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# Institutions and Market Integration

## The Case of Coffee in the Ethiopian Commodity Exchange

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## INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

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## ABSTRACT

While the Ethiopian Commodity Exchange (ECX) is widely credited to be a successful on several accounts, there has been little rigorous empirical investigation. This paper attempts to fill that gap by analyzing how ECX has influenced the international-domestic price relationships of coffee—the largest traded commodity on its floor. We examine three aspects of price dynamics—market interdependence, volatility transmission, and structural breaks—using a spatially disaggregated prices of five coffee varieties. The results indicate that contrary to popular media stories, ECX's success in improving coffee price relationships has been limited. The results appear to be robust under all three sets of analysis.



**Keywords: market interdependence, volatility transmission, coffee, Ethiopian Commodity Exchange**

*JEL codes: Q11, Q02, C32*

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# 1. INTRODUCTION

Perhaps no government-led initiative in Africa has received as much attention in recent years as the Ethiopian Commodity Exchange (ECX). Since its launch in 2008, ECX has made headlines in major news and digital media, with optimistic titles like "How Africa's First Commodity Exchange Revolutionized Ethiopia's Economy."[1] The British Broadcasting Corporation has broadcast ECX success stories and its role in improving food security while the Public Broadcasting Services in the United States produced a documentary called *Market Maker.*[2] The exchange has attracted visitors from around the world including heads of states and United Nations agencies as well as a wide range of actors from the international development community. Between 2009 and 2012, representatives from 18 countries visited Ethiopia with a hope to adapt or replicate similar institution in their countries. The presidents of Nigeria and Tanzania have visited the ECX floor, and so have the heads of the United Nation's World Food Programme (WFP) and the United Nation's Development Program (UNDP). Donors have enthusiastically supported ECX and continue to provide supports for capacity building and institutional development.

There are two main reasons why ECX has received such a high level of attention. The first reason is that ECX is the only functioning commodity exchange in Least Developed Countries. Although they have existed for more than a century, organized commodity exchanges remained largely confined to industrialized nations until the onset of structural adjustment programs in the 1980s and 1990s. With liberalization and dismantling of the marketing boards, it was commonly believed that the commodity exchange would offer the market-based solutions for price discovery and commodity risk management (Mattos and Garcia 2004; United Nation's Conference on Trade and Development 2009). Donors provided generous supports to establish agricultural commodity exchanges in developing countries, but the success was limited to emerging economies only (Rashid, Winter-Nelson, and Garcia 2010). Five African countries launched commodity exchanges following the market liberalization, but only South Africa succeeded in making its exchange sustainable without any external supports (Rashid, Winter-Nelson, and Garcia 2010).[3] Therefore, when ECX established electronic payments and Warehouse Receipts Systems and conducted US$1.0 billion[4] worth of trade on its floor, it generated real optimism in the development community.

The other reason is that ECX has been effective in communicating its early success stories. Several early ECX success stories—especially the ones about linking smallholders to markets, increasing coffee exports, and having zero defaults—were appealing to the media, policymakers, and development partners. Some success statistics include the following: ECX effectively linked 2.4 million smallholders through cooperatives;[5] ECX trade volume increased from a modest 138,000 tons in the first year to 508,000 tons in the third year; and in February 2011, ECX celebrated "1000 days of ECX, US$1.0 billion in trades, and zero defaults" (Gabre-Madhin 2012). These stories represented the promise that, if designed properly, the commodity exchanges might have the potential to address some of the most intricate development challenges of our times: transforming smallholder-dominated economies, where the livelihoods of the majority depend on production and trading of agricultural commodities. Changing the fate of these smallholders is central to putting many developing countries on the path to economic

[1] See http://allafrica.com/stories/201211301483.html.

[2] The British Broadcasting Corporation piece is available at http://www.bbc.com/news/business-11346643, and the Public Broadcasting Services documentary is available at http://www.pbs.org/wnet/wideangle/episodes/the-market-maker-full-episode/5293/.

[3] See Table A.1 in the Appendix for the list of commodity exchanges launched in Africa. Despite initial signs of success, Zambia and Zimbabwe suspended their operations following unusual price hikes and subsequent government intervention. Although they continue to exist with donor and government supports (in the case of Uganda), the Kenyan Agricultural Commodity Exchange and the Uganda Commodity Exchange, both launched in the late 1990s, have never been able to attract sizable trade volumes. Currently, their limited roles include providing price information in Kenya and regulating some warehouses on behalf of the government in Uganda.

[4] All dollars are US dollars.

[5] See www.theguardian.com/global-development/2012/dec/13/africa-commodity-exchange-ethiopia-economy.

development and prosperity. Ethiopia is such a country, and ECX's success stories resonated well among all actors in development policymaking.

However, most of these success stories are based on anecdotal evidence and lack systematic analysis to determine whether the accomplishments could be attributed exclusively to ECX, which is very different from traditional commodity exchanges. It is a public-private partnership with strong policy supports that has brought about several changes in the commodity value chains, especially export commodities like coffee, oil seeds, and pulses. For instance, coffee farmers are now required to sell their coffee at designated primary markets, called primary marketing centers, where only certified buyers are allowed to purchase. Similarly, the coffee processors are required to have approval to transport their coffee to the designated warehouses for their coffee to be graded and a warehouse receipt to be issued. This process also determines whether coffee in a given lot should be exported or released to the domestic markets. Clearly, these policy actions restrict market actors' choices along the whole value chain. What are the economic rationales behind these interventions in commodity markets? If the rationales are addressing market failures (for example, inadequate infrastructure, information asymmetry, and missing institutions, among others), then the establishment of ECX should be welfare enhancing. If not, all policy actions to support ECX would be distortionary and counterproductive. While the claims in popular media—such as linking smallholders to markets, improving marketing systems, and helping increase exports—have drawn attention from all corners, there is no study to address these fundamental questions.

This paper contributes to that knowledge gap. Using a unique set of spatially disaggregated price data, we undertake a set of econometric analyses to examine whether establishment of ECX has improved various aspects of price dynamics. The conceptual foundation of our econometric analysis is this: price is the outcome of an exchange process we call market, and the price relationships will improve if the new policies and institutions address market failures.[6] In other words, if ECX (and the policies to support it) adds value to the market, it should be reflected in the price behaviors through improvement in the price transmission and integration across space and times, particularly between international and local markets. We us a Multivariate Generalized Autoregressive Conditional Heteroskedasticity (MGARCH) model to analyze these relationships for coffee—the single largest commodity traded on ECX floor.

The rest of the paper is organized as follows. Section 2 provides overviews of the evolution of ECX and the coffee sector, which is followed by a discussion about the methodology. The data and their time series properties are discussed in section 4. Section 5 presents the results and their implications. The paper concludes with a summary of the analysis and concluding remarks.

[6] This is well documented in the literature on the liberalization and market integration literature. See Rashid (2004) for a case study on Uganda.

# 2. BACKGROUND

## Evolution of ECX

The underlying rationale for setting up ECX was not unique to Ethiopia. It was to address the problems of high transactions costs, information asymmetry, and other market failures that hindered price discovery. All other exchanges in Africa were founded on the same grounds. However, the forces behind the initiation of ECX and the approach to setting it up are uniquely different from all other exchanges in Africa. Unlike other African countries, Ethiopia had a series of consultations, starting from early 2005, to align the key stakeholders, including ensuring commitment from the highest level of political leadership. The highlights of the initial consultations were presented in a 2005 policy working paper, jointly published by the Ethiopian Development Research Institute and the International Food Policy Research Institute. However, it took more than two years to develop the policy framework for ECX to be established. An important force during this lengthy process was the leadership of ECX's founding CEO, Dr. Eleni Gabre-Madhin, who had a deep understanding of African grain markets as an agricultural policy researcher. The consultation and continuous persuasions finally paid off when the Ethiopian Parliament passed a landmark proclamation (Proclamation No-551/2007), paving the way for ECX to be established under the supervision of the Ministry of Agriculture and Rural Development.

ECX was formally launched in April 2008, with an initial focus on trading cereals and pulses. However, the launching of ECX coincided with the global food crisis, and the trading on the ECX floor fell far short of the expectation. From April 2008 to December 2008, ECX traded only 935 tons of maize, 90 tons of wheat, and 570 tons of beans. The corresponding trade values of these three commodities were about $794 thousand, which, at a commission rate of 0.2 percent, generated a total gross revenue of $1,588, equivalent to $144 per month. So it became clear to the government that the exchange would not be viable if it had to rely exclusively on cereals and beans, as envisioned in the report that made the case for setting up ECX.[7] As a strategic move, the exchange turned its focus mainly to export crops. To ensure that ECX gets large enough market shares, the government suspended the age-old coffee auction floor in Addis Ababa and made it mandatory to trade all coffee through ECX in December of 2008.[8]

Following these policy actions, the volume of coffee trade on the ECX floor increased rapidly from 64 thousand tons in 2008/2009 to more than 200 thousand tons in 2010/2011, representing around 47 percent of the total volume (not value) of transactions of ECX (Gabre-Madhin 2012). Leaving aside whether the policy actions were justified, this growth presented a monumental task for ECX with regard to ensuring all aspects of efficient transactions. And ECX is generally regarded as successful in effectively managing this growth. It ensured a t + 1 payment method (getting paid within a day after the transactions), disseminating market information and promoting export growth. The implementation of t + 1 payment addressed the age-old problem of defaults and dispute resolution, which in turn contributed to reducing transactions costs. The price tickers at 32 rural sites, provided real-time access to price information, and subscription for instant messaging brought about transparency in price information. However, as already discussed, ECX has also imposed restrictions on all actors along the value chain, which has increased market actors' transactions costs.

[7] In fact, the background report making the case for setting up the exchange has no mention of coffee and other export commodities.

[8] See Rashid, Winter-Nelson, and Garcia (2010) and Rashid (2014) for further details.

### Overview of Ethiopian Coffee Sector

Ethiopia is the birthplace of coffee, and it is the fifth largest coffee-producing country in the world.[9] According to official statistics, annual production has averaged 300,000 tons, with more than 95 percent of the total production concentrated in two main coffee-growing regions of the country, Oromia and Southern Nations and Nationalities (Table 2.1). Ethiopia also is well known for the diversity of its coffee production and marketing. All Ethiopian coffee is grown in three agro-climatic zones—namely, southwestern, southern, and eastern—with each accounting for 70 percent, 22 percent, and 8 percent, respectively. Most of the coffee grown in the southwestern part (which includes places like Illubabor, Kelem, Jimma, Kaffa, Shaka, Bench Maji, and Wollega) are sold dry and do not go through much processing. On the other hand, farmers in the southern part (for example, Sidama, Yirgachefe, and Wolayeta) sell their beans to the processors for washing, sorting, and final marketing. The eastern coffee growing zone, which includes West and East Hararghe (Harar), produces both dry and washed coffee beans. Figure A.1 in the Appendix presents a map with all growing areas of Arabica coffee in Ethiopia, distinguishing by volume of production and showing the five regions focused on in the study.

**Table 2.1 Coffee production in Ethiopia by region, 2005–2013**

| Region | Production estimate (in thousand tons) | | |
|---|---|---|---|
| | 2005–2008 | 2008–2013 | Average |
| Oromiya | 199.7 | 259.0 | 229.4 |
| SNNP | 113.0 | 138.1 | 125.5 |
| Gambella | 3.4 | 2.2 | 2.8 |
| Total national | 316.1 | 400.5 | 358.3 |
| Share of total (%) | | | |
| Oromiya | 63.2 | 64.7 | 64.0 |
| SNNP | 35.7 | 34.5 | 35.0 |
| Gambella | 1.1 | 0.5 | 0.8 |

Source: Volume of production was obtained from Ethiopia, CSA (various years). Average producers' price of agricultural products in rural Ethiopia obtained from Monthly Statistical Bulletins 156 to 384 (CSA various years).
Note: SNNP = Southern Nations Nationalities and Peoples. Of the five main coffee varieties analyzed in the study, Harar, Lekemt, and Jimma are part of the Oromiya production region, and Sidama and Yirgachefe are part of the SNNP production region.

Coffee has an important role in the Ethiopian economy. In 2012, more than 4.2 million smallholders were engaged in coffee production, and they accounted for 95 percent of total coffee production. Therefore, any institutional innovation or intervention that improves coffee marketing will have direct bearing on the poverty alleviation and well-being of the poor. In addition to this important social dimension, coffee plays an important role in the country's macroeconomic stability and balance of payment. It is a major foreign exchange earner, accounting for 35 percent of the country's total export revenues during 2000 and 2014 (National Bank of Ethiopia 2014). This link was manifested during the central planning regime, when an overvalued exchange rate and price control led to a severe deterioration of incentives for coffee production, affecting macroeconomic stability (Rashid, Assefa, and Ayele 2009). In the early 1990s, a series of policy measures—such as the dismantling of the coffee marketing board, elimination of production quota, withdrawal of price control, and significant tax reduction—were enacted to liberalize and jump-start the coffee sector. These reforms resulted in a significant reduction in distortions to coffee production incentives, and coffee production grew by 5.7 percent per year between 1995 and 2007 (the year before the launching of ECX). Production continues to grow, but export earnings have declined from their peak of $0.84 billion in 2012 to $0.74 in 2013, causing enough panic for the prime minister to call a special meeting to resolve the problem.[10]

[9] It is just behind Brazil, Vietnam, Colombia, and Indonesia. In terms of exports, Ethiopia represents less than 3 percent of total world exports. Visit www.ico.org for details.

[10] See http://addisfortune.net/columns/poor-export-revenue-demands-diversification/.

# 3. METHODOLOGY

## The Analytical Framework

The analytical basis of our econometric analysis is grounded on the fact that any institutional or regulatory interventions to a given commodity market should be reflected in the price dynamics. We hypothesize that the establishment of ECX, and regulatory supports to it, can be (1) welfare enhancing if there is an improvement in price relationship between international and domestic markets, (2) welfare reducing if there is a deterioration in price relationship, and (c) welfare neutral if there is no change in the price dynamics. In particular, controlling for other factors, an improvement in the price interrelationship would imply that ECX has addressed market failures. On the other hand, (2) and (3) would imply that ECX interventions have been distortionary and neutral, respectively.[11]

We test these hypotheses primarily with two sets of analyses: the interdependence and volatility transmission of price returns across international and domestic markets and over time. Conceptually, the interdependence analysis is similar to the analysis of spatial market integration. However, much of the market integration literature in the field of agricultural economics relies on the variations of the method of co-integration of prices across space and time. In this paper, we analyze the interdependence of markets over time, modeling the conditional variance instead of means, which permits us to recover time-varying conditional correlations. The volatility transmission, on the other hand, examines whether volatility triggered by a shock in the world market gets transmitted to various levels of domestic markets. An important feature of this analysis is that the method can tease out changes in the rate of transmission over time. For illustration, consider the case of ECX's relaying prices of coffee both in Addis Ababa and rural markets through price tickers. If this price dissemination mechanism is an improvement over the previous system and addresses information asymmetry, it should be reflected through a higher degree of volatility transmission.[12] In addition to interdependence and volatility transmission, we conduct an analysis to determine whether the establishment of ECX led to a structural break in the coffee price dynamics.

