They tested asymmetry in both the time- and frequency-domains. In the conventional time-domain, they confirmed the results of symmetric price transmission in Goodwin and Harper's (2000) study. However, they unearthed some asymmetries in the frequency-domain. In addition, a study for the 1990-2011 period showed APT in the farm-wholesale and wholesale-retail chains in the time-domain (Kuiper & Oude Lansink, 2013). The analysis also indicated that retailers (wholesalers) were more powerful than wholesalers (farmers) in the US pork market.

The results of APT for the US beef market were mixed. Goodwin and Holt (1999) focused on the vertical chain among farm, wholesale, and retail levels from 1981 to 1998. The paper concluded that price transmission could be regarded as symmetric because an asymmetry in the early period may be trivial in the economic sense. In contrast, a very recent study in the US beef market, using monthly prices between 1990 and 2014, led to different findings (Fousekis et al., 2016). It divided the three-level chain into two pairs: farm-wholesale and wholesale-retail. The results demonstrated APT in magnitude for the farm-wholesale chain and APT in both magnitude and speed for the wholesale-retail chain. The separation allowed the authors to show that processors were more advantageous relative to farmers and that retailers had some advantage in relation to processors. This inter-dominance was consistent with the results observed in Kuiper and Oude Lansink's (2013) study for the US pork market between 1990 and 2011.

There are several studies that failed to find vertical APT. In Germany, APT was not evident in the broiler industry (von Cramon-Taubadel, Loy, & Meyer, 2003), where price increases and decreases at the wholesale level were symmetrically transmitted to the retail level between 1995 and 2000. In addition, little evidence of asymmetry in the Australian pork market was realised for the relationship among farm, wholesale, and retail levels (Griffith & Piggott, 1994). Price transmission was also symmetric for beef and lamb in Australia. In particular, APT was absent in the farm-wholesale chain for beef and the farm-wholesale and farm-retail chains for lamb.

In the spatial context, Serra, Gil, and Goodwin (2006) investigated price transmission among four EU pork markets: Germany, Spain, France, and Denmark. Weekly prices from 1994 to 2004 were employed. Germany played the central role in the pair-wise analyses. The study was indicative of APT for Germany-Demark and Germany-France whereas the Germany-Spain price transmission was symmetric. The difference in price transmission can be justified by the closer proximity and higher intensity of trade flow between Germany, Denmark, and France than those between Germany and Spain. Furthermore, Germany and Spain were major pork producers, so this competition could

possibly make their price transmission more symmetric compared to those in other country pairs.

Symmetric price transmission was evidenced in some studies investigating the horizontal chain. The analysis in two Canadian regions used weekly pork prices from 1965 to 1989 (Punyawadee, Boyd, & Faminow, 1991). It concluded that price increases in the central market were generally passed on to the secondary market to the same extent as price decreases for most of the period. A minor asymmetry was observed in the period up to October 1969 when the transmission of falling prices was swifter than rising prices from the central to peripheral markets. Similarly, an early study found symmetric price transmission in the US beef market (Bailey & Brorsen, 1989). The authors used weekly prices between 1979 and 1986 in one minor and three major markets within the US. Although positive and negative lagged price changes were adjusted at different rates, their total effects were not significantly different, which implied a LR symmetric price transmission.

3.5.3. APT studies in the dairy sector

In the dairy sector, all studies reviewed in this section investigate APT vertically. The presence of asymmetry seems to dominate the results.

Empirical studies in the dairy sector dated back to Kinnucan and Forker (1987), whose paper dealt with the price relationship between farm and retail levels of four products: milk, butter, cheese, and ice cream, in the US. Monthly prices between 1971 and 1981 were used. The authors found that retail prices adjusted more slowly and to a lesser extent to decreases than to increases in farm prices, giving rise to positive APT for these products.

The farm-retail price transmission of milk was demonstrated to be asymmetric in two US cities. Lass, Adanu, and Allen (2001) investigated the period from 1982 to 1996. Deploying the same approach as that by Kinnucan and Forker (1987), they revealed the existence of APT in the SR, but did not have sufficient evidence of APT in the LR. Afterwards, the data from this study was extended until

September 2001 for further consideration (Lass, 2005). In the later analysis, the whole sample was split into two periods prior- and post-June 1997. For the prior-June 1997 period, the results were in line with the conclusions by Lass et al. (2001). For the second period, both SR and LR asymmetries were evident and positive. Put differently, retail prices of milk were more responsive to rising farm prices than to falling farm prices. The differing outcome for the two periods also implied that some structural changes in the market exerted impacts on price transmission between farm and retail levels during the 1982-2001 period.

Capps and Sherwell (2007) analysed price transmission from farm to retail levels for whole milk and 2% milk in seven US cities. They utilised monthly prices from 1994 to 2002. The Houck (1977) approach and error correction model were estimated. The results from both models were almost identical and consistent with those from previous studies in the US milk market. The Houck model confirmed APT in six cases and the error correction model found APT in five cities. In other words, responses at the retail level were dissimilar depending on increases or decreases in farm prices.

APT for dairy products was observed in several countries. As for Polish milk, price transmission between farm and retail markets was positively asymmetric from 1995 to 2007 (Bakucs, Fałkowski, & Fertő, 2012; Falkowski, 2010). Similar results were obtained for the SR and LR price relationships of milk in Greece for the 1989-2009 period (Rezitis & Reziti, 2011) and of milk and butter in Czech for the 2000-2013 period (Dudová & Bečvářová, 2015). Meanwhile, Acosta and Valdés (2014) found negative APT in the farm-wholesale chain in the Panamanian milk market. The direction of price transmission for Panamanian milk was from farmers to wholesalers for this two-decade period (1991-2011).

Studies provided mixed results of APT for some dairy products in the US. Awokuse and Wang (2009) detected asymmetry in price transmission for milk and butter for the 1987-2006 period. Retail prices responded more quickly and completely to shocks that squeezed margins than to shocks that stretched margins. Their findings were also indicative of the bidirectional flow of price information for the two products. A more recent work by Stewart and Blayney (2011) proved

the presence of APT from farm to retail levels for whole milk and cheddar cheese between 2000 and 2010. The finding for cheese differed from that of Awokuse and Wang (2009), who found that for cheese, the farm-retail chain appeared symmetric. For butter, another analysis offered evidence of symmetric price transmission between wholesalers and retailers from 1980 to 2001 (Chavas & Aashish, 2004).

Symmetric price transmission was reported in the dairy sector of several nations. Serra and Goodwin (2003) investigated price transmission of four dairy products: pasteurised milk, sterilised milk, cream caramel, and blended cheese, in Spain. From 1994 to 2010, the farm-retail asymmetry was conspicuous only for sterilised milk while the study failed to find APT for the other three products. Hungarian milk market was also characterised by the price symmetry from farm to retail levels between 1995 and 2007 (Bakucs et al., 2012). In like fashion, changes in international prices were transmitted symmetrically to domestic prices of milk in Panama from 2000 to 2011 (Acosta, Ihle, & Robles, 2014).

3.5.4. APT studies in the vegetable and fruit sector

The majority of APT studies focus on the vertical chain of vegetables and fruits. The findings of asymmetry are overwhelming.

APT held for a wide range of vegetables in the US. An early study by Ward (1982) examined the price linkage among retail, wholesale, and shipping points of 17 fresh vegetables such as carrots, celery, lettuces, cabbages, sweet corn, cucumbers, green peppers, potatoes, and tomatoes. Shipping-point prices represented spot prices at principal local points of sales or ports of entry (USDA, 2016), so they could be treated as prices at the upstream level in the vertical chain. For the relationship between shipping-point and wholesale prices, positive APT was present for all vegetables. However, price transmission between wholesalers and retailers exhibited negative asymmetry for almost all vegetables with the exception of carrots and cucumbers. Later another major study focused on nine vegetables: green beans, broccoli, cabbages, sweet corn, cucumbers, okra, green peppers, squashes, and tomatoes (Brooker, Eastwood, Carver, & Gray, 1997). The

overall result was that prices at the next level reacted asymmetrically to increases and decreases in prices at the previous level in the supply chain.

Some studies discerned asymmetries in the Dutch vegetable sector. Bunte and Peerlings (2003) found APT between farm and retail prices in the cucumber market. The Assefa et al. (2014) study proved the existence of APT for ware potatoes. Falling farm prices were partly transmitted to retail prices whilst farm price increases were passed on more completely to retail prices. Moreover, farmers' oligopoly power could deteriorate the APT which had already been influenced by the retailers' oligopsony power. In a recent study for onion and red pepper, all possible chain-wide levels including farm, wholesale, retail, import, and export were tested for APT (Verreth, Emvalomatis, Bunte, Kemp, & Oude Lansink, 2015). Asymmetries were present in the farm-wholesale, import-farm, and export-farm chains for onions and in the farm-retail chain for red peppers between 2005 and 2008.

Powers (1995) found mixed results of price transmission for iceberg lettuce among free-on-board (FOB), wholesale, and retail levels. The author used weekly prices in a number of US cities from 1986 to 1992. The first result was that wholesale prices reacted symmetrically in both speed and magnitude to FOB price increases and decreases. Secondly, the wholesale-retail price transmission was a mixture of symmetry and asymmetry. Half of the cases showed timely responses while in the other half, APT in speed was present. Retail prices seemed respond to a slightly larger extent to rising wholesale prices than to falling wholesale prices in all cities. Thirdly, APT existed between FOB and retail levels. In short, wholesale prices moved in tandem with changes in FOB prices whereas retail prices were more responsive to price increases than to price decreases at the upstream levels (FOB and wholesale).

In the US tomato market, the results of price transmission were not homogeneous. Price transmission was symmetric between shipping-point and retail levels from 1988 to 1996 (Parrott, Eastwood, & Brooker, 2001). One probable reason was the retailers' direct purchase of fresh tomatoes from farmers, eliminating middlemen in the supply chain and facilitating timely price adjustments. A study for the

earlier period of 1970-1988 detected both symmetry and asymmetry (Girapunthong, VanSickle, & Renwick, 2003). In particular, wholesale prices were more responsive to farm price decreases than to price increases while retail prices responded more rapidly to rises than to falls in prices at the wholesale level. In contrast, the farm-retail chain was symmetric. The study also confirmed the one-way price transmission between farm, wholesale, and retail levels.

