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RESEARCH ARTICLE

Black tea markets worldwide: Are they integrated?

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Abstract

Global tea consumption has risen significantly alongside rapid expansion of international trade in recent years. However, few studies have systematically examined the relationship among the major tea markets worldwide. Using weekly data from 2012–2019, this study empirically analyzed the price series of the world's major black tea auction markets. The estimation results showed that these markets are connected, even though heterogeneities vary. This finding holds not only for regional markets but also for international markets. The findings offer important implications for tea-producing countries with millions of smallholder farmers.

Keywords: black tea market, price, integration, VECM

1. Introduction

Tea is one of the three most consumed nonalcoholic beverages in the world, and its global consumption has risen significantly in recent years (FAO 2019). Tea is also considered to be more healthy than coffee and cocoa and is highly recommended by the World Health Organization (Dutta 2017). Many people in Asia, the European Union and the Middle East drink tea regularly (Hicks 2001). Previous studies showed that an increase in income and the development of special health-related tea led to a significant increase in tea consumption worldwide (Miller 2005; Koch *et al.* 2012). To meet the increase in tea consumption in countries with little or no tea plantations, total tea imports reached 1.92 million tons in 2017, with an annual increase rate of 2.1% during the last three decades (FAO 2019). In addition, tea consumption and international trade are projected to rise by approximately 2% annually in the coming decades (FAO 2018).

To meet this rising demand, world tea production has increased substantially. According to FAO (2019), world tea production increased more than 2.5 times from 2.52 million tons in 1990 to 6.34 million tons in 2018 (Appendix A). The growth rate of tea production is much higher than that of many other crops, including coffee and staple food crops (e.g., rice and wheat). The increase in global tea production has occurred mainly in major tea-producing countries such as China, India and Sri Lanka in Asia and Kenya in Africa (Appendix B). Previous studies have also shown that tea production would continue to expand due to increasing demand in the next decade (Hicks 2009; Chang 2015).

Accompanying the rapid increase in tea demand

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worldwide, the international tea trade has increased significantly. As shown in Appendix C, world tea export increased from 1.23 million tons in 1990 to 2.10 million tons in 2017, with an increase of 71% within less than three decades (or an annual growth rate of 2.53%). Among all traditional major tea export countries, Kenya has experienced the fastest growth in tea exports. Kenya's tea exports increased nearly two times during the past three decades, making Kenya the world's largest tea exporter for the first time in 2005 and remain the ranking in most years since then. In 2017, the tea exports of Kenya reached 0.47 million tons, accounting for 22% of the world's total exports.

Despite of the significantly rising consumption and trade of tea, few studies have systematically analyzed the relationship among the major tea markets in the world. This may be due to a fact that tea, not like staple grain crops, has no direct impact on hunger or malnutrition. Consequently, the tea market has been largely ignored in the literature for decades; there are a few exceptions, including Dharmasena and Bessler (2004), Sekhar (2012), and Tanui *et al.* (2012). Based on data from more than a decade ago, these studies showed that the markets were cointegrated within Asia but not across continents. For example, both Sekhar (2012) and Tanui *et al.* (2012) showed that India's tea market was cointegrated with that of Sri Lanka. On the other hand, the tea markets in Colombo in Sri Lanka and Mombasa in Kenya were not cointegrated (Dharmasena 2003; Dharmasena and Bessler 2004; Tanui *et al.* 2012). A few recent studies (e.g., Tanui 2018; Winrose 2019; Rembeza and Radlińska 2020) showed that the Kolkata, Colombo and Mombasa markets are connected. However, all of these studies are based on the monthly average prices of tea in the individual markets. Whether using averaged data led to biased estimation results remains unclear.

As data on the world's major tea markets become increasingly available in recent years, it is worth and possible systematically examining the spatial integration among the markets. As mentioned above, most existing studies were based on data from at least a decade ago, which cannot explain the relationship between major tea markets that might have changed significantly during the past decade. Many questions remain unclear. For example, are tea markets (e.g., auction markets) in the major tea-producing countries operated separately, or are they spatially connected? More importantly, are tea markets in Asia (the largest tea-producing continent) cointegrated with those in Africa? And which is the largest tea-producing continent? Finally, what are the implications of regional and global tea market integration (or no integration) for tea farmers in major tea-producing countries?