## The Econometric Model

To test the hypothesis outlined above, we use two specifications of an MGARCH model. This approach better captures the price dynamics between markets, as it formally accounts for market interactions in terms of the conditional second moment. The first specification, known as the dynamic conditional correlation (DCC) model, was proposed by Engle (2002) and is suitable for identifying changes in the degree of interdependence in spatially dispersed market locations over time. The other specification—originally proposed by Baba et al. (1991) but expanded by Engle and Kroner (1995)—is popularly known as the BEKK model for Baba, Engle, Kraft and Kroner. This specification is appropriate to examine the extent of volatility transmission across markets as it is flexible enough to account for own- and cross-volatility spillovers and persistence.[13] To examine whether ECX has improved the degree of price transmission, we focus on the transmission of volatility from international to domestic markets.[14]

Formally, consider the following vector stochastic process of price returns for each variety of coffee analyzed:

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[11] Certainly, being more connected to world markets, for example, may also make certain groups of populations more vulnerable to international price shocks, but quantifying this vulnerability is beyond the scope of the present study.

[12] Note that if the domestic market suffers from market failures, transmission of price volatility, especially for food staples, can have important negative effects on the poor. This issue was extensively discussed in the context of the 2007/2008 world food price crisis (see, for example, Robles and Torero 2010; Ivanic, Martin, and Zaman 2011; Bellemare, Barrett, and Just 2013).

[13] See Bauwens, Laurent, and Rombouts (2006) and Silvennoinen and Teräsvirta (2009) for an overview of different Multivariate Generalized Autoregressive Conditional Heteroskedasticity models.

[14] The estimated conditional mean and variance models are flexible enough to allow for bidirectional transmission between international and domestic markets. As expected, local Ethiopian prices do not significantly influence international prices.

$$r_t = \theta_0 + \sum_{j=1}^{p} \theta_j r_{t-j} + e_t,$$
$$e_t \mid I_{t-1} \sim (0, H_t), \quad (1)$$

where $r_t$ is a 3 × 1 vector of farm gate, auction, and international price returns; $\theta_0$ is a 3 × 1 vector of long-term drifts; $\theta_j$, $j$ = 1, …, $p$, are 3 × 3 matrices of parameters; and $e_t$ is a 3 × 1 vector of forecast errors for the best linear predictor of $r_t$, conditional on past information denoted by $I_{t-1}$, and with a corresponding variance-covariance matrix $H_t$. Similar to a standard Vector Autoregressive (VAR) model, the elements of $\theta_j$, $j$ = 1, …, $p$, provide direct measures of own- and cross-lead-lag relationships at the mean level between markets. It is worth noting that we checked for co-integration between producer, auction, and international log prices and did not find co-integrating relationships based on the Schwarz criterion of the Johansen test; hence, the VAR specification defined in equation 1 adequately captures the dynamics of the price returns used in the analysis.[15]

In the DCC model, the degree of volatility interdependence between markets is assumed to be time dependent across time and is captured through a conditional correlation matrix $R_t = (\rho_{ij,t})$, $i, j = 1,...,3$. The conditional variance-covariance matrix $H_t$ is defined as

$$H_t = D_t R_t D_t \quad (2)$$

where $D_t = diag(h_{11,t}^{1/2} ... h_{33,t}^{1/2})$; $h_{ii,t}$ is a Generalized Autoregressive Conditional Heteroskedasticity GARCH(1,1) specification, that is, $h_{iit} = \omega_i + \alpha_i e_{i,t-1}^2 + \beta_i h_{ii,t-1}$, i=1,…,3; $R_t = diag(q_{ii,t}^{-1/2}) Q_t diag(q_{ii,t}^{-1/2})$; $Q_t = (q_{ij,t}), i, j = 1,...,3,$ is a 3 × 3 symmetric positive-definite matrix given by $Q_t = (1-\alpha-\beta)\overline{Q} + \alpha u_{t-1} u_{t-1}^{'} + \beta Q_{t-1}$; and $u_{it} = e_{it} \big/ \sqrt{h_{iit}}$. $\overline{Q}$ is the 3 × 3 unconditional variance matrix of $u_t$, and $\alpha$ $\beta$ are nonnegative adjustment parameters satisfying $\alpha + \beta < 1$. The unconditional variance matrix $Q_t$ could be seen as an autoregressive moving average–type process capturing short-term deviations in the correlation around its long-run level.

In the BEKK model, the conditional variance-covariance matrix $H_t$ with one time lag is given by

$$H_t = C'C + A' e_{t-1} e_{t-1}^{'} A + G' H_{t-1} G, \quad (3)$$

where $C$ is a 3 × 3 upper triangular matrix of constants $c_{ij}$, $A$ is a 3 × 3 matrix of elements $a_{ij}$ that capture the degree of innovation from market $i$ to market $j$, and $G$ is a 3 × 3 matrix of elements $g_{ij}$ that measure the persistence in conditional volatility between markets $i$ and $j$. This specification allows us to analyze the magnitude and persistence of volatility transmission across the markets under analysis. We can derive impulse-response functions for the estimated conditional volatilities to show, for example, how a shock in international markets may affect local auction and producer markets.

[15] Further details are available on request.

## 4. THE DATA AND THEIR TIME SERIES PROPERTIES

This study heavily relies on the monthly average coffee prices at three levels: farmgate prices (producer price), the Addis Ababa price (auction price until 2008; ECX prices thereafter), and the international price of coffee Arabica. The period of analysis is January 1992 through June 2013. The producer price data are from five major Ethiopian coffee-growing sites, namely, Sidama, Yirgachefe, Harar, Lekemt, and Jimma. The five varieties considered in our analysis account for about 95 percent of the total coffee produced and exported in the country.[16] A distinguishing feature of the Ethiopian coffee is that, unlike many other coffee-growing countries, the specific locations of production are widely recognized at both domestic and international markets. For instance, two major varieties of coffee grown in the country, Sidama and Yirgachefe, are named after the locations in the Southern Nations and Nationalities region where these coffees are grown. Similarly, Harar and Jimma are named after two locations in Oromia. Recently, Ethiopia also secured exclusive trademark rights for Sidama, Yirgachefe, and Harar coffee, which further highlights these distinguishing features of the Ethiopian coffee types.[17]

Producer prices are compiled from the monthly report of the producer price surveys published by the country's statistical office, the Central Statistical Agency.[18] Pre-ECX auction prices, covering January 1992 to December 2008, were obtained from the Agricultural Market Promotion Department of the Ministry of Agriculture, and January 2009–onward prices were gathered directly from ECX.[19] The international price is the New York Arabica coffee price indicator calculated by the International Coffee Organization on the basis of different Arabica coffees traded.[20] Since the dataset covers times both before and since ECX, it enables us to examine whether there have been important changes since the enactment of mandatory trading through ECX, which became effective in January 2009. All prices in the analysis are standardized to US cents per pound.

Figure 4.1 shows the evolution of the international price and the producer and auction prices for the five coffee varieties. We observe that international and local prices, particularly auction prices, generally co-move in all five markets. The important spikes in the international price of coffee in 1994 and 2011, due to weather-related supply disruptions in Brazil and Colombia, also are observed in the auction price across all five coffee varieties; the international price spike of 1997, also due to supply shortages, is observed only in the auction price in Yirgachefe. Producer prices in all five markets, in turn, exhibit an important spike only in 2011. Table A.2 compares producer coffee prices collected in monthly surveys by the Central Statistical Agency, before and after the implementation of ECX, and shows that prices in all local markets have increased in recent years.

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[16] According to the Ethiopian Coffee Authority, in 2011 Sidama accounted for 41 percent (65,470 bags) of the total country exports, Jimma for 21 percent (33,476 bags), Lekempt for 17 percent (26,128 bags), Harar for 9 percent (13,697 bags), and Yirgachefe for 6 percent (9,914 bags).

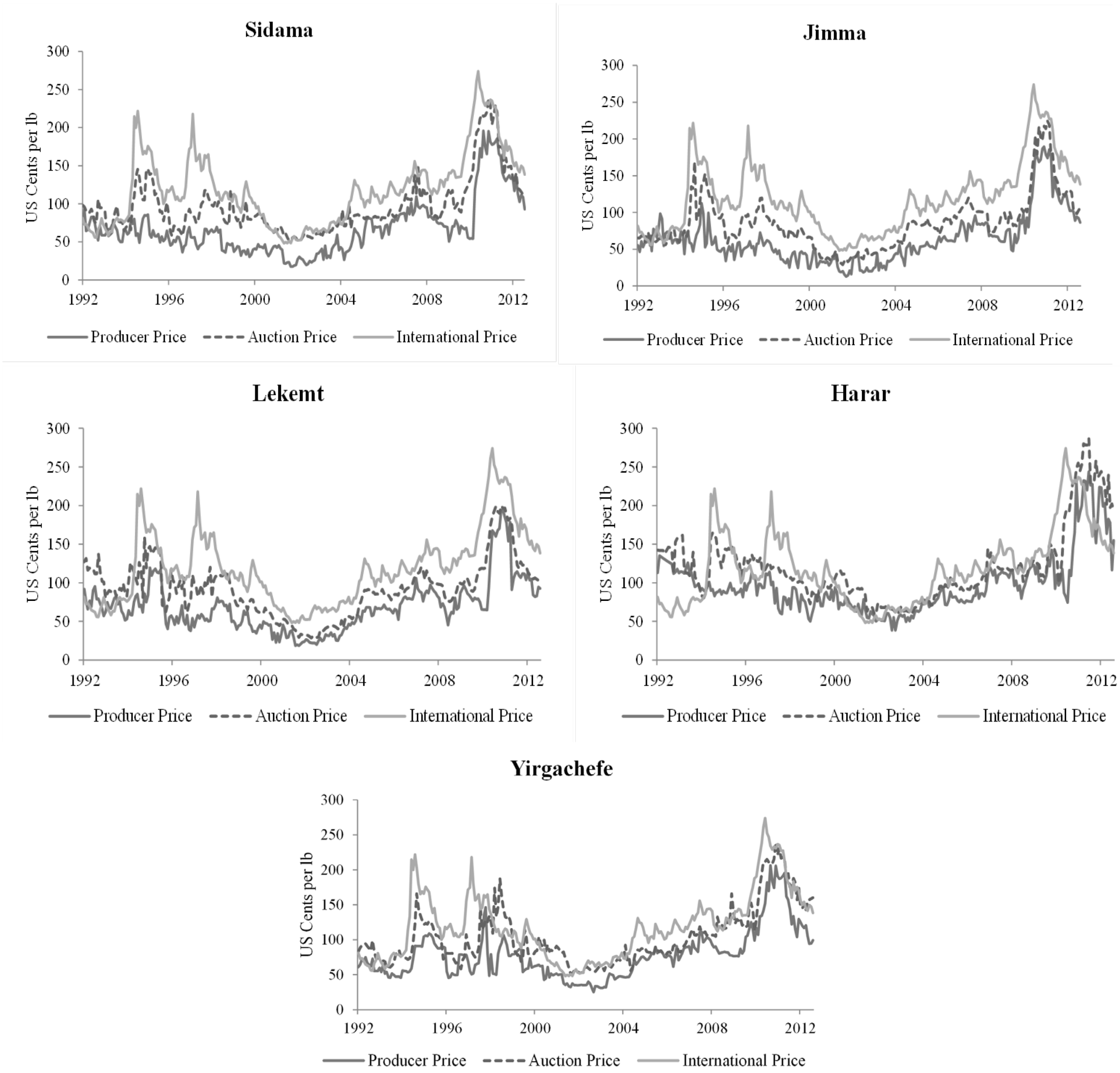
[17] Ethiopia has owned the trademark rights for the distinctive fine coffee of the Sidama, Yirgacefe, and Harar brands since 2008.

[18] The Central Statistical Agency conducts monthly surveys and has released monthly reports since 1981. Monthly Bulletins Numbers 44 to 450 were used to compile the producer price data.

[19] Prior to 2009, the Agricultural Market Promotion Department kept record in monthly (unpublished) bulletins of the average prices paid to suppliers at the Coffee Auction Market.

[20] We also considered the Brazilian Naturals price indicator as another relevant approximation of the international price for Ethiopian coffee and found qualitatively similar results. The Brazilian Naturals price indicator is the combination of ex-dock prices in New York and Germany of a group of traditional exporting coffee countries including Ethiopia. The correlation between the New York and Brazilian Naturals prices is .987.

**Figure 4.1 Producer, auction, and international prices**



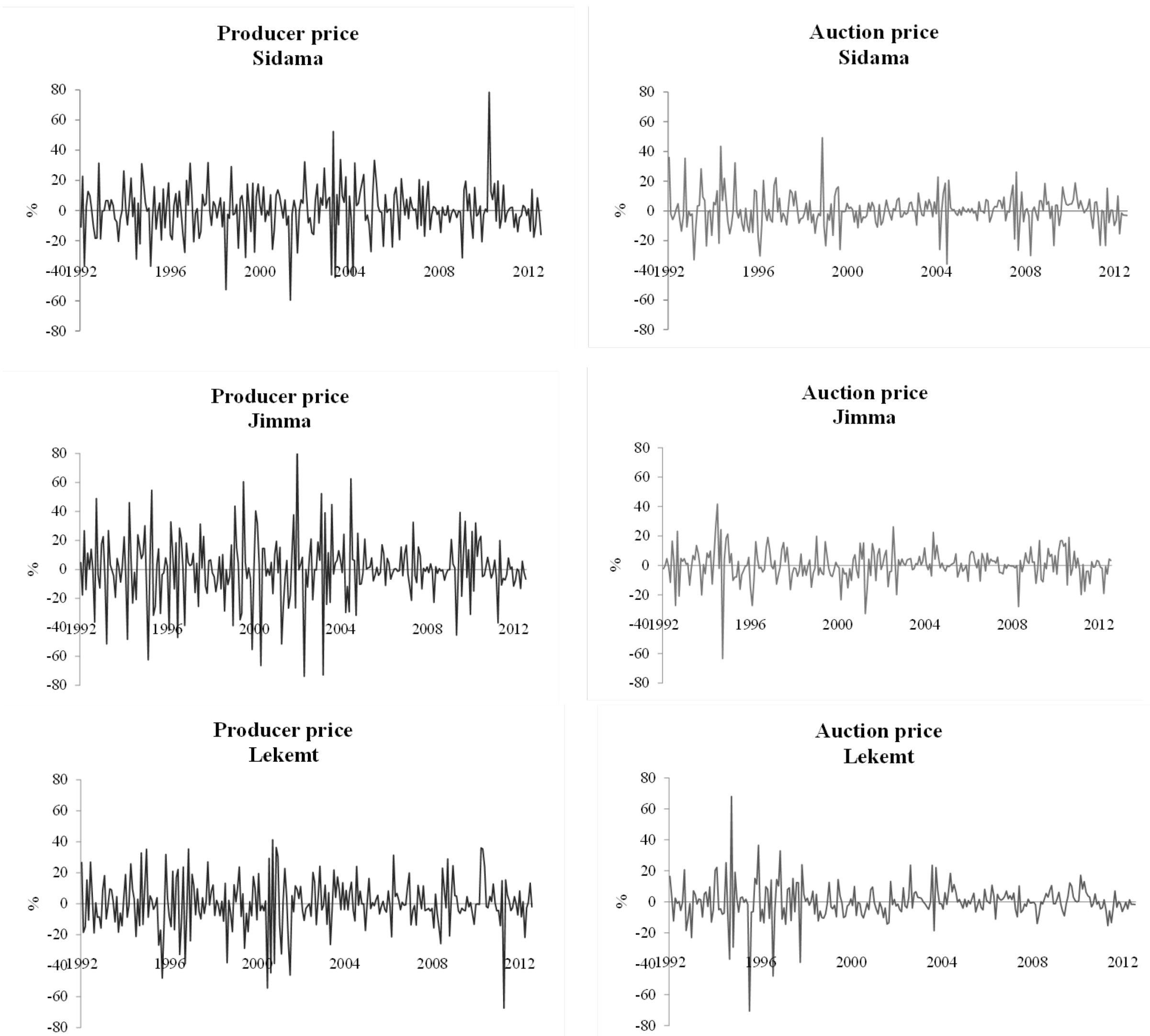

Source: Average producers' price of agricultural products in rural Ethiopia obtained from Statistical Monthly Bulletins numbers 132 to 384 (Ethiopia, CSA various years). Auction prices obtained from Agricultural Market Promotion Department from unpublished coffee statistics bulletin compiled for the period January 1992 to December 2008 (Ethiopia, MoARD various years) and from the Ethiopian Commodity Exchange for the period January 2009 to June 2013 (ECE various years). International prices from the International Coffee Organization (ICO various years).