Mixed findings of APT were observed in the French tomato and chicory markets (Hassan & Simioni, 2002). Not only did the study categorise the two products according to their variety, grade, area of production, and packaging, but it also estimated price transmission at different aggregate levels: national, regional, and store level. Shipping-point prices were weekly and collected in seven growing regions. Retail prices were obtained from 150 supermarkets of 21 store chains. In total, Hassan and Simioni (2002) tested 42 price relationships: 22 for tomatoes and 20 for chicory. Positive APT was present in seven cases whereas negative APT held for 11 cases. The majority of cases (24), however, were symmetric.

Price transmission between wholesale peanuts and peanut butter was asymmetric in the SR (Zhang, Fletcher, & Carley, 1995). Using monthly prices in the US from 1984 to 1992, the authors found that the adjustment process at the retail level to falling peanut prices occurred four months later than it did to rising peanut prices. However, prices of peanut butter reacted symmetrically to increases and decreases in peanut prices in the LR. This study also confirmed the unidirectional causal relationship from peanuts to peanut butter.

In the only spatial study for vegetables, price transmission was asymmetric in Europe (Santeramo, 2015). Prices for tomatoes and cauliflowers were collected on a weekly basis from 1996 to 2006. Tomatoes in four countries were investigated, generating five price pairs (i.e. France-Spain, Ireland-Spain, UK-Spain, Ireland-France, and UK-France). Of these five pairs, four pairs except the Ireland-France pair was characterised by asymmetric price transmission. For cauliflowers, the Netherlands market replaced France in the analysis. APT was present in four out of five pairs.

Another study showed APT in the US apple market for the year between the 1975/76 and 1990/91 crop years (Willett, Hansmire, & Bernard, 1997). The vertical chain between shipping point, wholesale, and retail levels was analysed in three apple-growing regions: West, North Central, and Northeast. Price transmission for the shipping-point-wholesale and wholesale-retail chains was asymmetric in all regions. For the shipping-point-retail chain, APT existed only in the North Central region.

Acharya, Kinnucan, and Caudill (2011) considered the seasonality of price transmission and evaluated the farm-retail chain of US fresh strawberries in two distinct seasons. The results for the two seasons were different for the 1980-1998 period. In the off-peak season, responses at the retail level to rising and falling farm prices were insignificantly different in the SR and LR. However, in the peak-harvesting season, this price transmission became asymmetric. This study also implied that the impact of market power on price transmission could be seasonal. Retailers were able to exercise market power in times of temporary supply surpluses. Their ability to do so waned as strawberries went out of season.

3.5.5. APT studies in the fishery sector

APT studies for seafood products seem less extensive than for other agricultural sectors. Almost all investigations focus on the vertical chain and the findings of asymmetry are more common.

Price transmission was asymmetric for several French seafood products. A study examined two supply chains of North Atlantic wild cod and imported Atlantic salmon from 1988 to 1999 (Gonzales, Guillotreau, Grel, & Simioni, 2003). Asymmetry existed in both chains and were opposite in nature: positive APT for wild-harvested cod and negative APT for imported Atlantic salmon. A probable explanation for this contradiction was the uncertainty of supply. For imported Atlantic salmon, the production could be adjusted more easily, so retailers could pass on farm price decreases more quickly to gain more sales. For wild-harvested cod, the supply was dependent on natural conditions and, therefore, retailers might not meet the increased demand if they reduce retail prices following a fall in farm

prices. Over the almost same period (1989-1999), the result for French hake was similar (Jaffry, 2004). Retail prices adjusted to both positive and negative shocks at the wholesale level, but to a greater extent for negative shocks. Meanwhile, auction/wholesale prices only responded to positive shocks at the retail level.

The findings of asymmetry in the fishery sector were mixed in some countries. In Bangladesh, some APT was found in the wholesale-retail chain for five fish products: hilsa, rohu, catla, pangas, and tilapia (Sapkota, Dey, Alam, & Singh, 2015). The study analysed 18 price pairs in four regions from 2005 to 2010. As a result, five pairs exhibited APT in the SR while there were 13 pairs having APT in the LR. In addition, the causal price relationship ran from retail to wholesale levels. The results in Thailand varied from species to species (Singh, Dey, Laowapong, & Bastola, 2015). From 2001 to 2010, APT was present for Asian sea bass in the LR and SR and for walking catfish in the LR only. For vannamei shrimp and tilapia, the study did not find enough evidence of asymmetry. In Uganda, price transmission differed among the levels in the catfish supply chain between 2006 and 2013 (Bukenya & Ssebisubi, 2015). APT was absent for the ex-vessel-retail and wholesale-retail chains. In contrast, the transmission between ex-vessel and wholesale prices was asymmetric. Likewise the study in Bangladesh, the price flow originated at the retail level and ran to wholesale and ex-vessel levels.

3.5.6. APT studies in the coffee sector

In the coffee sector, APT studies have been conducted for two main varieties: Robusta and Arabica coffee. The findings of APT between world and domestic markets for the two cultivars have been slightly different from each other in coffee-growing countries. For Arabica coffee, price transmission was reported to be both symmetric and asymmetric. Price increases and decreases in the world market were transmitted similarly to domestic prices in Colombia, India, and Mexico (González, 2007). In contrast, falling prices were passed on faster than rising prices in some Arabica coffee producers such as Ethiopia, Kenya, Tanzania, and Zambia (Mofya-Mukuka & Abdulai, 2013; Worako et al., 2013). The

Brazilian coffee bean sector demonstrated an opposing characteristic, namely negative APT from world prices to farm prices.

With regard to Robusta coffee, the evidence of APT has been more obvious between domestic and world markets. In González's (2007) extensive study, APT was found in Madagascar, Cameroon, Angola, and Central African Republic. The presence of APT was also shown in the Ugandan coffee sector because small occasional traders interrupted the supply chain between coffee farmers and permanent traders in times of world price hike (Fafchamps & Hill, 2008). Only in Togo did the prices of Robusta coffee transmit symmetrically.

The transmission between international prices of coffee beans and retail prices of roasted coffee was asymmetric (Bonnet & Villas-Boas, 2016; Gomez & Koerner, 2009). In main markets including France, Germany, and the US, global and retail prices both had significant instantaneous and lagged effects over each other, and such impacts differed according to price increases or decreases. A similar result of APT was also evident for soluble coffee in Brazil, which was also a major consumer of coffee (Aguiar & Santana, 2002).

Some research has delved into the nonlinearity and the direction of the adjustment along the coffee supply chain. Several papers found non-trivial threshold effects and took them into account when investigating APT (Lee & Gomez, 2011, 2013; Worako et al., 2013). Other papers provided different results of the direction of price flow among chain-wide agents. Gomez and Koerner (2009) confirmed a two-way relationship from retail prices to international prices in the US, but identified a one-way relationship in France and Germany. In addition, Alemu and Worako (2011) and Worako et al. (2013) also revealed a unidirectional transmission from world prices, to auction prices, and to farm prices in Ethiopia. The differences in price transmission may be dependent on the market structure of the coffee sector in each nation.

Another focus of the existing literature on APT in the coffee sector has been on the impact of liberalisation policies. These policies can be divided into two main groups: the end of the International Coffee Agreement (ICA) in 1990 on the

global scale, and market reforms during the late 1980s and early 1990s at the national level. Their impacts were somewhat intertwined due to their coincident occurrence. Firstly, after the termination of the ICA, price transmission seemed to improve between producers and international markets, and between international and importing markets (Gomez & Koerner, 2009; Lee & Gomez, 2013; Mehta & Chavas, 2008). However, Mehta and Chavas (2008) also found little evidence of APT for the relationship between Brazilian farm prices and US wholesale prices during the post-ICA period.

Secondly, after the implementation of market reforms, there was an improvement in price transmission in coffee-growing countries (González, 2007; Mofya-Mukuka & Abdulai, 2013; Musumba & Gupta, 2013; Worako et al., 2013). The impacts were more noticeable and significant in the group of countries whose market liberalisation was of the highest degree. Finally, the González (2007) study also indicated that the transmission remained largely asymmetric between producer prices and world prices after the reforms.

To date there is only one study examining price transmission for Vietnam's Robusta coffee (Li & Saghaian, 2013). The authors, using monthly prices from 1990 to 2011, indicated that about 44% of a deviation from the LR equilibrium value was corrected in farm prices in one month while world prices did not respond to the LR disequilibrium. However, their analysis had some methodological limitations. Firstly, it did not investigate different responses to rising and falling prices in the SR and LR. Secondly, it did not take into account the nonlinear adjustment probably caused by transaction costs and other price frictions.

This research aims to address the limitations of Li and Saghaian's (2013) study and to analyse the transmission between farmgate and export prices of Vietnam's Robusta coffee. It employs daily prices which are of higher frequency and are better at capturing the price dynamics. In addition, the price data used in this research is for a more recent time period, from mid-2011 until the end of 2015.

This chapter has reviewed the literature on APT in terms of theories, methods, and empirical findings. Previous APT studies for agricultural products other than coffee can be classified according to some main sectors: grain, meat, dairy, vegetables and fruits, and fishery. Grain and meat sectors captured more attention of agricultural economists than the other three. The majority of studies dealt with the US, followed by the European market. A smaller proportion of the literature investigated farm produce in Australia, Canada, some African and Asian countries. Additionally, the presence of APT was more frequent, but was subject to the products in question, geographic locations, estimation methods, assumptions of the adjustment process, time horizons, and data frequency. For coffee, many studies were undertaken, but only one concerned Vietnam's coffee sector despite Vietnam's importance in the world coffee market. This gap in the literature gives grounds for the research undertaken in this thesis. The next chapter will detail the methods used in this research to evaluate price transmission for Vietnam's Robusta coffee.

Chapter Four: METHODS

The richness of literature on APT reviewed in the previous chapter provides evidence of the importance of this subject in agricultural economics. The studies on APT have provided insights into the relationship among separate markets either horizontally or vertically (Meyer, 2004; Vavra & Goodwin, 2005). Hence, it is necessary to have adequate methods to empirically examine the asymmetry in the price transmission process.

As demonstrated in section 3.4 there has been little consensus as to which methods are inferior or superior. However, Meyer and von Cramon-Taubadel (2004) remarked that the cointegration-based approach was more suitable than the pre-cointegration approach because the former adequately handled the nonstationary property of the price data. Therefore, this research takes the cointegration-based approach and employs the VECM to evaluate the transmission between farmgate and export prices for Robusta coffee in Vietnam.