This study aimed to answer the above questions. Specifically, two objectives were addressed. First, it analyzed whether the markets are connected within the major tea-producing countries (e.g., India and Sri Lanka) and within the same auction market (i.e., Mombasa). Second, it investigated the connections in tea markets across continents (i.e., between Asia and Africa).

However, due to the heterogeneity between tea types (e.g., black tea and green tea) and limited data on all types of tea, this study focused only on black tea in three major markets: India, Colombo in Sri Lanka and Mombasa in Kenya. Black tea is the most important tea type for international trade. Its export reached 1.40 million tons in 2017, accounting for 78% of the total tea exports (ITC 2018). In addition, quality of black tea is stable and does not change significantly over time. Although black tea is produced in many countries, the three studied markets exported 1.38 million tons of black tea in 2017 (nearly 99% of global black tea exports) (ITC 2018). China is excluded from this study because there is no tea auction market in the country though it is the largest tea-producing country in the world.

This study has important implication for low-income tea farmers in major tea-producing countries. Different from farmers in developed countries, tea farmers live in mountainous or remote areas in developing countries. Tea producers and hired laborers are relatively poor as their income comes mainly from tea production (van der Wal 2008; Herath and Weersink 2009; Chasomeris *et al.* 2015). Hence, analysis of the tea price movement has important implication for tea farmers and poverty alleviation in major tea-producing countries.

The rest of the paper is organized as follows. Section 2 provides a brief review of black tea auction markets in India, Sri Lanka and Kenya. Section 3 first discusses the weekly data used for this study, and then tests tea price series in the same regions and international markets. Section 4 concludes the paper.

2. Tea auction markets

The first tea auction market in the world was established in London in the 1830s (Yu 1988; Maxwell 1998). During that time, British companies (e.g., East India Company) were the most powerful commercial organizations in the world, and they played a crucial role in all commodity trade, including tea. In addition, England and Western European countries were the largest tea consumers. As a result, tea chests were shipped to London from China, the British colonial territories (e.g., India, Sri Lanka and East and Central Africa), and other countries. Prior to the

Second World War, more than 60% of tea from across the world — much of which was under British control — was marketed in London (Hazarika 2008).

However, the London auction market was closed due to the Second World War and did not reopen until 1951 (Zhu 1994). The closure of the London market and the independence of colonial territories after the war led to the establishment of tea auction markets in major tea-producing countries, such as India, Sri Lanka, Kenya and other countries, in the 1950s. Consequently, the London tea auction center gradually lost its former prominence and was finally closed in 1998 (Chen 1998).

The first tea auction market in India was established in Kolkata in 1861; it was also the second tea auction market in the world at that time (Zhu 1994). The Cochin tea auction market was established in 1947, the same year India gained independence. Since then, more tea auction markets such as Guwahati opened in India. Currently, there are seven tea auction markets in India: Kolkata, Guwahati, Siliguri, Jalpiguri, Cochin, Coonoor and Coimbatore. Kolkata is the largest, while no tea was sold in Jalpiguri in 2019 (Tea Board of India e-Auction Project 2019).

Similar to India, the tea auction market in Colombo, Sri Lanka, was established in 1883, only 16 years after the country's first tea tree was planted in 1867. The rapid expansion of tea plantations and quick establishment of tea auction market was largely due to Sri Lanka's natural conditions that favor the production of high-quality tea (Herath and Weersink 2009). In terms of sales volume, the Colombo Tea Auction (CTA) is the largest single-origin black tea auction market (Tea Exporters Association of Sri Lanka 2019a). Tea is not only one of the major income sources for Sri Lankan farmers but also a main source of foreign exchange for the country (Sri Lanka Export Development Board 2014; Sankalpana *et al.* 2018).