Note: lb = pound.

Figure 4.2 plots the corresponding price returns, defined as $r_{it} = \ln(p_{it}/p_{it-1})$, where $p_{it}$ is the price of coffee at time *t* for location *i* (producer, auction, or international). This logarithmic transformation is generally used in empirical finance as a standard measure for net returns in a market, but the transformation has added advantage from an econometric standpoint, as it makes the time series stationary (Enders 2014). Two patterns emerge from this figure. First, all price returns exhibit important fluctuations across time, which is indicative of time-varying volatility in returns and motivates the use of

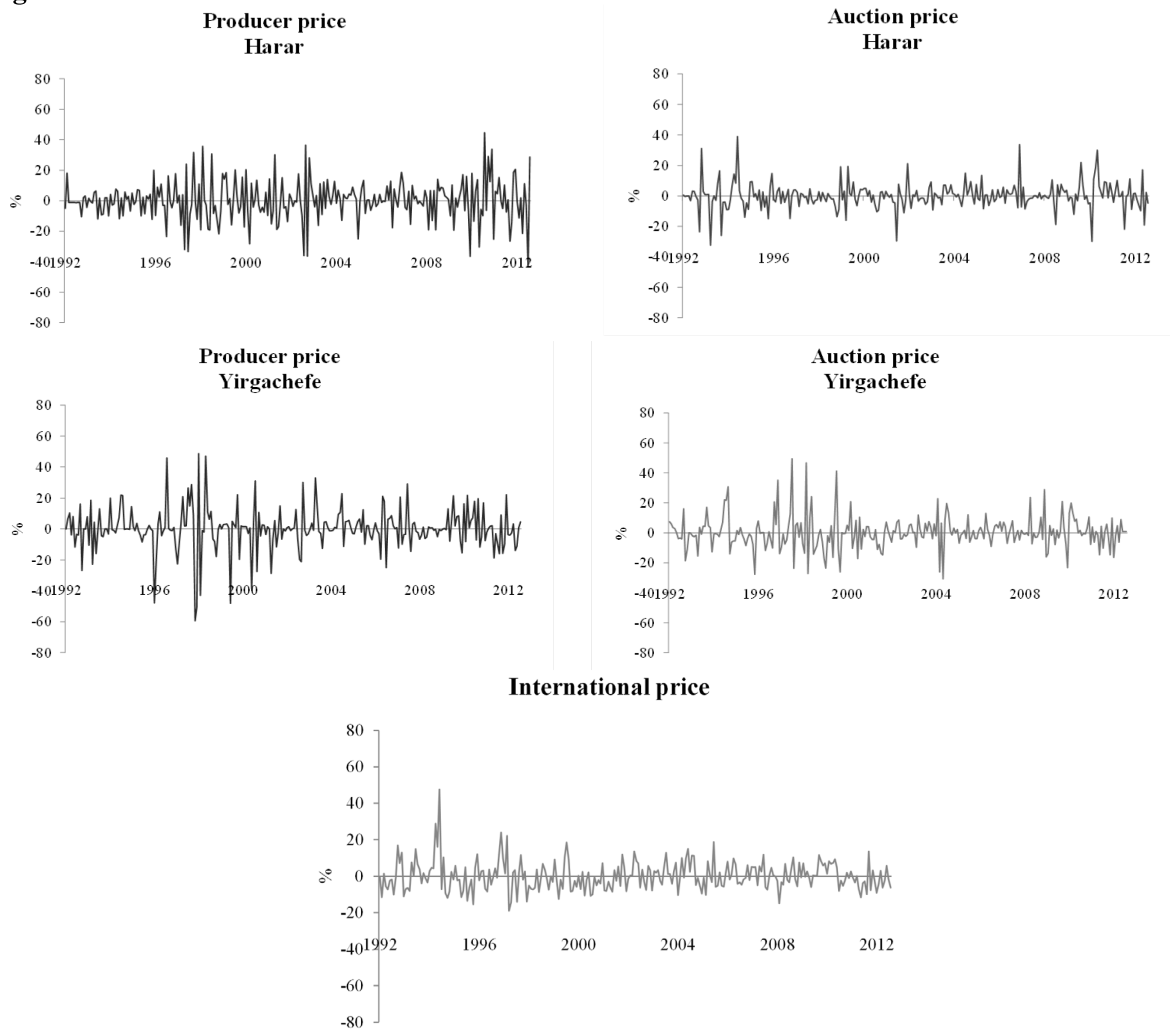
MGARCH models. Second, the fluctuations in price returns decrease as we move from producer to auction and international markets; that is, the returns in international markets are more stable than in auction and producer markets.[21] At the producer level, Jimma is clearly the region that shows the highest fluctuations during the sample period. Jimma's coffee is of lower quality compared to the other four coffee varieties, fluctuating between third- and second-grade coffee, which could explain this higher dispersion.

**Figure 4.2 Producer, auction, and international price returns**




[21] This is the opposite, for example, of the case of Uganda where farmgate coffee prices seem to fluctuate much less than international prices (Fafchamps and Vargas Hill 2008).

**Figure 4.2 Continued**




Source: Producer prices were obtained from Monthly Statistical Bulletins Numbers 44 to 450 (Ethiopia, CSA various years). Auction prices obtained from the Ministry of Agriculture and Rural Development for the period January 1992 to December 2008 (MoARD various years) and the Ethiopian Commodity Exchange for the period January 2009 to June 2013 (ECE various years). International prices obtained from the International Coffee Organization (ICO various years).

Table 4.1 reports summary statistics of all returns series. We observe that the returns in the international market are on average higher than in the auction and producer markets. In particular, the average monthly return in the international market is 0.2 percent, which is only exceeded by the average return in the auction market in Yirgachefe (0.28 percent). Yirgachefe is also the region that—together with Jimma—exhibits the highest return in the producer market (0.19 percent), although Jimma shows a much higher dispersion. We also note that the returns are on average higher in auction than producer markets in Sidama, Harar, and Yirgachefe.[22] As noted above, producer returns show a higher variation (standard deviation) than the returns in the other markets; in particular, they exhibit between 1.2 and 2.1 times more dispersion than auction returns and between 1.6 and 2.7 times more dispersion than international returns.

[22] When segmenting the sample, we find that producer and auction price returns seem to have increased across time in most of the analyzed coffee markets, as opposed to the price returns in the international market. As shown in Table A.3, in the 1990s and early 2000s the average returns in several of the markets were negative. Yet we start to observe higher average returns from 2005 and not necessarily after the implementation of the Ethiopian Commodity Exchange in December 2008.

**Table 4.1 Summary statistics for price returns**

| Statistic | Sidama | | Jimma | | Lekemt | | Harar | | Yirgachefe | | International price |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Producer price | Auction price | Producer price | Auction price | Producer price | Auction price | Producer price | Auction price | Producer price | Auction price | |
| Mean | 0.045 | 0.179 | 0.190 | 0.179 | 0.107 | –0.025 | 0.103 | 0.119 | 0.189 | 0.282 | 0.203 |
| Median | 0.587 | 0.000 | 0.299 | 0.095 | –0.461 | –0.590 | 0.080 | –0.040 | 0.000 | –0.142 | –0.774 |
| Minimum | –59.533 | –35.786 | –73.760 | –63.393 | –67.481 | –70.616 | –42.505 | –32.306 | –59.324 | –30.632 | –19.066 |
| Maximum | 78.392 | 49.232 | 87.960 | 41.654 | 41.278 | 67.947 | 44.558 | 38.849 | 48.691 | 49.506 | 47.499 |
| Standard deviation | 16.338 | 11.425 | 21.901 | 10.578 | 16.039 | 11.676 | 13.131 | 8.660 | 13.653 | 10.887 | 8.032 |
| Skewness | –0.018 | 0.388 | –0.114 | –0.737 | –0.462 | –0.276 | –0.034 | 0.306 | –0.404 | 0.847 | 1.168 |
| Kurtosis | 5.854 | 5.867 | 5.122 | 8.643 | 4.802 | 13.404 | 4.260 | 7.539 | 7.079 | 6.702 | 7.406 |
| Jarque-Bera | 87.6 | 94.9 | 49.0 | 365.7 | 44.1 | 1167.0 | 17.1 | 225.5 | 185.9 | 178.2 | 267.4 |
| *p* value | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| Number of observations | 258 | 258 | 258 | 258 | 258 | 258 | 258 | 258 | 258 | 258 | 258 |
| | Returns correlations | | | | | | | | | | |
| AC (lag = 1) | –0.164* | –0.082 | –0.253* | –0.001 | –0.186* | –0.158* | –0.298* | –0.026 | –0.067 | –0.089 | 0.177* |
| AC (lag = 2) | 0.015* | –0.056 | –0.106* | 0.011 | 0.028* | 0.034* | 0.074* | –0.005 | –0.087 | –0.018 | 0.140* |
| LB (6) | 14.470* | 7.477 | 27.301* | 15.871* | 11.616 | 20.505* | 32.466* | 9.057 | 7.159 | 5.952 | 24.994* |
| LB (12) | 25.736* | 15.832 | 45.358* | 22.256* | 15.843 | 30.606* | 36.626* | 15.596 | 15.576 | 21.383* | 33.070* |
| | Squared returns correlations | | | | | | | | | | |
| AC (lag = 1) | 0.049 | 0.068 | 0.0792 | 0.1175 | 0.183* | 0.171* | 0.231* | 0.074 | 0.307* | 0.193* | 0.109 |
| AC (lag = 2) | –0.053 | 0.070 | 0.0610 | 0.0685 | 0.214* | 0.041* | 0.1930* | –0.010 | 0.223* | 0.124* | 0.262* |
| LB (6) | 3.756 | 3.398 | 11.666 | 36.803* | 26.717* | 10.625 | 40.263* | 8.218 | 53.198* | 16.109* | 22.185* |
| LB (12) | 6.110 | 11.699 | 20.471* | 37.496* | 31.246* | 58.279* | 53.816* | 11.754 | 55.135* | 60.571* | 24.453* |
| | Tests for stationarity | | | | | | | | | | |
| ADF (lag = 6) | –7.096* | –6.561* | –7.534* | –5.744* | –7.546* | –5.866* | –6.869* | –7.296* | –8.067* | –7.235* | –5.901 * |
| KPSS (lag = 6) | 0.039 | 0.047 | 0.043 | 0.056 | 0.035 | 0.060 | 0.023 | 0.036 | 0.039 | 0.040 | 0.060 |

Source: Authors' estimations.

Note: AC = autocorrelation coefficient; LB = Ljung-Box autocorrelation test; ADF = Augmented Dickey-Fuller test; KPSS = Kwiatkowski-Phillips-Schmidt-Shin test for stationarity. *Rejection of the null hypothesis at the 5 percent significance level.

In addition, the Jarque-Bera test reveals that all returns series seem to follow a nonnormal distribution. The kurtosis is greater than three in all series, pointing to a leptokurtic distribution of returns and motivating the use of a Student's *t* density in the estimation of the DCC and BEKK models (hereafter T-DCC and T-BEKK). The Ljung-Box (LB) for up to 6 and 12 lags generally rejects the null hypothesis of no autocorrelation for the squared returns in most markets, which further motivates the use of MGARCH models given the apparent nonlinear dependencies in returns. Last, the Augmented Dickey-Fuller and Kwiatkowski-Phillips-Schmidt-Shin tests confirm the stationarity of the returns series.

# 5. RESULTS

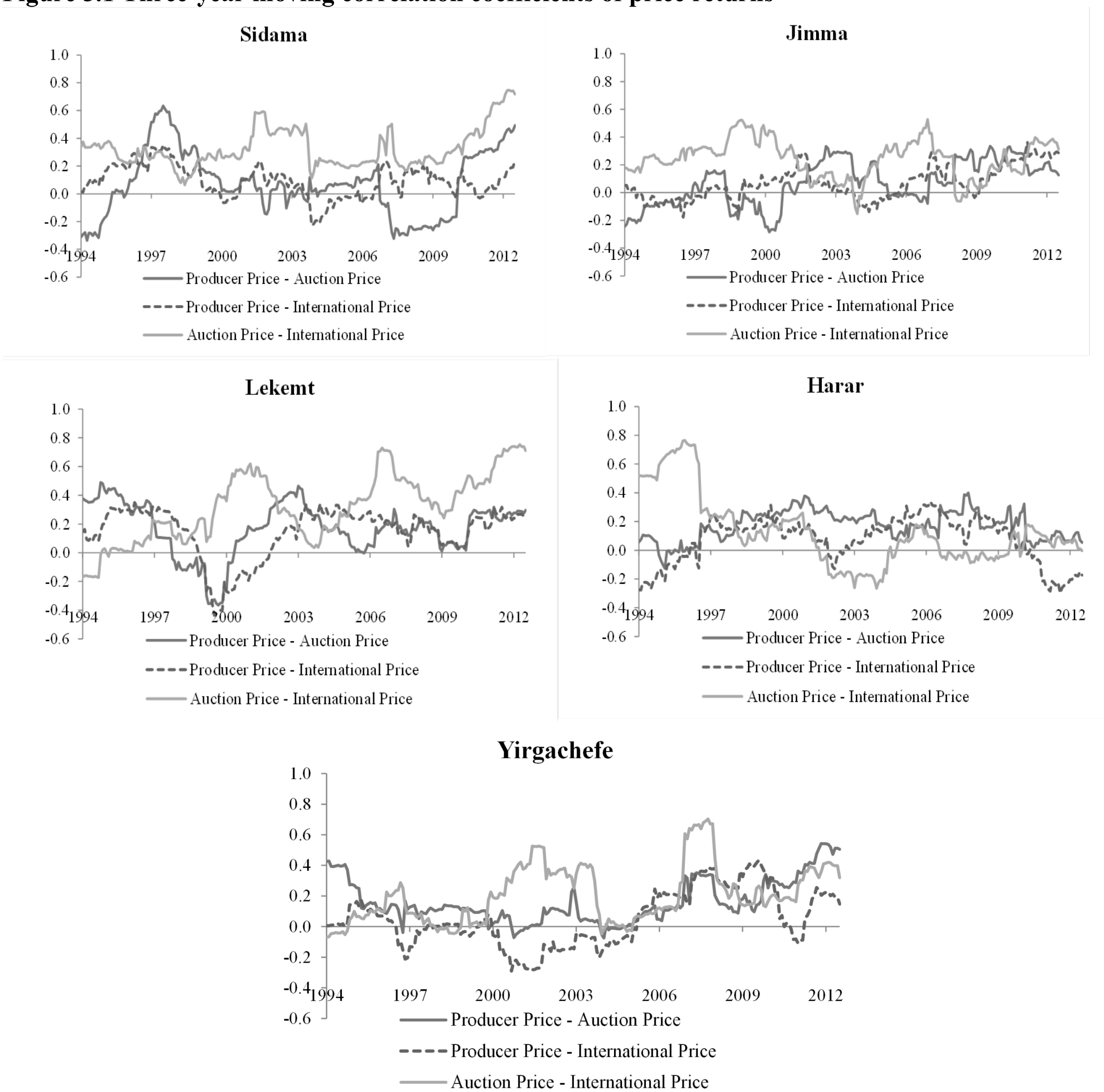
While the main analytical focus is on the econometrics of spatial price relationships, we begin by presenting some preliminary analysis to set the context. In particular, we first examine the co-movement of price returns across markets based on unconditional correlations. The econometric results are then presented in three subsections under the headings of interdependence, volatility transmission, and structural changes, respectively. We first focus on the estimation results of the T-DCC model, which allows us to identify whether the degree of interdependence (conditional correlations) between markets has changed due to the establishment of ECX (and regulations to support it). The discussion of the results of the T-BEKK model, which examines volatility transmission, is presented next. The third and final subsection discusses the results of our tests for the structural breaks in the price dynamics.