The purpose of this chapter is to present the detailed procedures for the estimation of VECMs and for the test for any APT in the LR and SR. The first section illustrates the Augmented Dickey-Fuller (ADF) and KPSS tests, which are used to determine the order of integration of export and farmgate prices. The second section describes the Engle-Granger method and the Johansen test for cointegration of the two price series. The results from these first two sections provide the necessary conditions to apply the linear and threshold VECMs to test for any asymmetries in price transmission. The third section expresses the system of linear VECMs for export and farmgate prices on the assumption of linear adjustment. This also briefly outlines how to estimate the linear system and the tests used to detect asymmetries afterwards. The fourth section introduces the system of threshold VECMs for export and farmgate prices on the assumption of nonlinear adjustment. This first introduces Tsay's (1989) test for nonlinearity and then discusses how to estimate the system of threshold VECMs and to discern any APT in the SR.

4.1. Test of integration

The property of export and farmgate prices of coffee that first needs to be verified is their order of integration. If the two price series are integrated of order zero, I(0), then they are said to be stationary and the pre-cointegration approach remains appropriate. If the two price series are integrated of higher order, I(n) (n > 0), then they are deemed to be nonstationary. In this situation, the cointegration-based approach may be fitting whereas the pre-cointegration approach is not suitable as it could lead to spurious regression (as discussed in section 3.4).

This section outlines the ADF and KPSS tests, which are common methods for integration. The ADF test has the null hypothesis of nonstationarity while the KPSS test the opposite null hypothesis of stationarity. The ADF and KPSS tests are first applied to export and farmgate prices and then to their first differences.

4.1.1. Augmented Dickey-Fuller test

This research uses the ADF tests with and without a constant to check whether export (EP_t) and farmgate prices (FP_t) are stationary. The similar procedure is also applied to the first differences of the two price series. If the ADF test confirms the stationarity of the two price series, they are integrated of order zero. If the reverse is true and the ADF test verifies the stationarity of the first differences of the two price series, they are integrated of order one, I(1).

The ADF tests with and without a constant are illustrated for export prices (EP_t) as follows. EP_t can be expressed in one of the two equations:

$$EP_t = a_1 EP_{t-1} + \varepsilon_t \quad (19)$$

$$EP_t = a_0 + a_1 EP_{t-1} + \varepsilon_t \quad (20)$$

where t = 1, 2, …, T;

ε_t is white noise error terms.

If a_1 = 1, then equation (19) is known as a random walk model and equation (20) as a random walk model with drift. If a_1 < 1, EP_t is said to be stationary. These two equations are transformed and incorporate lagged values of ΔEP_t to obtain:

$$\Delta EP_t = \gamma_1 EP_{t-1} + \sum_{j=1}^{m} \delta_j \Delta EP_{t-j} + \varepsilon_t \quad (21)$$

$$\Delta EP_t = a_0 + \gamma_1 EP_{t-1} + \sum_{j=1}^{m} \delta_j \Delta EP_{t-j} + \varepsilon_t \quad (22)$$

where $\gamma_1 = a_1 - 1$;

m is the number of lags selected according to the Bayesian Information Criterion (BIC);

ΔEP_{t-j} is the j[th] lagged value of ΔEP_t.

The hypothesis of the ADF tests with and without a constant becomew:

$$H_0: \gamma_1 = 0$$
$$H_A: \gamma_1 < 0 \quad (23)$$

The regression models (21) and (22) are run and the t-type test statistic for γ_1 is calculated.

$$t_1 = \frac{\widehat{\gamma_1}}{ss\widehat{\gamma_1}} \quad (24)$$

where $\widehat{\gamma_1}$ is the estimate of γ_1;

$ss\widehat{\gamma_1}$ is the standard error of $\widehat{\gamma_1}$.

If $t_1 < t^c$ (a critical value at a certain significance level, e.g. t^c = -1.95 at the 5% significance level), then the null hypothesis of nonstationarity ($H_0: \gamma_1 = 0$ in (23)) is rejected, which implies that EP_t is stationary. EP_t does not show any tendency to deviate from a LR equilibrium or a linear deterministic trend.

4.1.2. KPSS test

This research uses the KPSS test to verify the order of integration of export and farmgate prices (Kwiatkowski, Phillips, Schmidt, & Shin, 1992). In contrast to the ADF test, the null hypothesis of the KPSS test is a stationary time series. In addition, the KPSS test is more effective than the ADF test in determining the stationarity of time series whose roots are close to unity in absolute terms (Enders, 2015). Therefore, the results from the KPSS test reinforce the findings of stationarity or nonstationarity from the ADF test.

The KPSS test is applied to both export and farmgate prices. The first differences of export and farmgate prices are also checked for integration with the KPSS test. Consider again EP_t as an illustration of the way to apply the KPSS test. EP_t can be decomposed into a deterministic trend, a random walk, and a stationary error term.

$$EP_t = \xi t + r_t + \varepsilon_t \tag{25}$$

where r_t is a random walk, $r_t = r_{t-1} + u_t$;

u_t is an i.i.d.[1] sequence with (0, σ_u^2);

initial value r_0 is fixed and corresponds to the intercept in model (25).

The pair of hypotheses of the KPSS test is expressed as:

$$\begin{aligned} H_0&: \sigma_u^2 = 0 \\ H_A&: \sigma_u^2 > 0 \end{aligned} \tag{26}$$

If $\xi = 0$, then equation (25) becomes the special case and the null hypothesis in (26) is of level-stationarity. If $\xi \neq 0$, the null hypothesis in (26) is of trend-stationarity. Equation (25) is estimated and the Lagrange Multiplier (LM) test statistic for the hypothesis test in (26) is calculated.

$$LM = \frac{\sum_{t=1}^{T} S_t^2}{\hat{\sigma}_\varepsilon^2} \tag{27}$$

where S_t is the partial sum of residuals from equation (25), $S_t = \sum_{i=1}^{t} \hat{\varepsilon}_i$;

$\hat{\sigma}_\varepsilon^2$ is the estimate of the error variance from equation (25), which can be calculated by using the Bartlett window as suggested by Kwiatkowski et al. (1992).

If $LM > LM^c$ (a critical value at a certain significance level, e.g. LM^c = 0.46 at the 5% significance level), then the null hypothesis of stationarity (H_0: $\sigma_u^2 = 0$ in (26)) is rejected and EP_t can be seen as a nonstationary series. EP_t tends not to revert to a LR equilibrium or trend.

4.2. Test of cointegration

This section presents the Engle-Granger and the Johansen methods for checking the cointegration of export and farmgate prices. The Engle-Granger method is easy to carry out, but contains some defects (Enders, 2015). The Johansen test, albeit more complicated, is more effective in determining the cointegrating vector

[1] i.i.d.: identically and independently distributed

between the two price series. The results from the two methods provide a more accurate information about whether export and farmgate prices are cointegrated.

4.2.1. Engle-Granger method

The Engle-Granger (1987) method is used to test for cointegration between export and farmgate prices. The first step is to estimate the LR relationship in equation (28). This is done for the reason that if the two prices are cointegrated, the estimation in equation (28) will provide a 'super-consistent' estimate of the cointegrating vector (Enders, 2015, p. 361). In this equation, EP_t are assumed to influence FP_t as coffee producers tend to be price takers in the global coffee market (as cited in González, 2007).

$$FP_t = \beta_0 + \beta_1 EP_t + e_t \tag{28}$$

In the second step, the ADF test is applied to the $\hat{e}_t$ series from equation (28) to determine whether it is stationary or not. If $\hat{e}_t$ is a unit root process, then EP_t and FP_t are not cointegrated. Otherwise, they are cointegrated. Another point to note is that the critical values of the ADF test for cointegration are different from those of the ADF test for integration.

4.2.2. Johansen test

The Johansen test (Johansen, 1988, 1992a, 1992b; Johansen & Juselius, 1990) is applied to ascertain the cointegration between export and farmgate prices. In this test, two test statistics are calculated from the eigenvalues or characteristic roots of matrix on canonical correlations (π). The first figure is trace statistic. The null hypothesis for equation (29) is that the number of cointegrating vectors is less than or equal to r. The alternative hypothesis is of greater than r cointegration relations. The second value is max statistic (equation (30)). The hypothesis test is r cointegrating vectors against (r + 1) cointegrating vectors. If test statistics are greater than the critical values, then the null hypothesis is rejected. The results from both trace and max hypothesis tests would determine the number of distinct cointegrating vectors.

$$\lambda_{trace}(r) = -T \sum_{i=r+1}^{n} \ln(1 - \hat{\lambda}_i) \tag{29}$$

$$\lambda_{max}(r, r+1) = -T \ln(1 - \hat{\lambda}_{r+1}) \quad (30)$$

where $\hat{\lambda}_i$ is an estimate of characteristic roots of matrix π;

r is the number of distinct cointegrating vectors.

4.3. Estimation of VECMs

After the cointegration of export and farmgate prices is confirmed, the linear VECM is estimated on the assumption of linear adjustment. A single linear VECM for the transmission between export and farmgate prices is a restrictive assumption because the two price series can interact with each other, making a simultaneous equation system more accurate (Gomez & Koerner, 2009). Within this system, each equation is similar to the linear VECM expressed in equation (10) with p_t^{out} and p_t^{in} being FP_t and EP_t respectively and vice versa. The lag length is one according to the BIC (Lee & Gomez, 2011). Since the error terms in the system reflecting the relationship between export and farmgate prices are not independent, the Seemingly Unrelated Regression (SUR) (Zellner, 1962) is employed instead of the Ordinary Least Squares (OLS) method. The system of linear VECMs is:

$$\begin{aligned}\Delta EP_t &= \alpha_y + \beta_{1y}^{+}\Delta FP_t^{+} + \beta_{1y}^{-}\Delta FP_t^{-} + \beta_{2y}^{+}\Delta FP_{t-1}^{+} + \beta_{2y}^{-}\Delta FP_{t-1}^{-} \\ &\quad + \delta_y^{+} ECT_{t-1}^{+} + \delta_y^{-} ECT_{t-1}^{-} + \gamma_{1y}\Delta EP_{t-1} + \omega_{ty} \\ \Delta FP_t &= \alpha_x + \beta_{1x}^{+}\Delta EP_t^{+} + \beta_{1x}^{-}\Delta EP_t^{-} + \beta_{2x}^{+}\Delta EP_{t-1}^{+} + \beta_{2x}^{-}\Delta EP_{t-1}^{-} \\ &\quad + \delta_x^{+} ECT_{t-1}^{+} + \delta_x^{-} ECT_{t-1}^{-} + \gamma_{1x}\Delta FP_{t-1} + \omega_{tx}\end{aligned} \quad (31)$$

Subsequently, the two different sets of tests are carried out. The first is the test for equal coefficients of partitioning ECT_{t-1} and differences of EP_t or FP_t series. If the coefficients of ECT_{t-1}^{+} and ECT_{t-1}^{-} are equal, then asymmetry in the LR is not present. The coefficients for the following pairs: (ΔFP_t^{+}, ΔFP_t^{-}), (ΔFP_{t-1}^{+}, ΔFP_{t-1}^{-}), (ΔEP_t^{+}, ΔEP_t^{-}), and (ΔEP_{t-1}^{+}, ΔEP_{t-1}^{-}) are tested for equality in order to detect APT in the SR. The second set is the test for weak exogeneity of cointegrating equations. If only one price series is not weakly exogenous, the adjustment towards the LR equilibrium will occur in only one direction. If both price series are not characterised by weak exogeneity, there will exist "feedback relationships" between them (Gomez & Koerner, 2009, p. 15).