Unlike India and Sri Lanka, where tea markets were established more than a hundred years ago, Kenya did not open a tea auction market until 1969. Prior to that, tea produced from Kenya and other African countries was shipped to London. As these African countries gained independence and the London tea auction market faded out after World War II, international buyers were increasingly attracted to Africa, and a tea auction market was established in Mombasa, Kenya. Mombasa, a regional auction market, sells tea from Kenya, Uganda, Rwanda, Burundi, Tanzania, Mozambique and other countries. Kenya is the largest player in the Mombasa market, followed by Uganda (ITC 2018).

Although previous studies have shown that some tea markets in Asia (e.g., tea markets in India and Sri Lanka) were cointegrated, tea markets across continents are segmented (Su and Xu 2009; Sekhar 2012; Tanui *et al.* 2012). For example, both Dharmasena and Bessler (2004) and Tanui *et al.* (2012) showed that the Colombo market in Sri Lanka and the Mombasa market in Kenya were not cointegrated. Additionally, tea markets were not cointegrated even in one country (Dang 2009; Ghosh 2012). For example, Ghosh (2012) showed that the different tea markets in India were not connected.

Tea markets were segmented for at least three reasons. First, the very nature of tea as a product of infinite varieties has made the comovement of the tea market difficult. Unlike most other commodities, tea cannot be designed to be bought and sold on predetermined specifications. The quality of tea depends on tea varieties, natural production conditions (e.g., soil and climate conditions) and processing methods (Tanui *et al.* 2012). Second, high transaction costs caused by the remote location of tea farms and underdeveloped infrastructure have limited the development of the comovement of tea prices in major tea auction markets (Chang 2015; United Nations 2018). Finally, the existence of trade barriers limited the formation of cointegrated markets. Due to the importance of the tea industry, the major tea-producing countries have set many limitations on the tea trade. For example, tea imports to Sri Lanka were prohibited due to the opposition of producers (Ganewatta and Edwards 2000). Additionally, Egypt imposes lower tariff on Kenyan tea than Sri Lankan and Indian tea, because Kenya belongs to the Common Market for Eastern and Southern Africa, a regional group established to promote the tea trade in Africa.

In recent years, however, the segmentation of tea markets might have changed. As major tea-producing countries have gained access to the World Trade Organization, trade barriers have been gradually removed, and many high tariffs were significantly reduced. In addition, some countries also signed regional agreements to promote trade (e.g., Indo-Lanka 2000). These agreements have contributed to the connection of tea auction markets and the comovement of tea prices. Moreover, the rapid development of basic infrastructure and the information market have significantly reduced the transaction costs (de Silva and Ratnadiwakara 2008; United Nations 2018). Finally, while high-yield varieties remain dominant, cultivation practices have improved in recent years (Majumder *et al.* 2012), and standard processing methods replaced the traditional methods (e.g., crush, tear, and curl (CTC) methods) that vary significantly. Consequently, the comovement of tea markets has been improved (Ahmed *et al.* 2010; Dang and Lantican 2011; Induruwage *et al.* 2016).

3. Data and methods

3.1. Data

Due to data availability and estimation efficiency, this study focuses on auction price series of black tea. This study used weekly data of 15 tea auction price series from June 2, 2012, to October 28, 2019, provided by the Tea Research Institute (TRI) of the Chinese Academy of Agricultural Sciences (2017, 2019). The TRI usually releases these data on a monthly basis. As the data were obtained at different times, they were unavailable from December 27, 2016 to September 3, 2017. The missing data would not cause significant estimation bias for two reasons. First, the missing values represent less than 9% of the total observations. Second, the test results showed that considering this break did not change the stationarity of the price series. To avoid the impact of price inflation, all price series were converted into U.S. dollars before analysis. The exchange rates between local currencies and U.S. dollars are the weekly average exchange rates from the central banks of the respective countries (https://www.worldbank.org/).