## Preliminary Analysis

Figure 5.1 presents three-year pairwise Pearson correlations between producer, auction, and international markets in all five growing regions. Each point in the figure indicates the correlation coefficient between the two returns series during the past three years.[23] In terms of levels, auction and international price returns show a higher correlation than producer and auction and international returns in most markets (except Harar). In terms of the evolution across time, Sidama is the region that shows a higher interdependence across markets in recent years, particularly after 2009 when trading through ECX became effective. We observe an important increase in the region in the correlation between auction and international price returns, between producer and auction returns, and to a lesser extent between producer and international returns. Lekemt also shows an important increase in the past few years in the correlation between auction and international markets while Yirgachefe exhibits a higher interlinkage between producer and auction markets. The Jimma and Harar markets, in contrast, do not show any specific trend in the correlation between local and international prices. Opposite to Jimma, Harar's coffee has the highest quality relative to the other varieties. It is likely that as a well-established high premium coffee, the institutional changes resulting from the implementation of ECX may not have further changed the price linkages of this variety with international markets.

[23] Hence, the first values in the graph report correlation coefficients for the years 1992, 1993, and 1994.

**Figure 5.1 Three-year moving correlation coefficients of price returns**




Source: Authors' estimations.

These patterns are further confirmed in Table 5.1, which reports pairwise correlations for different subsample periods. For example, we find that the correlation between international and auction markets in Sidama increased from 0.37 in 1992 to 1995 to 0.64 in 2009 to 2013 and from zero to 0.63 in Lekemt; the correlation between these markets also increased in Yirgachefe, from zero to 0.33, but it was highest (0.45) in 2005 to 2008. Similarly, the correlation between producer and auction markets increased to 0.35 in Sidama, while in Yirgachefe it returned to the levels exhibited at the beginning of the sample period (around 0.4). Overall, a preliminary analysis suggests that only a few growing regions exhibit a higher interrelation with global markets in recent years, particularly Sidama and Lekemt at the auction-international price level.

**Table 5.1 Unconditional correlations of price returns**

| Price | January 1992–December 1995 | | | January 1996–December 2004 | | | January 2005–December 2008 | | | January 2009–June 2013 | | | Full sample | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PP | AP | IP | PP | AP | IP | PP | AP | IP | PP | AP | IP | PP | AP | IP |
| Sidama | | | | | | | | | | | | | | | |
| PP | 1.000 | –.201 | .044 | 1.000 | .194* | .059 | 1.000 | –.125 | .259 | 1.000 | .346* | .126 | 1.000 | .070 | .089 |
| AP | | 1.000 | .368* | | 1.000 | .221* | | 1.000 | .285* | | 1.000 | .636* | | 1.000 | .333* |
| IP | | | 1.000 | | | 1.000 | | | 1.000 | | | 1.000 | | | 1.000 |
| Jimma | | | | | | | | | | | | | | | |
| PP | 1.000 | –.181 | .004 | 1.000 | .108 | .051 | 1.000 | –.020 | .078 | 1.000 | .207 | .240 | 1.000 | .021 | .060 |
| AP | | 1.000 | .216 | | 1.000 | .211* | | 1.000 | .473* | | 1.000 | .266 | | 1.000 | .242* |
| IP | | | 1.000 | | | 1.000 | | | 1.000 | | | 1.000 | | | 1.000 |
| Lekemt | | | | | | | | | | | | | | | |
| PP | 1.000 | .403* | .194 | 1.000 | .062 | .099 | 1.000 | .171 | .207 | 1.000 | .225 | .198 | 1.000 | .187* | .146* |
| AP | | 1.000 | –.048 | | 1.000 | .222* | | 1.000 | .593* | | 1.000 | .624* | | 1.000 | .167* |
| IP | | | 1.000 | | | 1.000 | | | 1.000 | | | 1.000 | | | 1.000 |
| Harar | | | | | | | | | | | | | | | |
| PP | 1.000 | .017 | .101 | 1.000 | .244* | .152 | 1.000 | .242 | .260 | 1.000 | .083 | –.148 | 1.000 | .143* | .038 |
| AP | | 1.000 | .491* | | 1.000 | .062 | | 1.000 | .000 | | 1.000 | .057 | | 1.000 | .204* |
| IP | | | 1.000 | | | 1.000 | | | 1.000 | | | 1.000 | | | 1.000 |
| Yirgachefe | | | | | | | | | | | | | | | |
| PP | 1.000 | .410* | .021 | 1.000 | .052 | –.066 | 1.000 | .267 | .323* | 1.000 | .404* | .150 | 1.000 | .161* | .027 |
| AP | | 1.000 | –.004 | | 1.000 | .095 | | 1.000 | .453* | | 1.000 | .331* | | 1.000 | .135* |
| IP | | | 1.000 | | | 1.000 | | | 1.000 | | | 1.000 | | | 1.000 |
| Number of observations | | | 48 | | | 108 | | | 48 | | | 54 | | | 258 |

Source: Authors' estimations.
Note: PP = producer price; AP = auction price; IP = international price. The correlations reported are Pearson correlations. *Significance at the 5 percent level.

## Econometric Results

### *Market Interdependence*

Table A.4 presents the full estimation results of the T-DCC model. The upper panel reports the estimated coefficients of the conditional mean equation, and the lower panel reports the coefficients of the conditional variance-covariance matrix defined in equation 2. The estimated degrees of freedom parameter ($v$) is relatively small in all cases, ranging between 4 and 6, which supports the adequacy of the estimations using a Student's *t* distribution. The residual diagnostic tests, reported at the bottom of the table, also support the appropriateness of the model specification. The LB, Lagrange Multiplier (LM), and Hosking Multivariate Pormanteau (M) test statistics for 6 and 12 lags generally show no or weak evidence of autocorrelation, Autoregressive Conditional Heteroskedasticity (ARCH) effects, and cross-correlation in the standardized model residuals.

In terms of interactions at the mean level, we do not find any own- and cross-lead-lag relationships in the return series analyzed in each of the five regions. The Schwarz's Bayesian information criterion indicates that the expected price returns in a certain month do not depend on their past values and are not affected by past returns in the other markets. Hence, lagged local and international price returns do not seem to affect current local price returns at the mean level.

Turning to the conditional variance-covariance equation, however, we do find time-varying conditional correlations between international and domestic price returns in some regions. In particular, the Wald test rejects the null hypothesis that the adjustment parameters $\alpha$ and $\beta$ are jointly equal to zero with a 95 percent confidence level in Sidama, Lekemt, and Yirgachefe. In Jimma and Harar, in turn, these correlations seem to have remained relatively constant over the entire period of analysis.

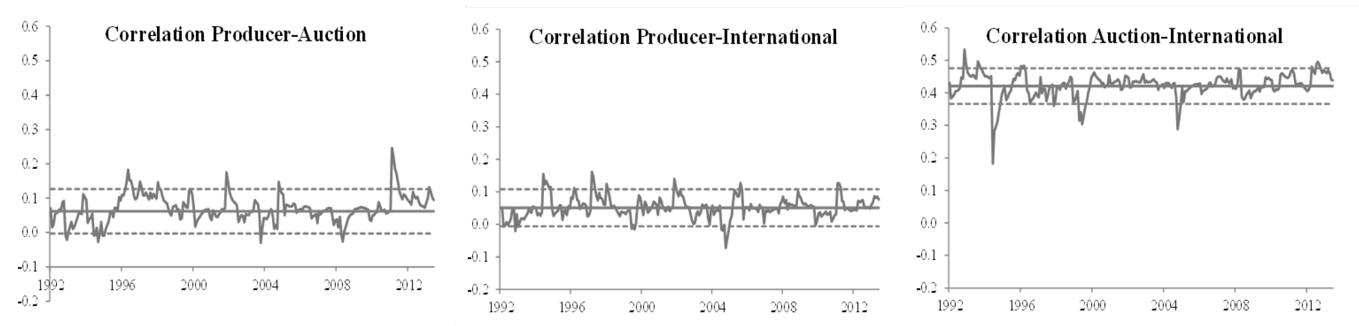
For a better understanding of the dynamics of correlations, Figure 5.2 presents the pairwise DCCs between producer, auction, and international price returns for each growing region, resulting from the T-DCC model estimates.[24] Several patterns emerge from the figures. First, the estimated conditional correlations confirm a higher interdependence between auction and international markets as compared to producer with auction and international markets. Second, we observe important fluctuations across time in the correlation between international and domestic markets, particularly in Lekemt and Sidama, and to a lower extent in Yirgachefe; in Jimma and Harar, which are the coffee varieties of the lowest and highest quality among the five varieties, the correlations across markets have remained fairly constant across time.[25] Third, similar to the preliminary analysis based on unconditional correlations, Lekemt and Sidama show a higher interdependence between auction and international markets in more recent years. The case of Lekemt is particularly notable; as shown in Table 5.2, which reports the average conditional correlations for different subperiods, the correlation between the auction market in Lekemt and the international market more than doubled from 0.20 in 1992 to 1995 to 0.44 in 2009 to 2013. In Sidama, this correlation has already been relatively high, fluctuating around 0.42 between 1992 and 2008, but it further increased to 0.44 after 2008. The auction market in Yirgachefe also shows a higher interrelation with the international market (as compared to the early 1990s), but the increase in the correlation occurred prior to 2009.

[24] The figure also includes constant conditional correlations and one standard deviation confidence bands based on Bollerslev's (1990) Constant Conditional Correlation model.

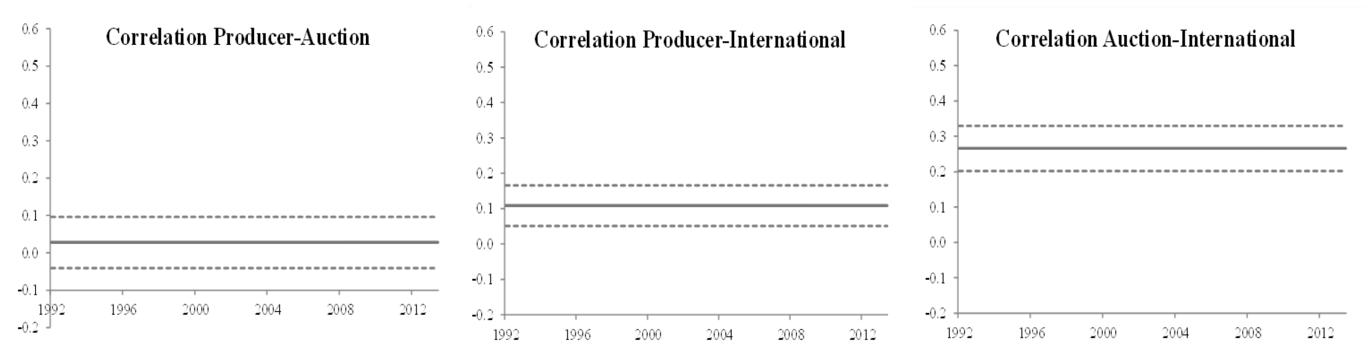
[25] In the case of Jimma and Harar, the correlations across markets could still have changed across time, but marginally. The resulting constant correlations are just indicative that a Constant Conditional Correlation model provides a better fit for the data than a Dynamic Conditional Correlation model.

**Figure 5.2 Dynamic conditional correlations based on T-DCC model**

**Sidama**




**Jimma**




**Lekemt**

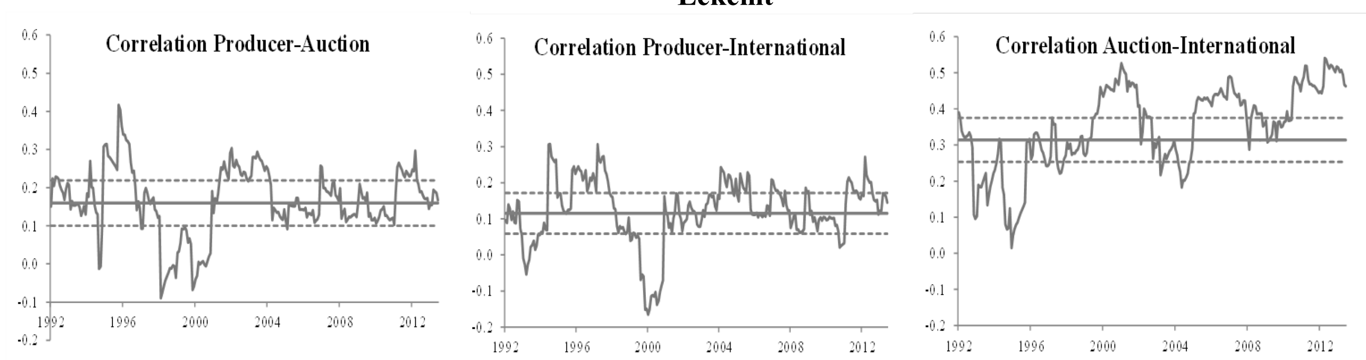
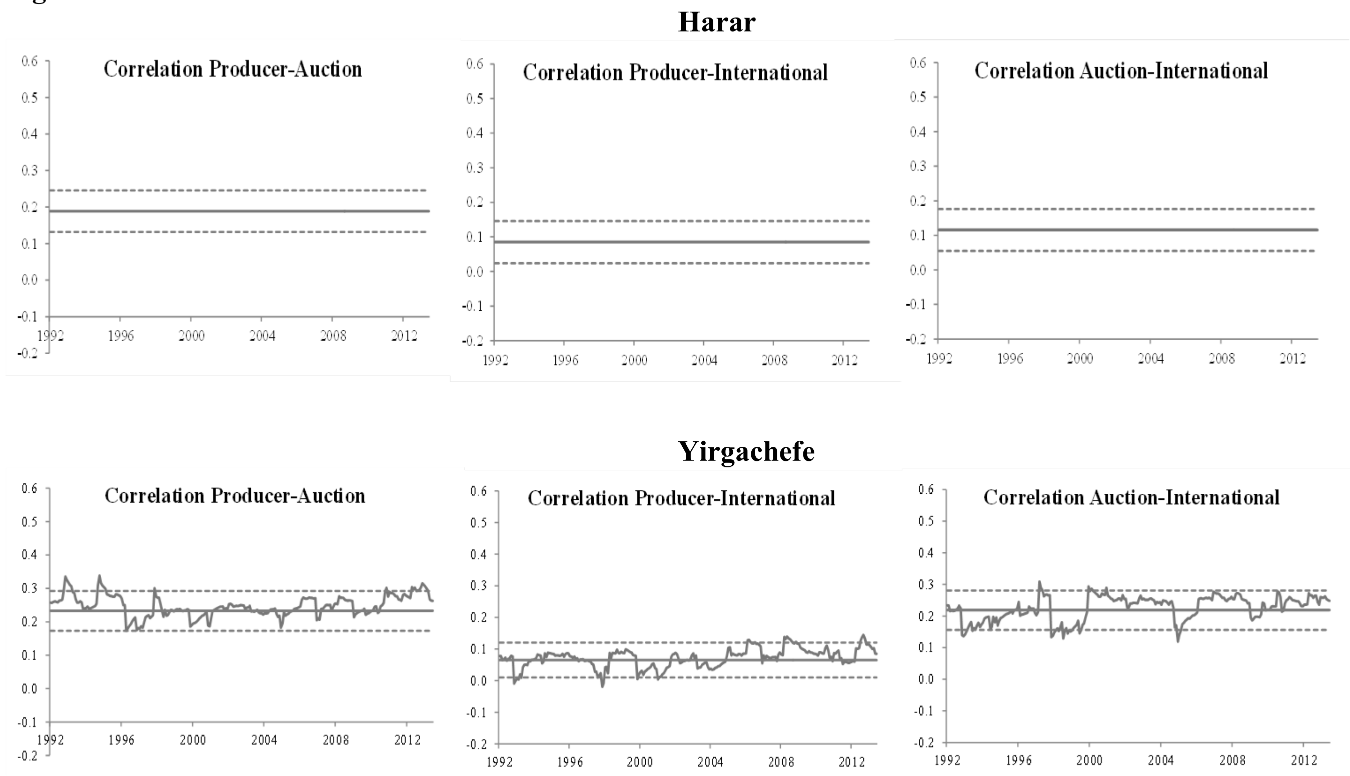


**Figure 5.2 Continued**




Source: Authors' estimations based on the T-DCC model.
Note: The solid line is the estimated constant conditional correlation following Bollerslev (1990), with confidence bands of one standard deviation.