4.4. Estimation of TVECMs

The estimation of TVECMs has four sequential stages. The procedure begins with Tsay's (1989) test to examine whether the threshold effect is present in the transmission process between export and farmgate prices. Once Tsay's (1989) test confirms the nonlinear effect, the estimation of the threshold model becomes valid. With the assumption of two thresholds in a three-regime TVECM (as explained in section 3.4.2), the lower and upper thresholds (θ_1 and θ_2) are calculated by using the two-dimensional grid search based on the minimum sum of squared residual criterion (Goodwin & Harper, 2000; Goodwin & Piggott, 2001). At the next stage, the Hansen's (1997) approach is deployed to check whether the coefficients across three regimes are statistically different or not. If the Hansen's (1997) approach verifies the significance of the optimal thresholds, they will be used to re-compute the system of TVECMs, expressed in (36), by the SUR method (Zellner, 1962).

Firstly, the research uses the extended version of Tsay's (1989) test, which was developed by Balke and Fomby (1997) for the cointegration framework. The cointegrated time series contain threshold effects if their *ECT* are characterised by a threshold autoregressive process (TAR). In particular, the transmission between export and farmgate prices is nonlinear if Tsay's (1989) test provides evidence of nonlinearity of the e_t (a.k.a. *ECT*) from equation (28).

The procedure for Tsay's (1989) test includes the following steps. The standard autoregressive model (AR(1)) of e_t is expressed as:

$$e_t = p_0 + p_1 e_{t-1} + \varepsilon_t \tag{32}$$

where ε_t is white noise error terms.

Consider each combination of (e_t, 1, e_{t-1}) as a case of data for the AR(1) model. These cases are rearranged according to e_{t-1}, which refers to the concept of arranged autoregression. Both ascending and descending orders are applied as a matter of practice (Obstfeld & Taylor, 1997). After that, standardised recursive predictive residuals ($\widehat{sa}_i$) are estimated by regressing model (32) for the first *m*

cases[2] and then for sequentially updated cases by adding a single new case. The $\widehat{sa}_i$ are used for the estimation of the model (33) and the F_1 test statistic is calculated as in equation (34). The F_1 test statistic approximately follows an F distribution with (p + 1) and (T – d – p – h – m) degree of freedom. Hence, if $F_1 > F^{p+1}_{T-d-p-h-m}$, then there is enough evidence of threshold effects for the cointegration between export and farmgate prices.

$$\widehat{sa}_i = q_0 + q_1 e_{i-1} + \omega_i \tag{33}$$

where i = m+1, …, T.

$$F_1 = \frac{(\sum \widehat{sa}_i^2 - \sum \widehat{\omega}_i^2)/(p+1)}{\sum \widehat{\omega}_i^2 /(T-d-p-h-m)} \tag{34}$$

where p is the order of autoregression in equation (32);

d is the delay of the threshold variable (e_{t-1});

$h = max\{1, p+1-d\}$;

Secondly, the lower and upper thresholds (θ_1 and θ_2) are selected among *ECT* by the two-dimensional grid search. θ_1 and θ_2 are assumed to be one of the negative and positive *ECT*, respectively. Besides, θ_1 and θ_2 need to ensure a sufficient number of observations per regime, specifically about 10% (120 observations) in this research (Hansen, 1999).

Another point about the selection of θ_1 and θ_2 is the computational complexity. The trial of every possible combination of (θ_1, θ_2) may become burdensome when the data are large. In order to avoid this problem, the research used the algorithm introduced by Balke and Fomby (1997). This algorithm searches the first potentially optimal threshold, and then finds the second potentially optimal threshold with the first threshold being fixed. After several iterations, this algorithm produces reasonably optimal thresholds while substantially cutting the number of calculations.

Thirdly, once two optimal thresholds are pinpointed, two TVECMs similar to equation (15) are estimated with p_t^{out} being FP_t and EP_t. The appropriate lag length is one according to the BIC. The modified approach of Hansen (1997) was

[2] The initial sample often includes 30 cases.

applied to test the significance of differences in coefficients across three regimes. Letting S_1 and S_3 denote the sum of squared residuals of model (9) and (15) (the linear VECM and three-regime TVECM, respectively), the sup-F test statistic is calculated as:

$$F_{13} = T\frac{S_1 - S_3}{S_3} \tag{35}$$

The sup-F test statistic has a nonstandard distribution (Hansen, 1996), so the simulation method is used to identify appropriate critical values (Hansen, 1997). In each simulated sample, the dependent variable is replaced by a standard normal random draw. After, the optimal thresholds are determined and the corresponding sup-F test statistic is computed. The asymptotic p-value of F_{13} is approximately the percentage of test statistics exceeding F_{13} in simulated samples[3].

If the differences in coefficients across three regimes of a TVECM are significant, then the estimation of TVECM is reasonable. As is the case for the linear VECM, a simultaneous equation system of TVECMs is more appropriate than a single TVECM. Within this system (36), each term for differences and lagged differences of export and farmgate prices is split into positive and negative terms. The SUR method (Zellner, 1962) is employed to account for the interdependence between export and farmgate prices. Subsequently, the test for equal coefficients of (ΔFP_t^+, ΔFP_t^-), (ΔFP_{t-1}^+, ΔFP_{t-1}^-), (ΔEP_t^+, ΔEP_t^-), and (ΔEP_{t-1}^+, ΔEP_{t-1}^-) is applied to test for APT in the SR.

$$\Delta EP_t = \begin{cases} \alpha_{1y} + \beta_{11y}^+\Delta FP_t^+ + \beta_{11y}^-\Delta FP_t^- + \beta_{12y}^+\Delta FP_{t-1}^+ + \beta_{12y}^-\Delta FP_{t-1}^- \\ \quad +\delta_{1y}ECT_{t-1} + \gamma_{1y}\Delta EP_{t-1} + \omega_{ty} \; if \; ECT_{t-1} < \theta_1 \\ \alpha_{2y} + \beta_{21y}^+\Delta FP_t^+ + \beta_{21y}^-\Delta FP_t^- + \beta_{22y}^+\Delta FP_{t-1}^+ + \beta_{22y}^-\Delta FP_{t-1}^- \\ \quad +\delta_{2y}ECT_{t-1} + \gamma_{2y}\Delta EP_{t-1} + \omega_{ty} \; if \; \theta_1 \le ECT_{t-1} \le \theta_2 \\ \alpha_{3y} + \beta_{31y}^+\Delta FP_t^+ + \beta_{31y}^-\Delta FP_t^- + \beta_{32y}^+\Delta FP_{t-1}^+ + \beta_{32y}^-\Delta FP_{t-1}^- \\ \quad +\delta_{3y}ECT_{t-1} + \gamma_{3y}\Delta EP_{t-1} + \omega_{ty} \; if \; ECT_{t-1} > \theta_2 \end{cases} \tag{36}$$

[3] If ω_t from model (9) is conditionally heteroskedastic, a heteroskedasticity-consistent Wald test statistic should be used instead (Hansen, 1997). See Appendix 1 for detail.

$$\Delta FP_t = \begin{cases} \alpha_{1x} + \beta_{11x}^{+}\Delta EP_t^{+} + \beta_{11x}^{-}\Delta EP_t^{-} + \beta_{12x}^{+}\Delta EP_{t-1}^{+} + \beta_{12x}^{-}\Delta EP_{t-1}^{-} \\ \quad +\delta_{1x}ECT_{t-1} + \gamma_{1x}\Delta FP_{t-1} + \omega_{tx}\ if\ ECT_{t-1} < \theta_1 \\ \alpha_{2x} + \beta_{21x}^{+}\Delta EP_t^{+} + \beta_{21x}^{-}\Delta EP_t^{-} + \beta_{22x}^{+}\Delta EP_{t-1}^{+} + \beta_{22x}^{-}\Delta EP_{t-1}^{-} \\ \quad +\delta_{2x}ECT_{t-1} + \gamma_{2x}\Delta FP_{t-1} + \omega_{tx}\ if\ \theta_1 \le ECT_{t-1} \le \theta_2 \\ \alpha_{3x} + \beta_{31x}^{+}\Delta EP_t^{+} + \beta_{31x}^{-}\Delta EP_t^{-} + \beta_{32x}^{+}\Delta EP_{t-1}^{+} + \beta_{32x}^{-}\Delta EP_{t-1}^{-} \\ \quad +\delta_{3x}ECT_{t-1} + \gamma_{3x}\Delta FP_{t-1} + \omega_{tx}\ if\ ECT_{t-1} > \theta_2 \end{cases}$$

This chapter presented how to analyse the coffee price data in order to detect any SR and LR APT on the assumption of linear and nonlinear adjustment. First of all, it is necessary to test for integration and cointegration of export and farmgate prices. After that, the systems of linear and threshold VECMs are estimated and the test for APT are carried out. The next chapter will describe the coffee price data and report the results of methods and tests in this chapter applied to the data.

Chapter Five: DATA DESCRIPTION, RESULTS AND DISCUSSIONS

Having discussed the methods to be used in this research, the purpose of this chapter is to describe the price data used, report the results from the data analysis, and discuss implications with respect to the literature. The results section begins with the integration and cointegration of export and farmgate prices. This is followed by summaries of APT in the linear VECMs and finishes with a focus on detecting APT in the threshold VECMs.

5.1. Data description

The data used for the research are the export and farmgate prices of Robusta coffee beans on a daily basis from June 1st, 2011 to December 31st, 2015, obtained from the Ministry of Agriculture and Rural Development in Vietnam. Export prices (EP_t) are denominated in US dollars (USD) per tonne and quoted on the FOB basis in Ho Chi Minh city, the commercial hub for Vietnam exports. Farmgate prices (FP_t) are expressed in Vietnam dongs (VND) and were collected in Dak Lak, which is the largest coffee-producing province in Vietnam. Farmgate prices are converted into USD by using the average daily exchange rate from Bloomberg (2016). The two price series are transformed into natural logarithms, which is the usual practice to alleviate the fluctuation of price series.