It should be noted that all price series have some missing observations. Specifically, there were 41 (11.8%) missing values for the Kolkata market, 45 for the Guwahati market, and 26 (7.5%) for the Cochin market in India. For the Colombo market of Sri Lanka, 18 (5.2%) observations were missing. Finally, Kenya, Uganda, Rwanda, Tanzania, Mozambique and Burundi had 18 (5.2%), 14 (4.0%), 14 (4.0%), 15 (4.3%), 113 (32.7%) and 10 (2.9%) missing observations, respectively.[1] Following the traditional method, the linear interpolation method was used to fill in these missing data (Dezhbakhsh and Levy 1994).[2]

The basic characteristics of the major variables used are summarized in Table 1. The tea prices in Sri Lanka were higher than those in India and Africa. As shown in rows 7–9 of Table 1, the average tea prices of low-grown, mid-grown and high-grown teas in Sri Lanka are 3.48, 2.97 and 3.18 USD kg^{-1}, respectively. Tea prices in Tanzania and Mozambique were the lowest (rows 13 and 15). In India, the tea prices of Kolkata and Guwahati were higher than those of Cochin (rows 1–6). Detailed dynamics of these price series are shown in Fig. 1.

3.2. Methods

The traditional measurements of global market integration which are based on international trade volume have been replaced by price behavior (Barret and Li 2002; Rembeza and Radlińska 2020). That is, markets are defined as cointegrated if there is a long-term relation between prices on these particular markets (Hanias *et al.* 2007). Empirically, traditional method testing market integration is based on bivariate correlation coefficients (Lele 1967; Jones 1968). Even though more recent testing methods were developed to address non-stationarity, common

Table 1 Basic characteristics of major variables

Market	Tea type	Observation	Mean	Standard deviation	Min.	Max.
India	Kolkata leaf	346	2.5479	0.4033	1.3865	3.4432
	Kolkata dust	346	2.3955	0.3709	1.3269	3.2892
	Guwahati leaf	346	2.1659	0.3039	1.4839	2.9838
	Guwahati dust	346	2.2517	0.3155	1.5028	3.0180
	Cochin leaf	346	1.9073	0.1648	1.4345	2.3364
	Cochin dust	346	1.7309	0.1779	1.3463	2.5150
Colombo	High-grown	346	3.1754	0.4142	2.4840	4.3926
	Mid-grown	346	2.9665	0.3519	2.2478	3.8672
	Low-grown	346	3.4804	0.4007	2.5975	4.4625
Mombasa	Kenya	346	2.5724	0.4275	1.9650	3.4768
	Uganda	346	1.5339	0.3112	0.7900	2.2900
	Rwanda	346	2.7286	0.3786	1.9850	3.7243
	Tanzania	346	1.4027	0.3289	0.5683	2.2077
	Burundi	346	2.4976	0.4834	1.7825	3.6325
	Mozambique	346	1.1745	0.3187	0.4430	1.8940

[1] Since the missing values of price series of Mozambique tea is relative large, we re-run the model by deleting this price series, and obtained similar results. Hence, we believe that missing values of price series of Mozambique tea did not lead to significant estimation bias.

[2] This study fills in the missing values by assuming that the weekly rate of change rate is same between two available and consecutive data points.