**Table 5.2 Average conditional correlations for different subperiods based on T-DCC model**

| Correlation | January 1992–December 1995 | January 1996–December 2004 | January 2005–December 2008 | January 2009–June 2013 | Full sample |
|---|---|---|---|---|---|
| | | | **Sidama** | | |
| Producer-Auction | .041 | .080 | .055 | .091 | .070 |
| | (.035) | (.039) | (.025) | (.040) | (.041) |
| Producer-International | .042 | .052 | .058 | .054 | .052 |
| | (.037) | (.037) | (.024) | (.026) | (.033) |
| Auction-International | .420 | .416 | .420 | .440 | .423 |
| | (.061) | (.035) | (.022) | (.025) | (.039) |
| | | | **Jimma** | | |
| Producer-Auction | .028 | .028 | .028 | .028 | .028 |
| | (.000) | (.000) | (.000) | (.000) | (.000) |
| Producer-International | .108 | .108 | .108 | .108 | .108 |
| | (.000) | (.000) | (.000) | (.000) | (.000) |
| Auction-International | .266 | .266 | .266 | .266 | .266 |
| | (.000) | (.000) | (.000) | (.000) | (.000) |
| | | | **Lekemt** | | |
| Producer-Auction | .203 | .148 | .153 | .177 | .165 |
| | (.084) | (.114) | (.037) | (.049) | (.089) |
| Producer-International | .114 | .110 | .138 | .134 | .121 |
| | (.090) | (.111) | (.046) | (.054) | (.088) |
| Auction-International | .201 | .336 | .417 | .441 | .348 |
| | (.101) | (.088) | (.037) | (.069) | (.115) |
| | | | **Harar** | | |
| Producer-Auction | .189 | .189 | .189 | .189 | .189 |
| | (.000) | (.000) | (.000) | (.000) | (.000) |
| Producer-International | .085 | .085 | .085 | .085 | .085 |
| | (.000) | (.000) | (.000) | (.000) | (.000) |
| Auction-International | .116 | .116 | .116 | .116 | .116 |
| | (.000) | (.000) | (.000) | (.000) | (.000) |
| | | | **Yirgachefe** | | |
| Producer-Auction | .275 | .227 | .249 | .265 | .248 |
| | (.027) | (.024) | (.021) | (.029) | (.032) |
| Producer-International | .065 | .055 | .098 | .090 | .072 |
| | (.025) | (.025) | (.023) | (.021) | (.030) |
| Auction-International | .192 | .226 | .239 | .238 | .225 |
| | (.027) | (.045) | (.034) | (.023) | (.040) |
| Number of observations | 48 | 107 | 49 | 54 | 258 |

Source: Authors' estimations based on the T-DCC model.
Note: Standard deviations are reported in parentheses.

The correlation between producer and auction markets in Sidama also exhibits an important increase after 2008, although the level of interdependence between these markets (0.09) is still not as strong as in Yirgachefe, Harar, and Lekemt (0.18–0.27). In both Lekemt and Yirgachefe, however, the degree of correlation between producer and auction price returns is lower in recent years than in the early 1990s. Finally, international and producer markets in Sidama, Lekemt, and Yirgachefe also appear to have become more interconnected during the past decade, but the increase in the correlation did not necessarily occur after 2008 when the regulation of trading and exporting all coffee through ECX became effective.

Despite some differences in the evolution of the correlations between local and international prices across different coffee varieties, the existence of the Coffee Auction Market (CAM) prior to ECX could generally explain the relatively high correlation between international and auction prices and the lack of further significant increases in the correlation between international and several domestic coffee prices after 2008. CAM was established by the Ethiopian government in 1992 as part of the liberalization of the domestic coffee marketing system. Thus, some markets could already have been more connected to world markets, and it would probably take a couple more years to observe the full effects of ECX in terms of further linking local coffee producers to global markets. Note also that while market (price) transparency has further increased with the implementation of ECX (favoring a higher correlation between domestic and international prices), direct trade agreements between exporters and local coffee producers have disappeared (favoring a lower correlation between domestic and international prices).

As an additional analysis, we examine whether local Ethiopian coffee markets have become more integrated at the producer and auction levels in recent years. We estimate two separate T-DCC models, one model including the five producer price returns series (corresponding to the five coffee varieties) and a second model including the five auction price returns series. The full estimations results are reported in Table A.5, while Figure A.2 presents the estimated pairwise conditional correlations for different subsample periods. Two patterns are worth remarking from the figure. First, markets are more integrated at the auction than at the producer level; except for Lekemt and Harar, the conditional correlations between markets at the auction level are higher and in most cases more than double the conditional correlations at the producer level. Second, markets in Ethiopia at both the producer and the auction stages have not necessarily become more integrated after the implementation of ECX.

### *Volatility Transmission*

We now turn to examine the cross-volatility dynamics from international to domestic price returns based on the estimation results of the T-BEKK model. Since we are interested in analyzing volatility interactions between international and domestic markets before and after the mandatory regulation of trading all coffee through ECX, we estimate the model over two subperiods: 1992 through 2008 and 2009 through 2013. Tables A.6 and A.7 present the corresponding results with the estimated coefficients of the conditional variance-covariance matrix defined in equation 3.[26] As in the T-DCC model, *v* supports the adequacy of the estimation with a Student's *t* distribution, and the reported diagnostic tests for the standardized squared residuals (LB, LM, and M statistics) generally support the appropriateness of the model specification.

The diagonal $a_{ii}$ coefficients, $i = 1,...,3$, capture own-volatility spillovers (the effect of own-lagged shocks on the current conditional return volatility in market *i*), while the diagonal $g_{ii}$ coefficients capture own-volatility persistence (the dependence of volatility in market *i* on its own past volatility). The off-diagonal coefficients $a_{ij}$ and $g_{ij}$ measure, in turn, direct spillover and persistence effects from market *i* to market *j*. The Wald joint test for cross-volatility rejects the null hypothesis that the off-diagonal

[26] To save space, we do not report the estimated constant terms in the conditional mean equation, which are similar to the Student's *t* density in the estimation of the Dynamic Conditional Correlation estimates.

coefficients $a_{ij}$ and $g_{ij}$ are jointly equal to zero, indicating that there are cross-spillovers and persistence effects across markets.

To examine volatility spillovers between specific markets, specifically from international to domestic markets, it is important to account for both direct and indirect cross-effects. This is because markets may be directly related through the conditional variance and indirectly related through the conditional covariance.[27] Following Gardebroek and Hernandez (2013) and Hernandez, Ibarra, and Trupkin (2014), we derive impulse-response functions, which control for both direct and indirect effects, to simulate how a shock in the (conditional) volatility of price returns in the international market will transmit to the volatility of price returns in the producer and auction markets.

Figure 5.3 presents the impulse-response functions resulting from a shock equivalent to a 1 percent increase in the own conditional volatility of the international market. The responses in each market are normalized by the size of the original shock. Two patterns are worth noting. First, it is clear that there is a higher volatility transmission from international to auction markets than to producer markets, but these spillover effects have not generally intensified after 2008. In Sidama and Lekemt, for example, the higher (conditional) correlation in price returns between international and auction markets observed in recent years is not accompanied by higher volatility spillovers from international to domestic markets; while a shock in the international market had a somewhat similar initial effect on the conditional volatility of auction returns in these two regions during 1992 to 2008, the effects after 2008 are much smaller (a 1 percent increase in volatility in international markets results in only a 0.2 percent initial increase in the volatility in auction markets). Second, except for Jimma, the volatility spillovers from international to producer price returns have either remained constant or marginally increased after 2008, although these cross-effects are still relatively small; in the case of Sidama and Lekemt, a 1 percent increase in volatility in international markets results in a 0.2 percent increase in volatility in producer markets, while in Yergachefe and Harar it results in only a 0.1 percent increase in volatility. Hence, the volatility transmission analysis is not conclusive on whether volatility spillovers from international to domestic markets have intensified after the mandatory regulation of December 2008 and, consequently, on the price dissemination role of ECX.

[27] The volatility dynamics across markets ultimately constitute all off-diagonal $a_{ij}$ and $g_{ij}$ coefficients.

**Figure 5.3 Impulse-response functions on conditional volatility after a shock in the international market, based on T-BEKK model**

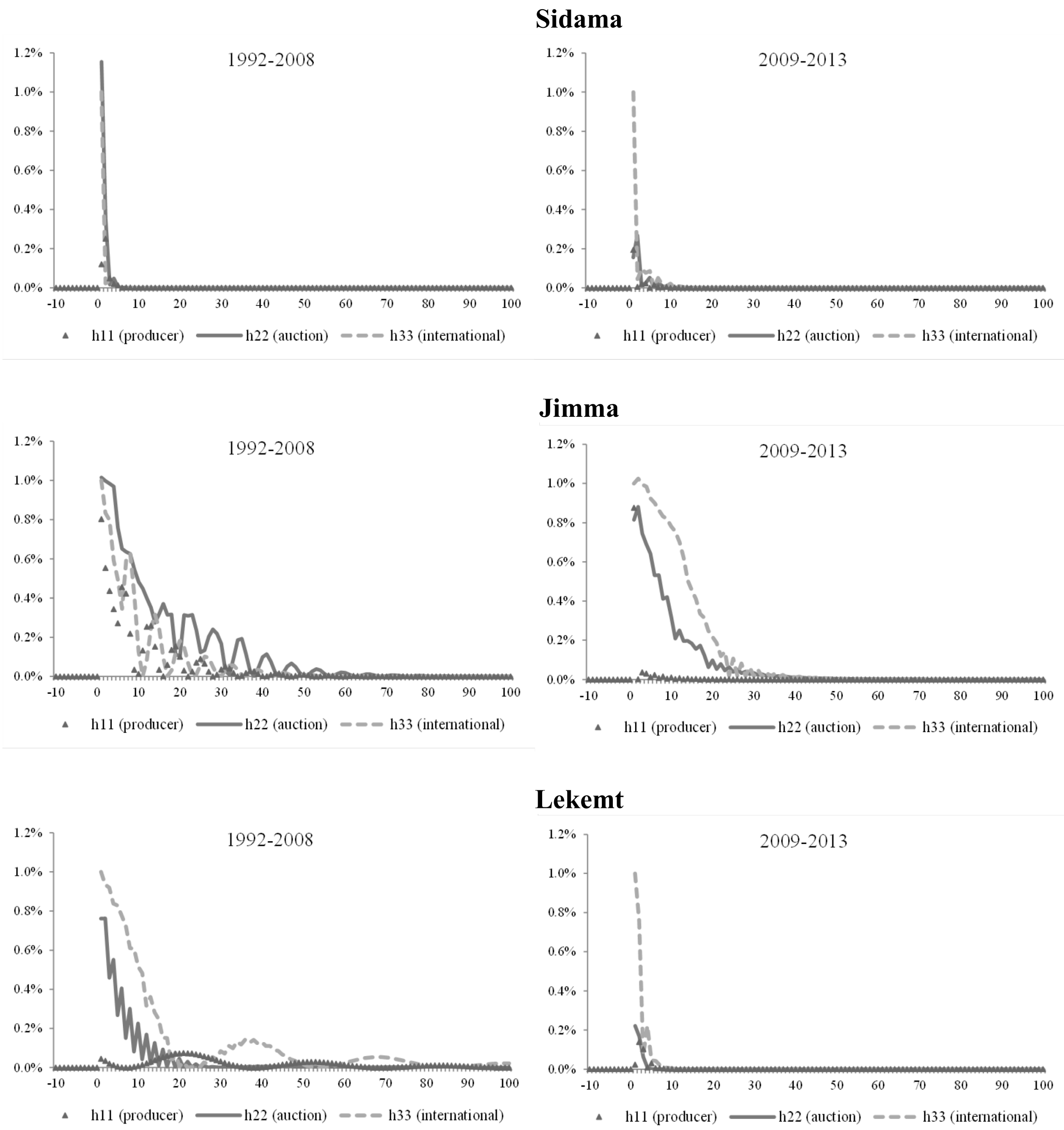
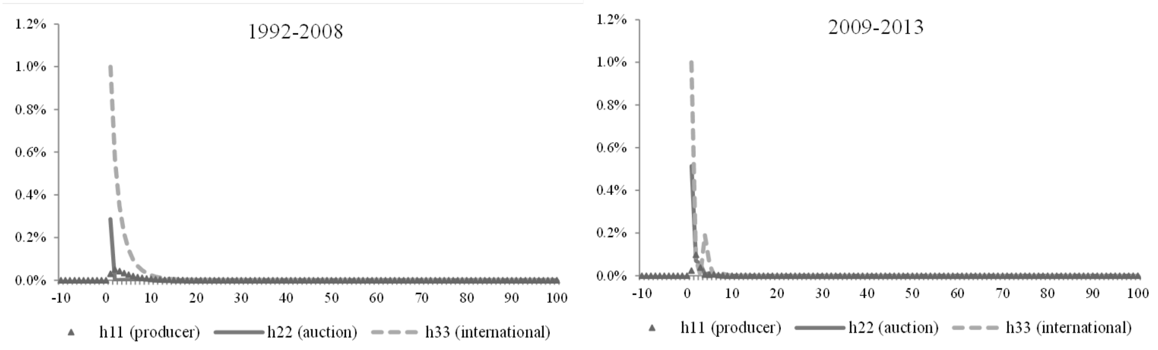
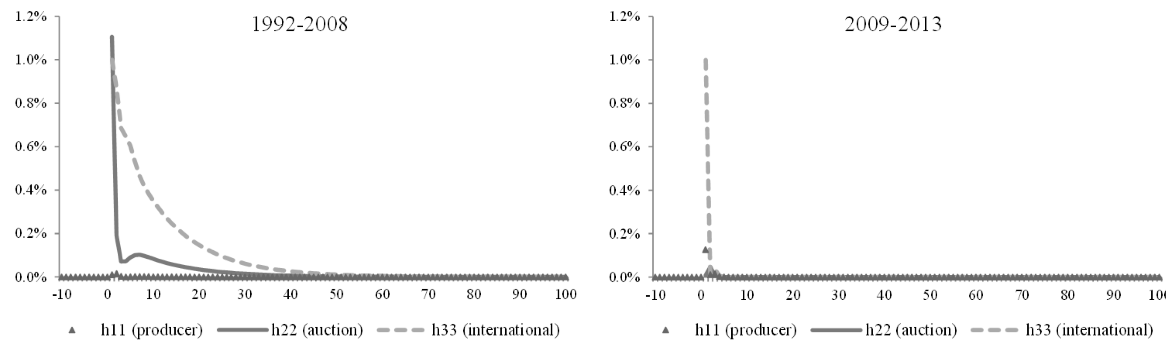


**Figure 5.3 Continued**

**Harar**




**Yirgachefe**




Source: Authors' estimations based on the T-BEKK model.
Note: The responses are the result of an innovation equivalent to a 1 percent increase in the own conditional volatility of the international market. The responses in each market are normalized by the size of the original shock.