The total number of observations in the data set is 1197. Around 90 export prices and 220 farmgate prices were missing. The way to fix the missing values is twofold. Firstly, if there was only one missing value, it was replaced by the average of its previous and next observed values. Secondly, if there were more than two consecutive missing values, replacements were generated by using the AR(2) model for one-step-ahead forecasts as suggested by Wooldridge (2009) for I(1) time series.

As shown in Figure 14, fluctuations in export and farmgate prices almost mirrored each other as they followed an overall downward trend over the period. Export prices were generally higher than farmgate prices except in the early period. The

two price series decreased sharply from over 2,500 USD/tonne to below 2,000 USD/tonne in the second half of 2011, then steadily recovered, but by the end of 2012 they had once again headed down to their previous low. They rose gradually over the next few months, but plunged to around 1,500 USD/tonne in November, 2013. Early 2014 saw a rise in both prices, however, both series were on the decline for the remainder of the period.

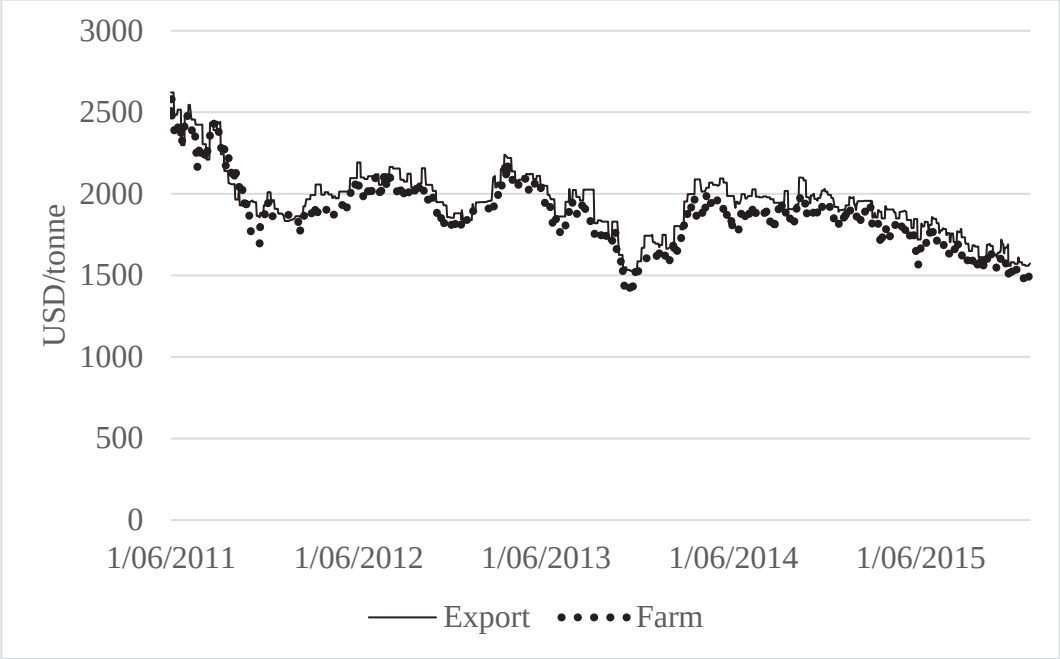

Figure 14: Daily coffee export and farmgate prices from 6/2011 to 12/2015

5.2. Results and discussions

Prior to applying the linear and threshold VECMs to detect the existence of any APT in the SR or the LR, the data are tested for integration and cointegration. The results of these tests are presented in the subsections which follow. All tests and models are computed using the R language and statistical computing environment (R Development Core Team, 2016) and other packages including urca, systemfit, vars, lmtest, and zoo (Henningsen & Hamann, 2007; Pfaff, 2008a, 2008b; Zeileis & Grothendieck, 2005; Zeileis & Hothorn, 2002).

5.2.1. Results of integration

The results from the ADF and KPSS tests for export and farmgate prices are presented in Table 1.

Table 1: Results of stationarity tests for export and farmgate prices

Tests		Critical values	EP_t	FP_t
ADF	with constant	-2.86	-2.96** [1]	-2.80 [1]
	no constant	-1.95	-1.09 [1]	-1.25 [1]
KPSS	no linear trend	0.463	5.39*** [7]	6.49*** [7]

Notes: *** and ** denote the 1% and 5% significance level respectively. Critical values are at the 5% significance level. The numbers in square brackets represent the lag length chosen based on the respective criterion for ADF and KPSS tests.

For export prices, the statistic of the ADF test without a constant is not statistically significant (Table 1). This means that EP_t is said to be a random walk without drift. This result is contrary to that of the ADF test with a constant whose result provides enough evidence that EP_t is a random walk with drift. Besides, the KPSS test statistic of 5.39 is greater than the critical value of 0.463, rejecting the null hypothesis of stationarity for EP_t. The contradictory results from the ADF and KPSS tests for EP_t are not entirely unexpected. This quandary frequently occurs in series whose roots are close to unity (in absolute terms) (Enders, 2015). In this situation, the KPSS test tends to be more powerful than the ADF test. For this reason, EP_t is nonstationary.

The results of integration for the farmgate price series are more consistent (Table 1). The test statistics of the ADF test with and without a constant are not significant (-2.8 and -1.25 respectively). Put simply, FP_t exhibit the nonstationary property according to the ADF tests. This is also validated by the KPSS test. As shown in Table 1, the test statistic is 6.49 and highly significant, leading to the rejection of the null hypothesis of stationarity. Therefore, FP_t is nonstationary.

The ADF and KPSS tests are applied to the first differences of export and farmgate prices. Their results are summarised in Table 2.

Table 2: Results of stationarity tests for first differences of export and farmgate prices

Tests		Critical values	ΔEP_t	ΔFP_t
ADF	with constant	-2.86	-25.52*** [1]	-24.22*** [1]
	no constant	-1.95	-25.5*** [1]	-24.19*** [1]
KPSS	no linear trend	0.463	0.077 [7]	0.071 [7]

Notes: *** denotes the 1% significance level. Critical values are at the 5% significance level. The numbers in square brackets represent the lag length chosen based on the respective criterion for ADF and KPSS tests.

Regarding the first difference of export prices (ΔEP_t), the statistics of the ADF test with and without a constant are very high (approximately 25.5 each) and significant (Table 2). These results show the stationary property of ΔEP_t based on the ADF tests. The result of the KPSS test is insignificant as the statistic of 0.077 is smaller than the critical value of 0.463. It does not provide enough evidence to reject the null hypothesis of stationarity. The two tests confirm that ΔEP_t is stationary.

The ADF and KPSS tests for the first difference of farmgate prices (ΔFP_t) lead to the same conclusion of stationarity (Table 2). The ADF tests with and without a constant provide sufficient evidence to reject the null hypothesis of a unit root process. The statistic of the KPSS test is lower than the critical value (0.071 and 0.463 respectively), so the null hypothesis of stationarity cannot be rejected. As a result, ΔFP_t is demonstrated to be stationary.

In short, export and farmgate price series are characterised by nonstationarity and their first differences are shown to be stationary. This means that export and farmgate prices are integrated of order one, I(1).

5.2.2. Results of cointegration

This research uses two common methods to test for cointegration between export and farmgate prices: the Engle-Granger method and the Johansen test. The cointegration results are reported in Table 3.

Table 3: Results of cointegration tests

Tests		Critical values	Test statistics
ADF	no constant	-3.35	-10.325*** [1]
Johansen	trace test: r = 0	19.96	126.48***
	max test: r = 0	15.67	117.55***
	trace test: r = 1	9.24	8.93
	max test: r = 1	9.24	8.93

Notes: *** denotes the 1% significance level. Critical values are at the 5% significance level. Number in square brackets represents the lag length chosen based on BIC.

The Engle-Granger method has two steps. Its first step is to estimate the cointegrating relationship between the two price series (as in the following equation). The second step is to apply the ADF test for the residuals from the cointegration equation. The residuals are stationary, demonstrating the cointegration of the two price series.

$$FP_t = -0.295 + 1.034EP_t$$

For the Johansen test, the results substantiate the existence of a cointegrating vector between export and farmgate prices. With regard to the trace test with r = 0, the statistic (approximately 126.5) is highly significant. This result provides enough evidence to reject the null hypothesis of non-cointegration. The trace test with r = 1 is not significant, so that the null hypothesis of one cointegrating vector cannot be rejected. As for the max test with r = 0, the statistic is 117.55, greater than the critical value of 15.67. This result is sufficient to reject the null hypothesis of zero cointegrating vectors in favour of the alternative hypothesis of one cointegrating vector. The max test with r = 1 is insignificant, verifying the null hypothesis of one cointegrating vector. In short, FP_t and EP_t are cointegrated.

Thus it is confirmed that export and farmgate prices are integrated of order one and are cointegrated. These are necessary conditions to be able to apply the linear and threshold VECMs to detect any asymmetry in the price transmission process. The subsequent sub-sections report the parameter estimation and the findings of any possible asymmetries in the SR and the LR.

5.2.3. APT in VECM estimation

The system of VECMs (expressed by equation (31) in section 4.3) is as follows:

$$\Delta EP_t = \alpha_y + \beta_{1y}^{+}\Delta FP_t^{+} + \beta_{1y}^{-}\Delta FP_t^{-} + \beta_{2y}^{+}\Delta FP_{t-1}^{+} + \beta_{2y}^{-}\Delta FP_{t-1}^{-} + \delta_y^{+}ECT_{t-1}^{+} + \delta_y^{-}ECT_{t-1}^{-} + \gamma_{1y}\Delta EP_{t-1} + \omega_{ty}$$

$$\Delta FP_t = \alpha_x + \beta_{1x}^{+}\Delta EP_t^{+} + \beta_{1x}^{-}\Delta EP_t^{-} + \beta_{2x}^{+}\Delta EP_{t-1}^{+} + \beta_{2x}^{-}\Delta EP_{t-1}^{-} + \delta_x^{+}ECT_{t-1}^{+} + \delta_x^{-}ECT_{t-1}^{-} + \gamma_{1x}\Delta FP_{t-1} + \omega_{tx}$$

The estimations for the two models explain only 9% and 1.4% of the variation in differenced export (ΔEP_t) and farmgate prices (ΔFP_t) respectively. The very low explanatory power reflects the fact that other factors such as the market structure and the sector's cost function are more important in determining changes in export and farmgate prices than the price each has on the other (Meyer & von Cramon-Taubadel, 2004). In addition, the Durbin-Watson test statistics (almost 2) fail to reject the null hypothesis of no autocorrelation at lag one in the error terms. Lastly, as export and farmgate prices have been expressed on a logarithmic scale, the coefficient estimates are interpreted in terms of growth rates.