## Structural Breaks

As a complementary exercise, we examine whether the change in the regulation in the coffee market is correlated with a structural break in the mean and volatility of the producer and auction returns series in any of the five growing regions. We want to assess whether the mandatory regulation had a major impact (structural break) in the dynamics of price returns in these markets.

We implement the test for the presence of unknown breakpoints developed by Lavielle and Moulines (2000). This test is suitable for strongly dependent processes such as GARCH processes as it assumes beta-mixing conditions (Carrasco and Chen 2002).[28] We test for structural breaks on the mean of the price returns and the square of the price returns as a proxy of volatility.[29]

Table A.8 reports the identified break dates for each returns series representing major change-points in both their mean and volatility. We observe important shifts in the mean of the producer returns of most regions in recent years, as opposed to the shifts in volatility, although the breaks did not occur right after the change in the regulation. The shifts occurred in December 2010 in Sidama and Lekemt, in April 2011 in Harar, and in February 2012 in Yergachefe. Sidama also shows a shift in volatility around December 2010. The breaks in the auction markets, and naturally in the international market, are more

[28] Bai and Perron (1998) test, for example, assumes uniform mixing conditions that are not satisfied by series exhibiting time-varying volatility, which is the case for the series used in the present analysis.

[29] The test searches for breaks in a maximum number of predefined potential segments and uses a minimum penalized contrast to identify the breaks. We set the minimum length of a segment as two months.

linked to the global supply shortages of 1994 and 1997. Hence, it is not clear that the mandatory trading regulation resulted in a breakpoint in the dynamics of the returns series in the growing regions, at least not immediately.

Overall, while a simple comparison between local coffee prices before and after the implementation of ECX in December 2008 reveals that local prices have increased (see Table A.2), our estimation results suggest that the mandatory regulation of trading all coffee through ECX has not necessarily promoted a higher integration of all Ethiopian regional coffee prices to world prices. Only Sidama and Lekemt show a higher interdependence, measured through conditional correlations, between local (mainly auction markets) and international markets. Yet the correlation between producer (farmgate) and international markets is still low. In addition, Ethiopian local markets do not seem to have become more horizontally integrated in recent years. We also do not find major volatility spillovers from international to local markets in recent years. Finally, the breakpoint analyses do not point to structural breaks in the dynamics of the producer and auction return series around the implementation of the mandatory regulation.

# 6. CONCLUDING REMARKS

ECX has received considerable attention since it began coffee trading on its floor in January 2009. The development community provided generous support, and respected news media highlighted ECX's success in addressing many challenges of agricultural markets such as linking smallholders to markets, reducing transactions costs, improving financial transparency, and increasing the country's coffee export revenues. However, hitherto there has been little rigorous analysis to substantiate (or refute) these popular claims. This is surprising given the fact that ECX, as well as other exchanges in developing countries, have received significant government and donor supports. Therefore, monitoring and evaluating the impacts of these exchanges should have been part of the project design (Rashid 2014). This paper has attempted to address this knowledge gap by examining various aspects of price interrelationships between before and after the establishment of ECX. In particular, using monthly price data for five coffee varieties, we have examined interdependence across international and various levels of domestic markets, examined transmission of volatility, and tested for structural breaks following the establishment of ECX and public policies to support it.

The results suggest that, despite a general increase in producer coffee prices after 2008, only two out of five coffee-producing locations—Sidama and Lekemt—exhibit higher interrelationships (conditional correlation) between Addis Ababa wholesale (auction price until December 2008 and ECX price since January 2009) and international prices. While this shows an improvement, the magnitudes of conditional correlation between farmgate and international prices remain low, suggesting that even though the relationship is significant, a very small fraction of increase (decrease) in international prices gets transmitted to the farmers. The analysis of interdependence of market locations also indicates that there have been no significant changes in the spatial integration of coffee markets following the establishment of ECX. Finally, we also do not find any significant change in the extent of volatility spillovers from international to domestic markets in recent years. This is surprising given several studies documented that the country experienced high levels of volatility in tradable staple food (Rashid, Winter-Nelson, and Garcia 2010; Durevall, Loening, and Birru 2013). Finally, our analysis indicates that the establishment of ECX did not produce a major shift in the dynamics of domestic coffee price returns, at least not in the months after its implementation.

In sum, these results suggest that ECX has had a limited impact in altering the coffee price dynamics in Ethiopia. Given all the ECX-related interventions to the coffee markets, one can find these results counterintuitive. However, there are a few logical interpretations. First, long before ECX, Ethiopia had a relatively well functioning CAM, which served as a centralized market location for price dissemination. Even though it did not have the same features as ECX, CAM probably generated enough information to integrate domestic and international markets. Second, ECX has brought about strict regulations to the Ethiopian coffee markets: it has eliminated direct trading relationships between exporters and small coffee producers, requiring them to sell in specific locations with a pool of licensed traders or processors, who in turn have to go through a certification process to sell their coffee. This has clearly resulted in higher transactions costs, which could potentially cancel out the benefits of electronic payments, aggregate price information, and other innovations ECX has introduced to coffee markets. Finally, there are fundamental challenges in the Ethiopian coffee sector (for example, weak infrastructure and low productivity), which are also important determinants of the price relationship and which have not been affected by ECX. Therefore, it should not be a surprise that there has been no significant shift in the price relationships.

We are cognizant of the fact that ECX is a relatively new institution; and one can argue that institutions take time to mature, and delivering on ECX's mandates would require a longer time horizon than what is considered in this study. We also recognize that our methods do not capture all the intricate benefits and costs of ECX in the way a comprehensive impact evaluation study would have captured. Nonetheless, it is safe to conclude from our analysis that many of the success stories in the popular media—such as linking smallholders to markets, improving market efficiency, and increasing export revenue—have been premature and may not hold up under rigorous scrutiny. Thus, if governments and donors continue to support setting up agricultural commodity exchanges in developing countries, they owe it to the citizens to make their investment decisions based on systematic assessments, not only on anecdotes. Surprisingly, this has not been the case in setting up commodity exchanges in Ethiopia or elsewhere in the developing world.

## APPENDIX: SUPPLEMENTARY TABLES AND FIGURES

**Table A.1 Commodity exchanges in Africa**

| Country | Exchange | Abbreviation | Established | Commodities traded |
|---|---|---|---|---|
| South Africa | South African Future Exchange | SAFEX | 1995 | Maize and wheat |
| Nigeria | Abuja Securities and Commodity exchange | ASCE | 2001 | Cotton, cassava, and coffee |
| Kenya | Kenya Agricultural Commodity | KACE | 1997 | Coffee |
| Malawi | Malawi Agricultural Commodity | MACE | 2004 | Rice, wheat |
| Uganda | Uganda Commodity Exchange | UCE | 2002 | Coffee, sesame, maize, beans |
| Ethiopia | Ethiopian Commodity Exchange | ECX | 2008 | Coffee, sesame, and beans |
| Zambia | Zambian Agricultural Commodity | ACE | 1994 | Maize, wheat, soya beans |
| Zimbabwe | Zimbabwe Agricultural Commodity | ZIMACE | 1994 | Maize |

Source: United Nations Conference on Trade and Development (2009).

**Table A.2 Average farmgate coffee prices before and since the Ethiopian Commodity Exchange**

| Region/zone | Average coffee price (US dollars per kilogram) | | | *t* test for mean difference (*p* value) |
|---|---|---|---|---|
| | 2005–2008 | 2009–2013 | Combined | |
| Oromiya | 1.08 | 1.58 | 1.39 | .000 |
| Lekemt | 0.94 | 1.50 | 1.28 | .000 |
| Jimma | 0.86 | 1.37 | 1.21 | .000 |
| Harar | 1.74 | 2.62 | 2.17 | .000 |
| SNNP | 0.96 | 1.19 | 1.12 | .000 |
| Kaffa | 0.96 | 1.13 | 1.08 | .000 |
| Sidama | 0.88 | 1.19 | 1.00 | .000 |
| Yirgachefe | 1.06 | 1.45 | 1.36 | .000 |

Source: Ethiopia, CSA (various years).
Note: SNNP = Southern Nations Nationalities and Peoples. Prices are based on producer prices collected by the Central Statistical Agency (CSA) between 2005 and 2013. Prices were collected by CSA on 119 selected rural and urban markets on a monthly basis.

**Table A.3 Summary statistics for price returns, different subperiods**

| Statistic | Sidama | | Jimma | | Lekemt | | Harar | | Yirgachefe | | International price |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Producer price | Auction price | Producer price | Auction price | Producer price | Auction price | Producer price | Auction price | Producer price | Auction price | |
| | | | | | **January 1992–December 1995 (48 observations)** | | | | | | |
| Mean | –1.008 | 0.262 | –0.209 | 0.676 | –1.162 | –0.818 | –0.530 | –0.558 | 0.808 | 0.441 | 0.415 |
| Standard deviation | 15.860 | 15.564 | 24.450 | 15.902 | 16.397 | 18.882 | 6.153 | 11.804 | 9.935 | 9.342 | 11.361 |
| | | | | | **January 1996–December 2004 (108 observations)** | | | | | | |
| Mean | –0.240 | 0.200 | –0.515 | –0.256 | 0.302 | –0.023 | –0.215 | –0.383 | –0.413 | –0.416 | 0.020 |
| Standard deviation | 18.476 | 10.682 | 25.951 | 9.881 | 18.192 | 11.788 | 14.831 | 6.695 | 17.524 | 13.455 | 7.877 |
| | | | | | **January 2005–December 2008 (48 observations)** | | | | | | |
| Mean | 1.525 | –0.324 | 2.371 | 0.709 | 0.424 | 0.333 | 0.441 | 0.981 | 0.809 | 1.619 | 0.189 |
| Standard deviation | 13.110 | 10.851 | 14.435 | 5.044 | 9.983 | 5.359 | 8.574 | 6.909 | 10.284 | 6.491 | 6.558 |
| | | | | | **January 2009–June 2013 (54 observations)** | | | | | | |
| Mean | 0.235 | 0.511 | 0.015 | 0.139 | 0.563 | 0.360 | 1.000 | 0.962 | 0.291 | 0.349 | 0.392 |
| Standard deviation | 15.052 | 9.108 | 15.676 | 9.888 | 15.832 | 6.165 | 17.079 | 10.245 | 10.057 | 9.584 | 5.901 |

Source: Authors' estimations.

**Table A.4 Estimation results of T-DCC model**

| Coefficient | Sidama | | | Jimma | | | Lekemt | | | Harar | | | Yirgachefe | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **PP** | **AP** | **IP** | **PP** | **AP** | **IP** | **PP** | **AP** | **IP** | **PP** | **AP** | **IP** | **PP** | **AP** | **IP** |
| | **($i$ =1)** | **($i$ = 2)** | **($i$ = 3)** | **($i$ = 1)** | **($i$ = 2)** | **($i$ = 3)** | **($i$ = 1)** | **($i$ = 2)** | **($i$ = 3)** | **($i$ = 1)** | **($i$ = 2)** | **($i$ = 3)** | **($i$ = 1)** | **($i$ = 2)** | **($i$ = 3)** |
| | **Conditional mean equation** | | | | | | | | | | | | | | |
| $g_0$ | –0.048 | 0.714 | –0.227 | –0.880 | –0.231 | –0.227 | 0.017 | 0.108 | –0.227 | –0.349 | –0.071 | –0.227 | 0.278 | 0.543 | –0.227 |
| | (1.071) | (0.805) | (0.492) | (1.524) | (0.610) | (0.492) | (0.902) | (0.576) | (0.492) | (0.629) | (0.464) | (0.492) | (0.801) | (0.569) | (0.492) |
| | **Conditional variance-covariance equation** | | | | | | | | | | | | | | |
| $w_i$ | 46.180 | 11.234 | 21.213 | 22.159 | 39.524 | 21.213 | 102.875 | 1.633 | 21.213 | 8.921 | 20.445 | 21.213 | 8.990 | 8.681 | 21.213 |
| | (57.299) | (7.555) | (6.596) | (37.240) | (12.598) | (6.596) | (35.836) | (1.402) | (6.596) | (7.717) | (21.516) | (6.596) | (10.941) | (9.340) | (6.596) |
| $\alpha_i$ | 0.013 | 0.143 | 0.180 | 0.182 | 0.291 | 0.180 | 0.258 | 0.104 | 0.180 | 0.192 | 0.180 | 0.180 | 0.057 | 0.117 | 0.180 |
| | (0.033) | (0.086) | (0.094) | (0.213) | (0.135) | (0.094) | (0.126) | (0.044) | (0.094) | (0.082) | (0.219) | (0.094) | (0.035) | (0.075) | (0.094) |
| $\beta_i$ | 0.812 | 0.778 | 0.478 | 0.789 | 0.358 | 0.478 | 0.345 | 0.884 | 0.478 | 0.778 | 0.577 | 0.478 | 0.893 | 0.816 | 0.478 |
| | (0.214) | (0.068) | (0.102) | (0.234) | (0.142) | (0.102) | (0.136) | (0.033) | (0.102) | (0.107) | (0.383) | (0.102) | (0.085) | (0.136) | (0.102) |
| $\alpha$ | | | 0.025 | | | 0.000 | | | 0.039 | | | 0.000 | | | 0.015 |
| | | | (0.024) | | | (0.000) | | | (0.012) | | | (0.000) | | | (0.018) |
| $\beta$ | | | 0.733 | | | 0.006 | | | 0.900 | | | 0.605 | | | 0.884 |
| | | | (0.462) | | | (1.186) | | | (0.025) | | | (4.734) | | | (0.089) |
| $V$ | | | 4.940 | | | 5.031 | | | 6.000 | | | 5.338 | | | 4.397 |
| | | | (0.657) | | | (0.800) | | | (0.961) | | | (0.733) | | | (0.530) |
| Wald joint test for adjustments coefficients ($H_0 : \alpha = \beta = 0$) | | | | | | | | | | | | | | | |
| Chi-square | | | 16.409 | | | 0.576 | | | 1,765.850 | | | 0.036 | | | 154.720 |
| $p$ value | | | .000 | | | .750 | | | .000 | | | .982 | | | .000 |

**Table A.4 Continued**

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LB test for autocorrelation ($H_0$: no autocorrelation in squared residuals) | | | | | | | | | | | | | | | |
| LB(6) | 3.164 | 2.205 | 16.180 | 1.735 | 4.540 | 13.271 | 1.202 | 7.920 | 16.361 | 6.575 | 9.852 | 12.122 | 3.182 | 7.127 | 16.696 |
| *p* value | .788 | .900 | .013 | .942 | .604 | .039 | .977 | .244 | .012 | .362 | .131 | .059 | .786 | .309 | .010 |
| LB(12) | 5.007 | 5.390 | 18.142 | 10.732 | 6.576 | 16.190 | 2.869 | 19.158 | 19.658 | 13.337 | 12.969 | 16.676 | 12.147 | 32.951 | 19.560 |
| *p* value | .958 | .944 | .111 | .552 | .884 | .183 | .996 | .085 | .074 | .345 | .371 | .162 | .434 | .001 | .076 |
| LM test for ARCH residuals ($H_0$: no serial correlation in squared residuals) | | | | | | | | | | | | | | | |
| LM(6) | 2.751 | 2.416 | 16.834 | 1.751 | 4.692 | 13.335 | 1.237 | 6.498 | 15.839 | 7.049 | 9.293 | 12.070 | 2.716 | 5.818 | 17.628 |
| *p* value | .839 | .878 | .010 | .941 | .584 | .038 | .975 | .370 | .015 | .316 | .158 | .060 | .843 | .444 | .007 |
| LM(12) | 4.278 | 4.578 | 17.420 | 10.101 | 6.266 | 15.196 | 2.613 | 14.234 | 19.479 | 14.033 | 13.836 | 15.012 | 12.460 | 30.812 | 19.289 |
| *p* value | .978 | .971 | .134 | .607 | .902 | .231 | .998 | .286 | .078 | .299 | .311 | .241 | .409 | .002 | .082 |
| M test for cross-correlation ($H_0$: no cross-correlation in squared residuals) | | | | | | | | | | | | | | | |
| M(6) | | | 49.273 | | | 62.872 | | | 71.216 | | | 58.039 | | | 68.806 |
| *p* value | | | .657 | | | .191 | | | .058 | | | .329 | | | .085 |
| M(12) | | | 71.285 | | | 124.321 | | | 118.736 | | | 97.560 | | | 126.974 |
| *p* value | | | .998 | | | .135 | | | .226 | | | .755 | | | .103 |
| Log likelihood | | | –2,906.6 | | | –2,957.2 | | | –2,867.4 | | | –2,779.4 | | | –2,835.1 |
| SBIC | | | 22.919 | | | 23.311 | | | 22.615 | | | 21.933 | | | 22.365 |
| Number of observations | | | 258 | | | 258 | | | 258 | | | 258 | | | 258 |

Source: Authors' estimations based on the T-DCC model.