The estimations for the system of VECMs (equation 31) are presented as follows: Table 4 for export prices and Table 5 for farmgate prices.

Table 4: VECM estimation results, export price equation

Export price equation		Coefficients	Standard errors
Intercept		0.0009	(0.0007)
ΔEP_{t-1}		0.0193	(0.0281)
ΔFP_t^+		0.4934	(0.0547)***
ΔFP_t^-		0.4029	(0.0492)***
ΔFP_{t-1}^+		-0.0372	(0.0553)
ΔFP_{t-1}^-		-0.0358	(0.0517)
ECT_{t-1}^+		0.0879	(0.0222)***
ECT_{t-1}^-		0.2220	(0.0258)***
Durbin-Watson statistic[a]	1.9968	Adjusted R^2	0.0896

Notes: ** and *** denote 5% and 1% significance level respectively. [a] test for autocorrelation.

Four of the coefficients reported in Table 4 are significant. They validate the contemporaneous impact of farmgate prices and the responsiveness of export prices to deviations from the LR equilibrium level. In particular, a 1% increase in farmgate prices (ΔFP_t^+) will instantly lead to about 0.49% increase in export prices (ΔEP_t) while a 1% decrease in farmgate prices (ΔFP_t^-) about 0.4% decrease in export prices (ΔEP_t). About 8.8% of the positive disequilibrium error (ECT_{t-1}^+) is corrected in one time period (a day) whilst over 22% of the negative disequilibrium error (ECT_{t-1}^+) is adjusted per day. In contrast, the coefficients of the lagged difference of export (ΔEP_{t-1}) and farmgate prices (ΔFP_{t-1}^+ and ΔFP_{t-1}^-) are marginal and statistically insignificant having adjusted for other variables. This result diminishes the impact of changes in export and farmgate prices at the previous point in time (ΔEP_{t-1} and ΔFP_{t-1}) on variations in current export prices (ΔEP_t).

Table 5: VECM estimation results, farmgate price equation

Farmgate price equation	Coefficients	Standard errors
Intercept	-0.0008	(0.0006)
ΔFP_{t-1}	0.0705	(0.0301)**
ΔEP_t^+	0.3823	(0.0383)***
ΔEP_t^-	0.3537	(0.0346)***
ΔEP_{t-1}^+	0.0233	(0.0383)
ΔEP_{t-1}^-	-0.0431	(0.0345)
ECT_{t-1}^+	-0.0753	(0.0203)***
ECT_{t-1}^-	-0.1009	(0.0240)***
Durbin-Watson statistic[a] 1.9599	Adjusted R^2	0.0139

Notes: ** and *** denote 5% and 1% significance level respectively. [a] test for autocorrelation.

It can be seen from Table 5 that the coefficients of the difference of export prices (ΔEP_t), ECT_{t-1}, and the lagged difference of farmgate prices (ΔFP_{t-1}) are significant. This provides evidence for the contemporaneous impact, the adjustment towards the LR equilibrium level, and the autoregressive effect at lag one. Specifically, around 38% of a 1% rise in export prices (ΔEP_t^+) will be immediately passed on to farmgate prices (ΔFP_t) whereas a 1% fall in export prices (ΔEP_t^-) will lead to about 0.35% fall in farmgate prices (ΔFP_t). The speeds of adjustment for positive and negative disequilibrium (ECT_{t-1}^+ and ECT_{t-1}^-) are about 7.5% and 10.1% per day respectively. The lagged difference of farmgate prices (ΔFP_{t-1}) also has a significant effect on changes in current farmgate prices (ΔFP_t). Lastly, the coefficients of the lagged differences of export prices (ΔEP_{t-1}^+ and ΔEP_{t-1}^-) are low and not significant having adjusted for other variables.

The results for asymmetries in the SR and the LR in VECMs are reported in the following two tables.

Table 6: Tests of SR and LR asymmetries in VECM, export price equation

Null hypothesis of equal coefficients		Critical values ($\chi^2(1)$)	Test statistics
SR	$(\Delta FP_t^+, \Delta FP_t^-)$	3.84	1.1612
	$(\Delta FP_{t-1}^+, \Delta FP_{t-1}^-)$	3.84	0
LR	$(ECT_{t-1}^+, ECT_{t-1}^-)$	3.84	11.405***

Notes: *** denotes the 1% significance level. Critical values are at the 5% significance level.

Table 7: Tests of SR and LR asymmetries in VECM, farmgate price equation

Null hypothesis of equal coefficients		Critical values ($\chi^2(1)$)	Test statistics
SR	$(\Delta EP_t^+, \Delta EP_t^-)$	3.84	0.2953
	$(\Delta EP_{t-1}^+, \Delta EP_{t-1}^-)$	3.84	1.6363
LR	$(ECT_{t-1}^+, ECT_{t-1}^-)$	3.84	0.4971

Note: Critical values are at the 5% significance level.

As can be seen from Table 6 and Table 7, price transmission between farm and export levels is largely symmetric in the SR and the LR. In the SR, all four tests for APT in export and farmgate price equations are not significant. In other words, the response of a price series to increases and decreases in the other price series is not statistically different. For example, a 1% increase in farmgate prices will be transmitted to export prices at the same speed as a 1% decrease in farmgate prices. In the LR, the test for APT (statistic of nearly 0.5) is also insignificant in the farmgate price equation. In contrast, the LR asymmetry in the export price equation is significant (test statistic of 11.4). As the transmission is assumed to run from export prices to farmgate prices, this negative APT in the LR seems detrimental to exporters. Fortunately, the speed of adjustment (about 8.8% and 22% per day for positive and negative deviations, respectively) is high, so the harmful impact of this negative APT is short-lived. Therefore, the conclusion of symmetric price transmission still holds.

Another point of VECMs is to test whether farm and export prices will respond to a deviation from the LR equilibrium. If a price series does not react to such

disequilibrium, then it is considered to be weakly exogenous (Enders, 2015). The test of weak exogeneity is reported in Table 8.

Table 8: Tests of weak exogeneity

	Critical values ($\chi^2(2)$)	Test statistics
Export price equation ($H_0: \delta_y^+ = \delta_y^- = 0$)	5.99	225.76***
Farmgate price equation ($H_0: \delta_x^+ = \delta_x^- = 0$)	5.99	168.05***

Notes: *** denotes the 1% significance level. Critical values are at the 5% significance level.

Both test statistics for export and farmgate price equations are highly significant, indicating that the two price series are not weakly exogenous. This confirms that any deviations from the LR equilibrium will be corrected at both levels of the coffee marketing chain. The two-way adjustment also implies a close relationship between domestic and international markets.

5.2.4. APT in TVECM estimation

Each stage of the TVECM estimation procedure will be reported in the following paragraphs. After the estimation of the system of TVECMs, the test of equal coefficients will be implemented to discern any APT in the SR on the assumption of nonlinear adjustment.

Tsay's (1989) test results for the threshold effect are reported in Table 9.

Table 9: Results of Tsay's test

Arranged autoregression	Critical values	Tsay's test statistics
Increasing	3	3.24**
Decreasing	3	4.17**

Notes: ** denotes the 5% significance level. Critical values are at the 5% significance level.

For the ascending order of arranged autoregression of ECTs, the test statistic is 3.24 and is statistically significant at the 5% significance level. The same result

holds for the descending order of arranged autoregression as the corresponding test statistic is 4.17. Therefore, Tsay's (1989) test confirms the nonlinearity in the adjustment process of export and farmgate prices.

The two optimal thresholds are calculated for the TVECMs for export and farmgate prices. Regarding the TVECM for export prices, the lower and upper thresholds are -0.023 and 0.024 respectively (see Appendix 2, Table A1). The number of observations in Regimes I, II, and III are 238, 742, and 215, respectively. The Breusch-Pagan test is not significant, so there is insufficient evidence to reject the null hypothesis of homoscedasticity. As a result, the sup-F test statistic is plausible to test the significance of this TVECM. In addition, the sup-F test statistic is 51.98 and highly significant based on the asymptotic distribution of 1000 simulations of the Hansen's (1997) approach. Hence, the TVECM for export prices is statistically significant.

For the TVECM for farmgate prices, the lower and upper thresholds are -0.016 and 0.008 respectively (see Appendix 2, Table A2). The numbers of observations per regime are more even than those for the TVECM for export prices. These figures are 343, 420, and 432 for regime I, II, and III, respectively. The Breusch-Pagan test is insignificant, which confirms the homoscedasticity of error terms of the TVECM for farmgate prices. The sup-F test statistic, however, is not significant based on the result computed from 1000 simulations of the Hansen's (1997) approach. As a result, the TVECM for farmgate prices is not significant.