Note: PP = producer price; AP = auction price; IP = international price; ν = estimated degrees of freedom parameter; LB = Ljung-Box; LM = Lagrange Multiplier; ARCH = Autoregressive Conditional Heteroskedasticity; M = Hosking Multivariate Portmanteau; SBIC = Schwarz's Bayesian information criterion. Standard errors are reported in parentheses.

**Table A.5 Estimation results of T-DCC model across coffee varieties**

| Coefficient | Producer price | | | | | Auction price | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Sidama ($i$ = 1) | Jimma ($i$ = 2) | Lekemt ($i$ = 3) | Harar ($i$ = 4) | Yirgachefe ($i$ = 5) | Sidama ($i$ = 1) | Jimma ($i$ = 2) | Lekemt ($i$ = 3) | Harar ($i$ = 4) | Yirgachefe ($i$ = 5) |
| | **Conditional mean equation** | | | | | | | | | |
| $g_0$ | –0.048 | –0.880 | 0.017 | –0.349 | 0.278 | 0.714 | –0.231 | 0.108 | –0.071 | 0.543 |
| | (1.071) | (1.524) | (0.902) | (0.629) | (0.801) | (0.805) | (0.610) | (0.576) | (0.464) | (0.569) |
| | **Conditional variance-covariance equation** | | | | | | | | | |
| $w_i$ | 46.180 | 22.159 | 102.875 | 8.921 | 8.990 | 11.234 | 39.524 | 1.633 | 20.445 | 8.681 |
| | (57.299) | (37.240) | (35.836) | (7.717) | (10.941) | (7.555) | (12.598) | (1.402) | (21.516) | (9.340) |
| $a_i$ | 0.013 | 0.182 | 0.258 | 0.192 | 0.057 | 0.143 | 0.291 | 0.104 | 0.180 | 0.117 |
| | (0.033) | (0.213) | (0.126) | (0.082) | (0.035) | (0.086) | (0.135) | (0.044) | (0.219) | (0.075) |
| $b_i$ | 0.812 | 0.789 | 0.345 | 0.778 | 0.893 | 0.778 | 0.358 | 0.884 | 0.577 | 0.816 |
| | (0.214) | (0.234) | (0.136) | (0.107) | (0.085) | (0.068) | (0.142) | (0.033) | (0.383) | (0.136) |
| $a$ | | | | | 0.058 | | | | | 0.055 |
| | | | | | (0.033) | | | | | (0.027) |
| $b$ | | | | | 0.416 | | | | | 0.204 |
| | | | | | (0.217) | | | | | (0.349) |
| $v$ | | | | | 5.651 | | | | | 3.856 |
| | | | | | (0.841) | | | | | (0.281) |
| Wald joint test for adjustments coefficients ($H_0$: $a = b = 0$) | | | | | | | | | | |
| Chi-square | | | | | 40.183 | | | | | 12.976 |
| $p$ value | | | | | .000 | | | | | .002 |

**Table A.5 Continued**

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| LB test for autocorrelation ($H_0$: no autocorrelation in squared residuals) | | | | | | | | | | |
| LB(6) | 3.513 | 1.102 | 1.380 | 6.160 | 3.845 | 0.784 | 4.159 | 10.010 | 9.530 | 5.581 |
| *p* value | .742 | .981 | .967 | .405 | .698 | .993 | .655 | .124 | .146 | .472 |
| LB(12) | 5.013 | 10.054 | 3.692 | 11.922 | 12.251 | 2.832 | 9.259 | 25.994 | 12.577 | 29.751 |
| *p* value | .958 | .611 | .988 | .452 | .426 | .997 | .681 | .011 | .401 | .003 |
| LM test for ARCH residuals ($H_0$: no serial correlation in squared residuals) | | | | | | | | | | |
| LM(6) | 3.060 | 1.073 | 1.360 | 6.932 | 3.319 | 0.781 | 4.395 | 9.026 | 8.901 | 5.052 |
| *p* value | .801 | .983 | .968 | .327 | .768 | .993 | .623 | .172 | .179 | .537 |
| LM(12) | 4.188 | 9.592 | 3.340 | 12.967 | 12.140 | 1.445 | 8.223 | 19.517 | 13.714 | 27.212 |
| *p* value | .980 | .652 | .993 | .371 | .434 | 1.000 | .767 | .077 | .319 | .007 |
| M test for cross-correlation ($H_0$: no cross-correlation in squared residuals) | | | | | | | | | | |
| M(6) | | | | | 121.765 | | | | | 155.213 |
| *p* value | | | | | .944 | | | | | .326 |
| M(12) | | | | | 297.777 | | | | | 281.790 |
| *p* value | | | | | .493 | | | | | .742 |
| Log likelihood | | | | | –5,274.5 | | | | | –4,609.3 |
| SBIC | | | | | 41.598 | | | | | 36.441 |
| Number of observations | | | | | 258 | | | | | 258 |

Source: Authors' estimations based on the T-DCC model.

Note: ν = estimated degrees of freedom parameter; LB = Ljung-Box; LM = Lagrange Multiplier; ARCH = Autoregressive Conditional Heteroskedasticity; M = Hosking Multivariate Portmanteau; SBIC = Schwarz's Bayesian information criterion. Standard errors are reported in parentheses.

**Table A.6 Estimation results of T-BEKK model, 1992–2008**

| Coefficient | Sidama | | | Jimma | | | Lekemt | | | Harar | | | Yirgachefe | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **PP ($i$ = 1)** | **AP ($i$ = 2)** | **IP ($i$ = 3)** | **PP ($i$ = 1)** | **AP ($i$ = 2)** | **IP ($i$ = 3)** | **PP ($i$ = 1)** | **AP ($i$ = 2)** | **IP ($i$ = 3)** | **PP ($i$ = 1)** | **AP ($i$ = 2)** | **IP ($i$ = 3)** | **PP ($i$ = 1)** | **AP ($i$ = 2)** | **IP ($i$ = 3)** |
| | Conditional variance-covariance equation | | | | | | | | | | | | | | |
| $c_{i1}$ | 12.497 | –2.994 | –3.688 | 3.998 | –0.062 | 5.263 | –0.002 | 0.002 | 0.002 | 3.405 | 0.569 | 4.766 | 1.625 | 4.359 | –5.240 |
| | (3.276) | (1.730) | (4.252) | (7.065) | (0.053) | (2.019) | (0.034) | (0.055) | (0.041) | (1.074) | (7.120) | (0.943) | (1.771) | (1.422) | (1.801) |
| $c_{i2}$ | | –0.002 | –0.002 | | 0.000 | 0.005 | | 0.003 | 0.000 | | 6.078 | 0.707 | | 0.024 | –0.026 |
| | | (0.040) | (0.068) | | (0.038) | (0.021) | | (0.023) | (0.021) | | (0.952) | (5.772) | | (0.298) | (0.122) |
| $c_{i3}$ | | | –0.001 | | | 0.005 | | | 0.000 | | | 0.000 | | | 0.002 |
| | | | (0.060) | | | (0.009) | | | (0.029) | | | (0.058) | | | (0.046) |
| $a_{i1}$ | 0.312 | 0.070 | 0.053 | 0.263 | –0.026 | 0.170 | 0.123 | –0.103 | 0.037 | 0.652 | 0.017 | 0.099 | 0.650 | –0.005 | –0.025 |
| | (0.169) | (0.096) | (0.050) | (0.448) | (0.085) | (0.096) | (0.080) | (0.061) | (0.022) | (0.130) | (0.139) | (0.103) | (0.228) | (0.126) | (0.088) |
| $a_{i2}$ | –0.099 | 0.299 | –0.190 | 0.350 | 0.268 | –0.209 | 0.018 | 0.269 | –0.154 | 0.099 | –0.510 | 0.302 | –0.041 | 0.926 | –0.283 |
| | (0.204) | (0.119) | (0.088) | (0.366) | (0.225) | (0.112) | (0.048) | (0.073) | (0.038) | (0.203) | (0.325) | (0.185) | (0.199) | (0.227) | (0.188) |
| $a_{i3}$ | –1.130 | 0.038 | –0.152 | –0.109 | 0.111 | 0.190 | –0.171 | –0.261 | 0.177 | –0.242 | –0.261 | –0.565 | 0.132 | 0.104 | –0.043 |
| | (0.240) | (0.160) | (0.183) | (0.161) | (0.142) | (0.102) | (0.109) | (0.094) | (0.086) | (0.188) | (0.141) | (0.173) | (0.128) | (0.111) | (0.144) |
| $g_{i1}$ | –0.128 | –0.480 | –0.254 | 0.817 | 0.183 | 0.064 | 0.966 | –0.039 | –0.052 | 0.802 | 0.086 | –0.038 | 0.601 | 0.060 | –0.055 |
| | (0.233) | (0.108) | (0.149) | (0.150) | (0.021) | (0.061) | (0.019) | (0.071) | (0.014) | (0.078) | (0.103) | (0.068) | (0.182) | (0.130) | (0.060) |
| $g_{i2}$ | 0.596 | 0.575 | 0.082 | –0.946 | 0.871 | 0.143 | –0.354 | –0.725 | 0.315 | –0.064 | 0.078 | 0.035 | –0.712 | 0.398 | 0.223 |
| | (0.290) | (0.134) | (0.157) | (0.580) | (0.096) | (0.183) | (0.255) | (0.149) | (0.183) | (0.428) | (0.152) | (0.180) | (0.167) | (0.198) | (0.094) |
| $g_{i3}$ | 0.072 | –0.396 | 0.665 | –0.545 | –0.089 | 0.574 | 0.386 | 0.951 | 0.817 | –0.278 | –0.001 | 0.701 | 0.655 | 0.512 | 0.754 |
| | (0.956) | (0.400) | (0.298) | (1.272) | (0.142) | (0.346) | (0.146) | (0.170) | (0.141) | (0.085) | (0.086) | (0.101) | (0.249) | (0.130) | (0.152) |
| $N$ | | | 4.995 | | | 4.438 | | | 6.597 | | | 4.214 | | | 3.164 |
| | | | (0.983) | | | (0.952) | | | (1.580) | | | (0.796) | | | (0.524) |
| Wald joint test for cross-volatility coefficients ($H_0$: $a_{ij} = g_{ij} = 0$, ∀j≠i | | | | | | | | | | | | | | | |
| Chi-square | | | 255.295 | | | 1737.751 | | | 337.627 | | | 44.105 | | | 127.233 |
| $p$ value | | | .000 | | | .000 | | | .000 | | | .000 | | | .000 |

**Table A.6 Continued**

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LB test for autocorrelation ($H_0$: no autocorrelation in squared residuals) | | | | | | | | | | | | | | | |
| LB(6) | 5.759 | 1.963 | 15.511 | 4.570 | 11.230 | 4.111 | 23.415 | 5.520 | 18.461 | 2.983 | 22.124 | 11.483 | 2.101 | 2.993 | 23.566 |
| *p* value | .451 | .923 | .017 | .600 | .082 | .662 | .001 | .479 | .005 | .811 | .001 | .075 | .910 | .810 | .001 |
| LB(12) | 10.315 | 7.056 | 16.911 | 7.001 | 14.182 | 8.290 | 26.837 | 10.597 | 20.796 | 7.249 | 24.702 | 15.531 | 3.568 | 17.917 | 25.634 |
| *p* value | .588 | .854 | .153 | .858 | .289 | .762 | .008 | .564 | .053 | .841 | .016 | .214 | .990 | .118 | .012 |
| LM test for ARCH residuals ($H_0$: no serial correlation in squared residuals) | | | | | | | | | | | | | | | |
| LM(6) | 4.874 | 1.356 | 15.109 | 4.078 | 10.845 | 3.580 | 17.461 | 5.607 | 18.303 | 3.271 | 18.098 | 11.703 | 2.497 | 3.519 | 22.875 |
| *p* value | .560 | .968 | .019 | .666 | .093 | .733 | .008 | .469 | .006 | .774 | .006 | .069 | .869 | .741 | .001 |
| LM(12) | 8.968 | 4.374 | 15.403 | 7.563 | 12.717 | 5.538 | 21.618 | 9.074 | 18.307 | 7.968 | 31.458 | 16.006 | 4.169 | 20.520 | 23.111 |
| *p* value | .706 | .976 | .220 | .818 | .390 | .938 | .042 | .697 | .107 | .788 | .002 | .191 | .980 | .058 | .027 |
| M test for cross-correlation ($H_0$: no cross-correlation in squared residuals) | | | | | | | | | | | | | | | |
| M(6) | | | 58.992 | | | 67.272 | | | 77.067 | | | 60.453 | | | 59.595 |
| *p* value | | | .298 | | | .106 | | | .021 | | | .254 | | | .279 |
| M(12) | | | 87.327 | | | 111.411 | | | 103.478 | | | 91.541 | | | 90.283 |
| *p* value | | | .928 | | | .392 | | | .605 | | | .872 | | | .891 |
| Log likelihood | | | –2,315.9 | | | –2,349.3 | | | –2,288.6 | | | –2150.5 | | | –2243.6 |
| SBIC | | | 23.356 | | | 23.684 | | | 23.089 | | | 21.735 | | | 22.648 |
| Number of observations | | | 204 | | | 204 | | | 204 | | | 204 | | | 204 |

Source: Authors' estimations based on the T-BEKK model.

Note: PP = producer price; AP = auction price; IP = international price; ν = estimated degrees of freedom parameter; LB = Ljung-Box; LM = Lagrange Multiplier; ARCH = Autoregressive Conditional Heteroskedasticity; M = Hosking Multivariate Portmanteau; SBIC = Schwarz's Bayesian information criterion. Standard errors are reported in parentheses.

**Table A.7 Estimation results of T-BEKK model, 2009–2013**

| Coefficient | Sidama | | | Jimma | | | Lekemt | | | Harar | | | Yirgachefe | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PP ($i$ = 1) | AP ($i$ = 2) | IP ($i$ = 3) | PP ($i$ = 1) | AP ($i$ = 2) | IP ($i$ = 3) | PP ($i$ = 1) | AP ($i$ = 2) | IP ($i$ = 3) | PP ($i$ = 1) | AP ($i$ = 2) | IP ($i$ = 3) | PP ($i$ = 1) | AP ($i$ = 2) | IP ($i$ = 3) |
| | Conditional variance-covariance equation | | | | | | | | | | | | | | |
| $c_{i1}$ | 3.986 | 3.930 | 3.843 | –2.891 | 0.985 | 1.519 | 7.614 | 2.518 | 0.745 | 7.599 | 5.934 | –1.638 | 4.941 | 3.383 | 3.383 |
| | (5.762) | (1.617) | (1.100) | (1.980) | (1.772) | (1.131) | (2.845) | (1.438) | (1.423) | (1.796) | (1.428) | (1.018) | (4.121) | (1.911) | (1.470) |
| $c_{i2}$ | | 0.001 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | –0.014 | –0.001 | | 0.000 | 0.000 |
| | | (0.188) | (0.155) | | (0.180) | (0.056) | | (0.128) | (0.088) | | (0.056) | (0.030) | | (0.156) | (0.048) |
| $c_{i3}$ | | | 0.000 | | | 0.000 | | | 0.000 | | | 0.002 | | | 0.000 |
| | | | (0.267) | | | (0.095) | | | (0.110) | | | (0.052) | | | (0.096) |
| $a_{i1}$ | –0.065 | 0.460 | 0.138 | 0.278 | –0.183 | –0.183 | –0.812 | –0.037 | –0.044 | –0.514 | 0.197 | 0.070 | –0.083 | 0.216 | 0.213 |
| | (0.214) | (0.135) | (0.093) | (0.272) | (0.217) | (0.107) | (0.384) | (0.201) | (0.135) | (0.126) | (0.095) | (0.045) | (0.746) | (0.408) | (0.135) |
| $a_{i2}$ | –0.151 | –0.161 | 0.177 | 0.899 | 0.196 | 0.066 | –1.233 | –0.062 | –0.138 | 0.576 | 0.309 | 0.321 | 0.655 | 0.177 | 0.054 |
| | (0.169) | (0.205) | (0.158) | (0.634) | (0.200) | (0.051) | (0.519) | (0.307) | (0.223) | (0.202) | (0.126) | (0.077) | (0.568) | (0.369) | (0.131) |
| $a_{i3}$ | 0.662 | 1.170 | 0.449 | 1.086 | –0.020 | –0.196 | 1.037 | –0.466 | –0.294 | –0.786 | 0.132 | 0.447 | 0.342 | –0.527 | 0.600 |
| | (0.453) | (0.302) | (0.325) | (0.756) | (0.346) | (0.181) | (0.846) | (0.606) | (0.261) | (0.481) | (0.149) | (0.129) | (0.526) | (0.627) | (0.207) |
| $g_{i1}$ | –0.464 | –0.268 | 0.175 | –0.066 | 0.088 | 0.126 | –0.020 | 0.006 | –0.372 | 0.553 | 0.189 | 0.092 | –0.475 | –0.380 | 0.096 |
| | (0.145) | (0.172) | (0.145) | (0.166) | (0.169) | (0.179) | (0.167) | (0.106) | (0.106) | (0.163) | (0.071) | (0.053) | (0.848) | (0.683) | (0.279) |
| $g_{i2}$ | 1.330 | 0.008 | 0.107 | 0.462 | –0.681 | 0.276 | –0.254 | –0.583 | –0.098 | –0.456 | 0.011 | 0.328 | 0.660 | –0.291 | –0.425 |
| | (0.378) | (0.949) | (0.507) | (0.386) | (0.335) | (0.195) | (0.814) | (0.350) | (0.287) | (0.277) | (0.016) | (0.091) | (0.395) | (0.248) | (0.214) |
| $g_{i3}$ | –1.865 | 0.417 | 0.197 | 0.995 | 1.430 | 0.427 | –0.381 | 0.835 | 0.536 | 1.101 | –0.903 | 0.197 | –0.727 | –0.628 | 0.203 |
| | (0.814) | (0.853) | (0.548) | (0.686) | (0.267) | (0.719) | (0.309) | (0.259) | (0.199) | (0.302) | (0.226) | (0.147) | (0.816) | (1.120) | (0.508) |
| $v$ | | | 6.807 | | | 20.178 | | | 4.919 | | | 815.858 | | | 6.289 |
| | | | (4.035) | | | (45.520) | | | (2.239) | | | (197.076) | | | (2.860) |
| Wald joint test for cross-volatility coefficients ($H_0$: $a_{ij}$ = $g_{ij}$ = 0, ∀i≠ | | | | | | | | | | | | | | | |
| Chi-square | | | 1023.340 | | | 361.019 | | | 658.147 | | | 365.035 | | | 343.127 |
| $p$ value | | | .000 | | | .000 | | | .000 | | | .000 | | | .000 |

**Table A.7 Continued**

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LB test for autocorrelation ($H_0$: no autocorrelation in squared residuals) | | | | | | | | | | | | | | | |
| LB(6) | 0.454 | 5.776 | 4.391 | 9.361 | 6.369 | 4.031 | 1.244 | 1.573 | 6.510 | 4.020 | 4.736 | 4.846 | 3.294 | 3.228 | 12.173 |
| *p* value | .998 | .449 | .624 | .154 | .383 | .672 | .975 | .955 | .369 | .674 | .578 | .564 | .771 | .780 | .058 |
| LB(12) | 0.958 | 7.941 | 13.608 | 15.704 | 9.030 | 5.357 | 6.415 | 3.180 | 14.438 | 9.708 | 7.187 | 11.458 | 4.384 | 7.192 | 19.332 |
| *p* value | 1.000 | .790 | .326 | .205 | .700 | .945 | .894 | .994 | .274 | .642 | .845 | .490 | .975 | .845 | .081 |
| LM test for ARCH residuals ($H_0$: no serial correlation in squared residuals) | | | | | | | | | | | | | | | |
| LM(6) | 0.417 | 5.602 | 6.332 | 7.676 | 8.790 | 4.108 | 1.041 | 2.134 | 6.681 | 3.678 | 3.843 | 3.943 | 3.044 | 2.742 | 5.229 |
| *p* value | .999 | .469 | .387 | .263 | .186 | .662 | .984 | .907 | .351 | .720 | .698 | .684 | .803 | .840 | .515 |
| LM(12) | 0.857 | 8.477 | 15.587 | 9.630 | 11.985 | 6.341 | 4.916 | 3.081 | 12.689 | 8.990 | 5.922 | 12.112 | 8.904 | 17.229 | 13.266 |
| *p* value | 1.000 | .747 | .211 | .648 | .447 | .898 | .961 | .995 | .392 | .704 | .920 | .437 | .711 | .141 | .350 |
| M test for cross-correlation ($H_0$: no cross-correlation in squared residuals) | | | | | | | | | | | | | | | |
| M(6) | | | 37.895 | | | 52.704 | | | 65.190 | | | 39.425 | | | 49.142 |
| *p* value | | | .953 | | | .524 | | | .142 | | | .932 | | | .662 |
| M(12) | | | 99.662 | | | 91.079 | | | 107.970 | | | 81.075 | | | 109.468 |
| *p* value | | | .704 | | | .879 | | | .483 | | | .975 | | | .442 |
| Log likelihood | | | –555.6 | | | –573.8 | | | –536.8 | | | –584.0 | | | –547.9 |
| SBIC | | | 22.423 | | | 23.100 | | | 21.728 | | | 23.478 | | | 22.140 |
| Number of observations | | | 54 | | | 54 | | | 54 | | | 54 | | | 54 |

Source: Authors' estimations based on the T-BEKK model.

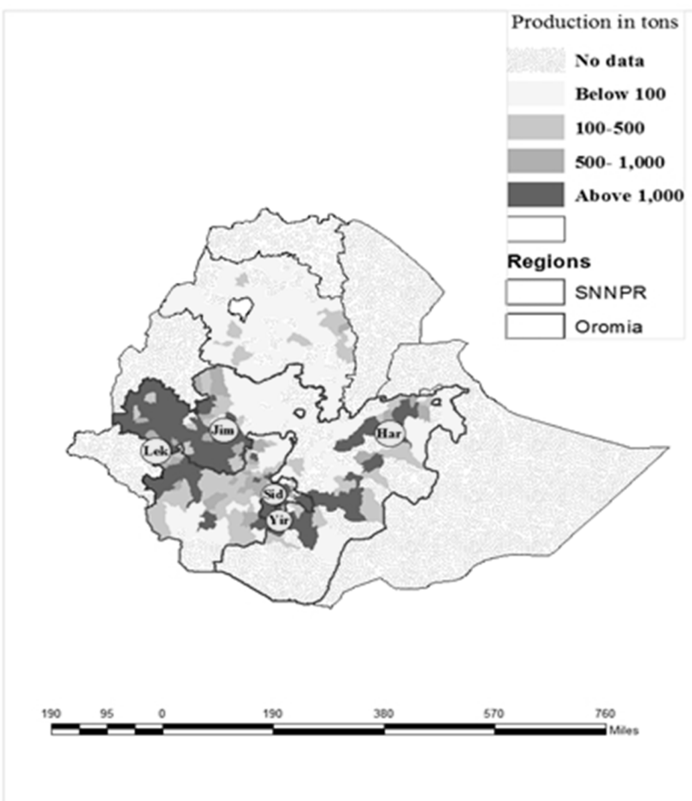
Note: Standard errors are reported in parentheses. PP = producer price; AP = auction price; IP = international price; ν = estimated degrees of freedom parameter; LB = Ljung-Box; LM = Lagrange Multiplier; ARCH = Autoregressive Conditional Heteroskedasticity; M = Hosking Multivariate Portmanteau; SBIC = Schwarz's Bayesian information criterion.

**Table A.8 Estimated break dates for price returns and squared price returns**

| Market | Returns | Squared returns |
|---|---|---|
| Sidama | | |
| Producer price | December 2010 | December 2010 |
| Auction price | May 1994 | February 1999 |
| Jimma | | |
| Producer price | May 2002 | July 2003 |
| Auction price | June 1994 | September 1994 |
| Lekemt | | |
| Producer price | December 2010 | October 2000 |
| Auction price | August 1995 | September 1994 |
| Harar | | |
| Producer price | April 2011 | December 2002 |
| Auction price | April 1994 | May 1994 |
| Yirgachefe | | |
| Producer price | February 2012 | January 1998 |
| Auction price | August 1997 | September 1997 |
| International price | April 1994 | April 1994 |

Source: Authors' estimations.
Note: The estimated break dates are based on Lavielle and Moulines's (2000) test for structural breaks on the mean of price returns and the square of price returns as a proxy for volatility. The minimum length of a segment is two months.

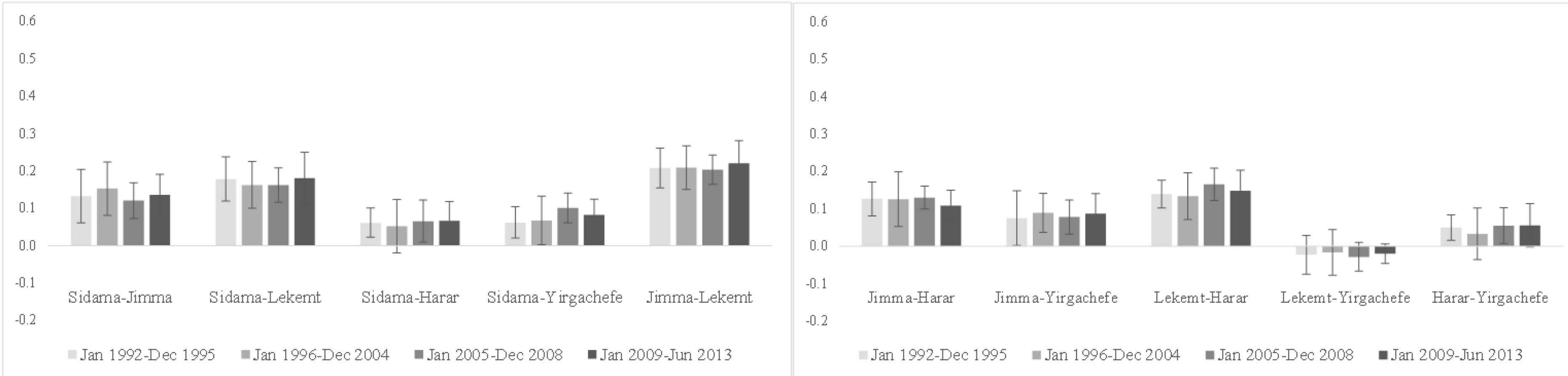
**Figure A.1 Growing areas of Arabica coffee in Ethiopia, 2009–2013**



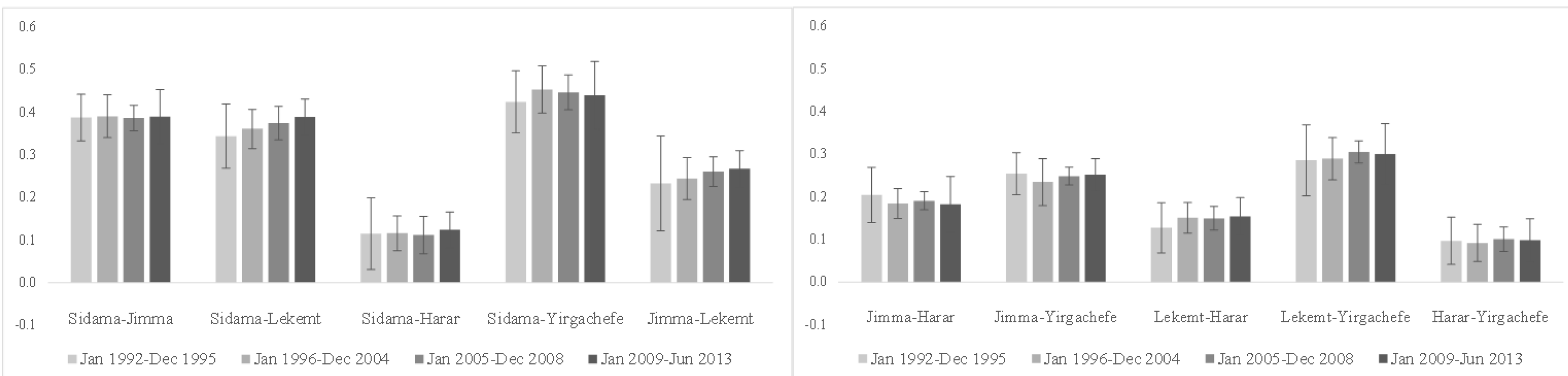

Source: Ethiopia, CSA (various years).
Note: Sid = Sidama; Jim = Jimma; Lek = Lekemt; Har = Harar; Yir = Yirgachefe; SNNPR = Southern Nations Nationality Peoples region. The map is based on the weighted production average during 2009 to 2013. The volume of production was obtained from the monthly reports for the period 2009–2013.

**Figure A.2 Average conditional correlations for different subperiods based on T-DCC model across coffee varieties**

**Producer level**




**Auction level**




Source: Authors' estimations based on the T-DCC model.
Note: The vertical lines are confident bands of one standard deviation. Jan = January; Dec = December; Jun = June.

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