According to the results from the Hansen's (1997) approach, the TVECM for export prices is significant whereas the TVECM for farmgate prices is not. This will suffice to demonstrate the nonlinear adjustment in the transmission process between export and farmgate prices. The thresholds (-0.023 and 0.024 respectively) in the TVECM for export price equation will be used to re-compute the system expressed by equation (36) in section 4.4. The system of TVECMs is:

$$\Delta EP_t = \begin{cases} \alpha_{1y} + \beta_{11y}^{+}\Delta FP_t^{+} + \beta_{11y}^{-}\Delta FP_t^{-} + \beta_{12y}^{+}\Delta FP_{t-1}^{+} + \beta_{12y}^{-}\Delta FP_{t-1}^{-} \\ \quad +\delta_{1y}ECT_{t-1} + \gamma_{1y}\Delta EP_{t-1} + \omega_{ty}\ if\ ECT_{t-1} < \theta_1 \\ \alpha_{2y} + \beta_{21y}^{+}\Delta FP_t^{+} + \beta_{21y}^{-}\Delta FP_t^{-} + \beta_{22y}^{+}\Delta FP_{t-1}^{+} + \beta_{22y}^{-}\Delta FP_{t-1}^{-} \\ \quad +\delta_{2y}ECT_{t-1} + \gamma_{2y}\Delta EP_{t-1} + \omega_{ty}\ if\ \theta_1 \le ECT_{t-1} \le \theta_2 \\ \alpha_{3y} + \beta_{31y}^{+}\Delta FP_t^{+} + \beta_{31y}^{-}\Delta FP_t^{-} + \beta_{32y}^{+}\Delta FP_{t-1}^{+} + \beta_{32y}^{-}\Delta FP_{t-1}^{-} \\ \quad +\delta_{3y}ECT_{t-1} + \gamma_{3y}\Delta EP_{t-1} + \omega_{ty}\ if\ ECT_{t-1} > \theta_2 \end{cases}$$

$$\Delta FP_t = \begin{cases} \alpha_{1x} + \beta_{11x}^{+}\Delta EP_t^{+} + \beta_{11x}^{-}\Delta EP_t^{-} + \beta_{12x}^{+}\Delta EP_{t-1}^{+} + \beta_{12x}^{-}\Delta EP_{t-1}^{-} \\ \quad +\delta_{1x}ECT_{t-1} + \gamma_{1x}\Delta FP_{t-1} + \omega_{tx}\ if\ ECT_{t-1} < \theta_1 \\ \alpha_{2x} + \beta_{21x}^{+}\Delta EP_t^{+} + \beta_{21x}^{-}\Delta EP_t^{-} + \beta_{22x}^{+}\Delta EP_{t-1}^{+} + \beta_{22x}^{-}\Delta EP_{t-1}^{-} \\ \quad +\delta_{2x}ECT_{t-1} + \gamma_{2x}\Delta FP_{t-1} + \omega_{tx}\ if\ \theta_1 \le ECT_{t-1} \le \theta_2 \\ \alpha_{3x} + \beta_{31x}^{+}\Delta EP_t^{+} + \beta_{31x}^{-}\Delta EP_t^{-} + \beta_{32x}^{+}\Delta EP_{t-1}^{+} + \beta_{32x}^{-}\Delta EP_{t-1}^{-} \\ \quad +\delta_{3x}ECT_{t-1} + \gamma_{3x}\Delta FP_{t-1} + \omega_{tx}\ if\ ECT_{t-1} > \theta_2 \end{cases}$$

The estimations for the system of TVECMs are shown in Table 10 and Table 11. The adjusted R^2 are 12.9% and 3.2% in two equations, indicating the low explanatory power of the system to model variations in export and farmgate prices (as was the case for the linear VECMs). The Durbin-Watson test confirms no first order autocorrelation in the error terms of the system of TVECMs.

Table 10: TVECM estimation results, export price equation

Export price equation	Regime I	Regime II	Regime III
Intercept	-0.0002	0.0002	0.0073
ΔEP_{t-1}	-0.0186	-0.0066	0.1284**
ΔFP_t^{+}	0.4646***	0.3325***	1.2837***
ΔFP_t^{-}	0.4622***	0.3288***	0.3613***
ΔFP_{t-1}^{+}	-0.0782	0.0285	-0.2192**
ΔFP_{t-1}^{-}	-0.1366	0.0102	0.1231
ECT_{t-1}	0.2127***	0.0986**	-0.0391
Durbin-Watson statistic[a]	1.9906	Adjusted R^2	0.129

Notes: ** and *** denote 5% and 1% significance level respectively. [a]: test for autocorrelation.

Table 11: TVECM estimation results, farmgate price equation

Farmgate price equation	Regime I	Regime II	Regime III
Intercept	-0.0009	-0.0007	-0.0012
ΔFP_{t-1}	0.1327**	0.0732	-0.007
ΔEP_t^+	2.0335***	0.3734***	0.3299***
ΔEP_t^-	0.3091***	0.3386***	0.6443***
ΔEP_{t-1}^+	0.0829	0.0154	-0.3216
ΔEP_{t-1}^-	0.0704	-0.0582	-0.0239
ECT_{t-1}	-0.1009**	-0.0656	-0.0456
Durbin-Watson statistic[a]	1.9525	Adjusted R^2	0.032

Notes: ** and *** denote 5% and 1% significance level respectively. [a]: test for autocorrelation.

The speed of adjustment in the lower regimes is higher than that in the upper regimes (Table 10 and Table 11). For instance, in the export price equation about 21% of a LR disequilibrium (coefficient of ECT_{t-1}) is corrected after a day in regime I whereas nearly 10% of disequilibrium adjusted if ECT_{t-1} lies in regime II. The same holds for the farmgate price equation. Around 10% of a LR discrepancy in regime I is eliminated whilst the speed of adjustment in regime II and regime III is about 6.6% and 4.6% per day respectively, though the two coefficients are insignificant. Furthermore, the coefficient for ECT_{t-1} in regime III for the export price equation is unexpectedly negative (-0.0391). This means that the LR disequilibrium in regime III tends to be widened instead of being narrowed. Fortunately, the coefficient might not be an issue as it is not statistically significant.

The estimation results in Table 10 and Table 11 verify the contemporaneous impacts of export and farmgate prices on each other. All the coefficients for ΔFP_t^+, ΔFP_t^-, ΔEP_t^+, and ΔEP_t^- are highly significant. More than 30% of a 1% change in farmgate prices is instantly transmitted to export prices and vice versa. Additionally, two coefficient estimates (ΔFP_t^+ in regime III and ΔEP_t^+ in regime I) are greater than unity. In particular, a 1% increase in farmgate prices instantaneously lead to a 1.28% increase in export prices when ECT_{t-1} is greater than θ_2 (Table 10). A 1% increase in export prices contemporaneously result in

2.03% increase in farmgate prices when ECT_{t-1} lies in regime I (Table 11). This is unexpected as the cointegration-based approach would have expected a more gradual adjustment.

Since the system of TVECMs assume that each regime differs in the speed of adjustment towards the LR equilibrium, APT is tested only in the SR. The results for SR APT in the system of TVECMs are reported in Table 12 and Table 13.

Table 12: Tests of SR asymmetries in TVECM, export price equation

Null hypothesis of equal coefficients		Critical values (χ2(1))	Test statistics
Regime I	$(\Delta FP_t^+, \Delta FP_t^-)$	3.84	0
	$(\Delta FP_{t-1}^+, \Delta FP_{t-1}^-)$	3.84	0.0782
Regime 2	$(\Delta FP_t^+, \Delta FP_t^-)$	3.84	0.001
	$(\Delta FP_{t-1}^+, \Delta FP_{t-1}^-)$	3.84	0.0286
Regime 3	$(\Delta FP_t^+, \Delta FP_t^-)$	3.84	21.366***
	$(\Delta FP_{t-1}^+, \Delta FP_{t-1}^-)$	3.84	2.6694

Notes: *** denotes the 1% significance level. Critical values are at the 5% significance level.

Table 13: Tests of SR asymmetries in TVECM, farmgate price equation

Null hypothesis of equal coefficients		Critical values (χ2(1))	Test statistics
Regime I	$(\Delta EP_t^+, \Delta EP_t^-)$	3.84	14.322***
	$(\Delta EP_{t-1}^+, \Delta EP_{t-1}^-)$	3.84	0.0085
Regime 2	$(\Delta EP_t^+, \Delta EP_t^-)$	3.84	0.1237
	$(\Delta EP_{t-1}^+, \Delta EP_{t-1}^-)$	3.84	1.2094
Regime 3	$(\Delta EP_t^+, \Delta EP_t^-)$	3.84	5.9596**
	$(\Delta EP_{t-1}^+, \Delta EP_{t-1}^-)$	3.84	1.0723

Notes: *** and ** denote the 1% and 5% significance level respectively. Critical values are at the 5% significance level.

As shown in Table 12 and Table 13, price transmission between export and farm levels remains mostly symmetric when thresholds are considered. In the export

price equation (Table 12), of six SR asymmetry tests, only the coefficients for rising and falling of current farmgate prices (ΔFP_t^+, ΔFP_t^-) in the regime III are statistically different (test statistic of 21.4). In the farmgate price equation (Table 13), two of six SR asymmetries are statistically significant. However, two of these three possible SR APT must be discarded because their coefficients are unexpectedly greater than unity, leaving one SR asymmetry in the price transmission process ($\Delta EP_t^+$and ΔEP_t^- in regime III). For this positive SR APT, rising export prices are transmitted more slowly to farmgate prices than falling export prices (coefficients of 0.33 and 0.64 respectively). This highlights the slightly disadvantaged position of farmers in relation to exporters, in the coffee supply chain. Since the variation in export price changes will be reflected in farmgate prices within several days, it is evident that this APT in the SR is minimal in Vietnam's Robusta coffee sector even when the threshold effects are taken into account.

Overall, the research confirms that price transmission between farm and export levels is almost symmetric for Vietnam's Robusta coffee. These results are not consistent with the previous findings for Vietnam's Robusta coffee (Li & Saghaian, 2013). Li and Saghaian (2013) found APT in direction by using monthly coffee prices from 1990 to 2011. It may be that this low frequency data may not truly reflect the nature of price transmission. It is also worth noting that Li and Saghaian's (2013) study investigated Vietnam's coffee sector since the market reform began while this research examined the recent period from mid-2011 to 2015. The research also verifies the significance of transaction costs and other price fictions in the price transmission process. The TVECM in this research, therefore, provides better model specification than the VECM used in Li and Saghaian (2013).

Furthermore, the findings of this research also differ from the conclusions reached in the previous studies that investigated price transmission for Robusta coffee in other countries, namely Fafchamps and Hill (2008) and González (2007). They both showed APT between domestic and world markets, and confirmed that market reforms did not eliminate APT despite enhancing the degree of price transmission. The use of monthly data may be a reason for the different result. A

further reason may result from the distinct characteristic of Vietnam's coffee sector in which Vietnamese exporters did not have enough market power to maintain a gap between world prices and domestic farmgate prices. The concentration of the eight largest export firms in Vietnam's coffee sector remained under 50% in 2014 (Vu, 2015). Meanwhile, in Uganda, the proportion of top ten exporters was about 87% in 2000/01 while Ethiopia established a committee to regulate its coffee sector (González, 2007).

There are two factors that may have impacted the results of symmetric price transmission in this research. The first is the exchange rate pass-through (Liefert & Persaud, 2009). Between mid-2011 and 2015, as the VND depreciated against the USD, there might be a case in which such depreciation made price transmission for Vietnam's Robusta coffee symmetric. Vietnam's coffee exporters may observe an increase in export prices in VND (Bussière, 2007) although the export prices in USD in fact decreased. Suppose coffee exporters transmitted rising export prices in USD faster than falling export prices in USD to farmgate prices in VND. The faster transmission of export price increases minus the exchange rate pass-through could equal the slower transmission of export price decreases plus the exchange rate pass-through. This leads to the symmetric transmission between export and farmgate prices when both are denominated in USD. However, it was difficult to separate the transmission of changes in world prices and exchange rates to domestic prices because Liefert and Persaud (2009) mentioned only one study doing so, but they identified a serious methodological problem in this work. In theory, the exchange rate pass-through for export prices is expectedly equal to zero under the local currency pricing hypothesis (Choudhri & Hakura, 2015), in which export prices are denominated in the currency of the import market (Fendel, Frenkel, & Swonke, 2008). Therefore, it is unclear whether the exchange rate pass-through would affect the result of symmetric price transmission for Vietnam's Robusta coffee. A full investigation of the role of the exchange rate is warranted; however, this is outside the scope of this research.

The second factor possibly influencing the findings of this research is that of data frequency. There is a trade-off between data frequency and useful estimation. Meyer and von Cramon-Taubadel (2004) stated that empirical studies on APT

needed to work with data of greater frequency than the frequency of the adjustment process. At the same time, data with high frequency (e.g. weekly or daily data) may not have enough variation to provide useful estimates of price transmission (Gomez & Koerner, 2009). In order to examine the issue of data frequency, this research aggregated the daily coffee prices to weekly prices and re-evaluated price transmission between export and farm levels on a weekly basis. For the weekly price data, both export and farmgate prices respond asymmetrically to the LR disequilibrium in linear VECMs. No SR asymmetries, in contrast, are found in TVECMs. The total number of APT found in linear and threshold VECMs for weekly coffee prices is equal to that for daily coffee prices. Hence, data frequency (daily and weekly data) do not significantly affect the result of symmetric price transmission for Vietnam's Robusta coffee. Since the daily data was only available from mid-2011 to the end of 2015, there was insufficient data to make a comparison between price transmission for daily data and monthly data.

This chapter described the price data, implemented the methods outlined in Chapter Four, presented and interpreted the results from the analysis. First of all, export and farmgate prices from mid-2011 to the end of 2015 are integrated of order one, and are cointegrated. As for price transmission in linear and threshold VECMs, one asymmetry was found for each case, however, the speed of adjustment was high. This means that the transmission between export and farmgate prices for Robusta coffee in Vietnam is symmetric. The result of symmetric price transmission is different from that of the previous studies in Vietnam's coffee sector in particular and in other Robusta producers in general. In addition, exchange rate pass-through and data frequency may not affect the findings. The final chapter will summarise the main findings of price transmission of Vietnam's Robusta coffee and answer the research questions raised at the beginning of this research.

Chapter Six: CONCLUSION

This research built on the work of Li and Saghaian (2013) who examined the transmission between world prices and farmgate prices based on monthly data for the Vietnamese Robusta coffee market. In their study, the authors found that some 44% of a deviation from the LR equilibrium was adjusted in farmgate prices in the next month while there was no significant response by world prices to the LR disequilibrium. However, Li and Saghaian's (2013) analysis did not allow for testing positive and negative APT nor for the nonlinear adjustment towards the LR equilibrium. The research presented here addresses these limitations and analyses price transmission between export and farmgate prices for Vietnam's Robusta coffee using daily price data between mid-2011 and the end of 2015.

Results from this research provide evidence that price transmission between farm and export levels is mostly symmetric for Vietnam's Robusta coffee. This is not consistent with the findings of previous price transmission studies for Robusta coffee in Vietnam (Li & Saghaian, 2013) and in other countries (Fafchamps & Hill, 2008; González, 2007). In addition, this research also found that threshold effects due to transaction costs and other adjustment costs are significant in price transmission, an issue often ignored in the literature on APT for Robusta coffee. Such differences in price transmission might result from the use of high frequency data (daily data in this research versus monthly data in previous studies) and the distinct characteristics of Vietnam's coffee market.

Following the Vietnam government's economic policy reforms three decades ago, the coffee sector became increasingly market-driven and export-oriented. This development made farmgate coffee prices more aligned with world coffee prices, which means of course that they are also subject to the fluctuations of the global coffee market. This leads to the question: what impact have such policy reforms exerted on farmgate prices for coffee and then on coffee farmers' welfare?

The insights into price transmission between export and farmgate prices provide the degree of relationship between the world and Vietnam's coffee markets. This

research used vector error correction models to estimate price transmission as the method handles the time-series aspect of the price data. Both linear and threshold VECMs were used to take into account the linear and nonlinear adjustment of prices towards the LR equilibrium. A downside of this method is the sole reliance on price data, and therefore, it does not help in detecting the causes of APT.

The following paragraphs will answer the research questions of this thesis in turn. The first research question is about the nature of transmission between export and farmgate coffee prices. There was evidence of negative APT in the LR in the linear VECMs and of positive APT in the SR in the TVECMs. However, these asymmetries in price transmission are minor because the daily speed of adjustment is high. Therefore, price transmission is mostly symmetric for Vietnam's Robusta coffee over the period from mid-2011 until the end of 2015.

The effects of exchange rate pass-through and data frequency on price transmission may be insignificant in this research. Firstly, the exchange rate pass-through theoretically equals zero when export prices are denominated in the currency of the import market. This is the case here as export coffee prices were denominated in US dollars. However, a further study of the role of the exchange rate is needed, but is beyond the scope of this research. Secondly, this research investigates price transmission using weekly prices converted from the original daily prices. For weekly prices, in the linear VECM two APT in the LR are found, whereas little APT is present in the threshold VECM. The number of APT for weekly price data is the same as that for daily price data. Therefore, the result of symmetric price transmission in this research does not vary with data frequency.

As for possible reasons behind this symmetric price transmission, some can be derived from the characteristics of Vietnam's coffee sector. First of all, market reforms have made the domestic coffee sector more competitive as the market share of the eight largest export firms remained under 50% in 2014 (Vu, 2015). Vietnamese exporters did not have enough market power over coffee farmers to squeeze farmgate prices to their advantage. Secondly, Robusta coffee is of lower quality than Arabica coffee (Ghoshray, 2010), lowering the bargaining power of Vietnamese exporters in the global coffee market (Li & Saghaian, 2013). Another

cause could be the oversupply of Robusta coffee. Farmers do not have bargaining power over local exporters and tend to accept the prices driven by market forces. Therefore, the gap between export and farmgate prices tends to be narrowed and may not be stable.

The finding of symmetry in price transmission provides evidence for the success of the government's liberalisation policies in terms of market efficiency and integration in Vietnam's coffee sector. Liberalisation policies have indeed moved the Vietnamese economy into a market economy and as such exposed its farmers to the fluctuations of global prices. This means that when global prices are high and there is very little APT, the farmers' profits are also high. However, as is currently the case, when global coffee prices are subdued, symmetric price transmission results in lower prices and hence a fall in welfare for those coffee farmers. Is this a reason to interfere with the workings of the market? Whilst tempting, raising and stabilising prices to coffee farmers would create incentives for expansion in coffee production, exaggerating the problem of a coffee glut and dampening future coffee prices. For these unintended consequences, the government should be very cautious if wanting to intervene in the market price in the coffee sector.

The second research question queries what policies the result of symmetric price transmission implies for the VCCB in ensuring coffee farmers' welfare whilst maintaining a market economy. If global coffee prices followed an upward trend as they did in the 2000s, the VCCB would only need to sustain the current policies and coffee farmers would fare well. However, as global coffee prices have been on the decline for the studied period (2011-2015), the finding of this research may have at least two policy implications. Firstly, the VCCB could keep the present state of market reforms intact as this slack period may not be long-lasting. If the global coffee market becomes buoyant, coffee farmers will be better-off without worries about the unintended consequences of price interventions. The second implication is based on the scenario of the continuation of downward prices in the world coffee market because there is an oversupply of both Arabica and Robusta coffee worldwide every year. In this scenario, the VCCB could shift the coffee sector's focus to quality differentiation from emphasis on yield. The reports by Vu

(2015, 2016) suggested that producing coffee in accordance with certifications such as Rainforest Alliance, UTZ, and Fairtrade International, is an appealing option. With some 25% of coffee plantations in Vietnam being over 15 years old and in need of replanting, the VCCB could promote the adoption of these coffee production practices in these older farms via the farmer's representatives in its board committee.

The research has some limitations, which could be the subject of further research. The four-and-a-half year time period of daily price data is relatively brief, so later an analysis of a longer time span may provide better evidence of price transmission in Vietnam's Robusta coffee market. Additionally, the study does not model retail prices in the price transmission process. The inclusion of retail prices would offer a more complete understanding of price transmission in the coffee supply chain. Finally, the investigation of the role of exchange rate would allow one to better understand price transmission from the global market to domestic farmgate prices.

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Appendices

Appendix 1: Sup-Wald test statistic

The sup-Wald test statistic is calculated as:

$$W_3 = \left(R\widehat{\mathrm{B}}\right)'[R(M_T^{-1}V_T M_T^{-1})R']^{-1}(R\widehat{\mathrm{B}})$$

where R is a $q \times k$ matrix that assumes q restrictions on a $k \times 1$ vector of coefficients in (15);

$\widehat{\mathrm{B}}$ is a $k \times 1$ vector of coefficient estimates in model (15);

X_T is a $T \times k$ matrix of regressors with thresholds;

e_T is a $T \times k$ matrix with each column being equal to the $T \times 1$ vector ω_t;

$M_T = X_T' X_T$;

$Xe_T = X_T \circ e_T$;

$V_T = Xe_T' Xe_T$.

Appendix 2: TVECM Estimation

Table A1: TVECM estimation results, export price equation

Variables	Regime I	Regime II	Regime III
Intercept	0	0.0002	0.0095
ΔEP_{t-1}	-0.0034	-0.012	0.1003
ΔFP_t	0.2758	0.1203	0.4372
ΔFP_{t-1}	-0.0997	0.038	-0.1129
ECT_{t-1}	0.2056	0.0912	-0.0477
Number of observations	238	742	215
Lower threshold	-0.023		
Upper threshold	0.024		
Breusch-Pagan test against heteroskedasticity	2.4313		
Hansen's test statistic	51.98***		

Table A2: TVECM estimation results, farmgate price equation

Variables	Regime I	Regime II	Regime III
Intercept	-0.001	0.0002	-0.0005
ΔFP_{t-1}	0.0487	0.2097	-0.0497
ΔEP_t	0.1501	0.2251	0.2093
ΔEP_{t-1}	0.0619	-0.0547	-0.0265
ECT_{t-1}	-0.07	0.0151	-0.0576
Number of observations	343	420	432
Lower threshold	-0.016		
Upper threshold	0.008		
Breusch-Pagan test against heteroskedasticity	2.6191		
Hansen's test statistic	20		