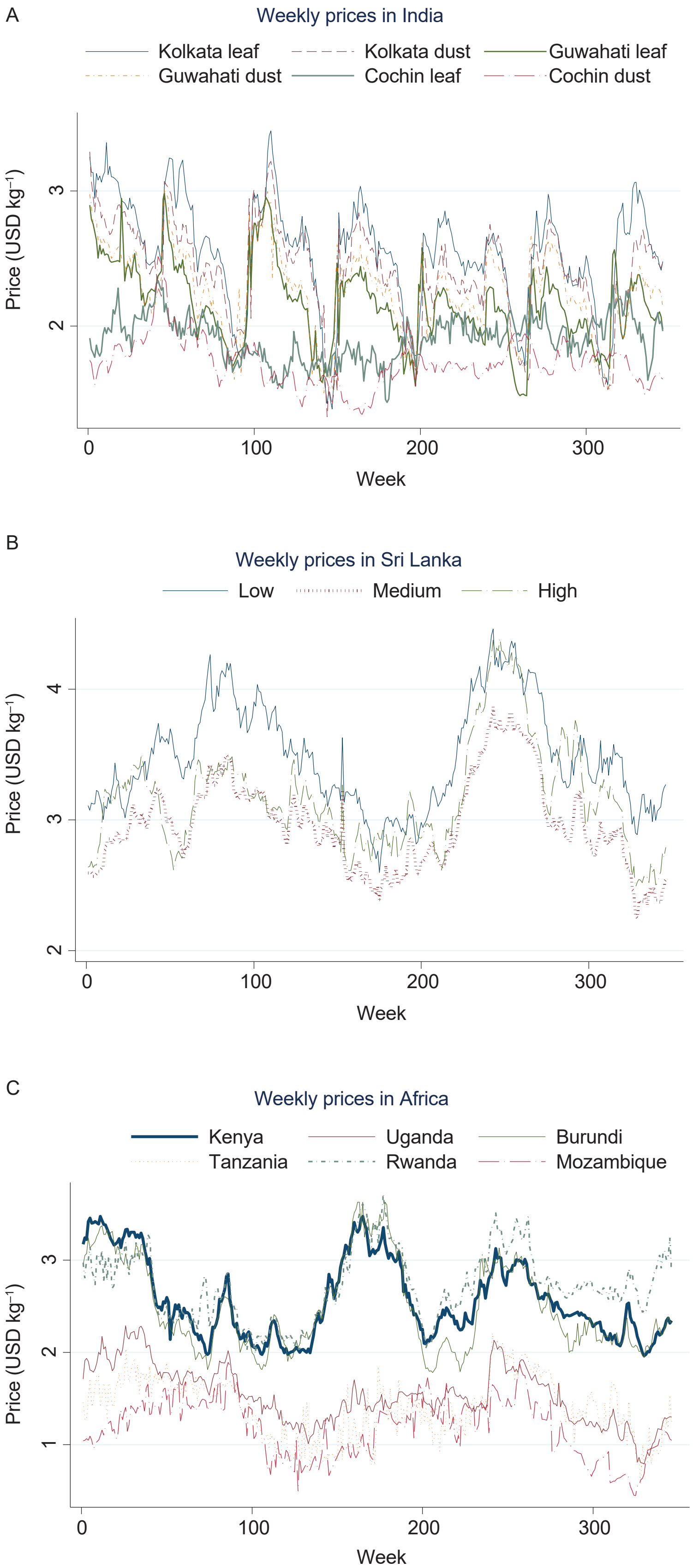

Fig. 1 Weekly tea prices of different auction markets.

trends and endogeneity of market prices, they have drawn criticism due to their inability to take market structure into account (Sekhar 2012). Further testing of central market and/or price formation are commonly based on vector Granger causality tests and the vector error correction model (Tanui *et al.* 2012; Rembeza and Radlińska 2020).

This study analyzed tea price series in three steps. First, a stationary test was performed for all price series using Augmented Dickey Fuller (ADF) test, the most commonly used method in time series analysis. Second, the study analyzed the relationship between these price series in India, Colombo (in Sri Lanka) and Mombasa (in Kenya). Specifically, the India market includes six price series: Kolkata leaf tea price, Kolkata dust tea price, Guwahati leaf tea price, Guwahati dust tea price, Cochin leaf tea price, and Cochin dust tea price. Colombo market includes three price series: low-grown tea price, mid-grown tea price, and high-grown tea price. And the Mombasa market includes six prices series: Kenya tea price, Uganda tea price, Burundi tea price, Rwanda tea price, Tanzania tea price, and Mozambique tea price. The Granger causality test was used for those stationary price series, while the vector error correction model (VECM) was used for nonstationary price series which were cointegrated. If some of the series were stationary and others were non-stationary, the study first tested whether these non-stationary series are cointegrated, and then obtained the cointegrating equation which includes the non-stationary series.

Finally, the cointegrating equation was added into a vector Granger causality test which includes all the other stationary price series. Optimal lag length is based on prediction error (FPE), Akaike's information criterion (AIC), Schwarz's Bayesian information criterion (SBIC), and Hannan and Quinn information criterion (HQIC). In addition, majority rule and parsimony rule are applied in the selection of lag length (Woodridge 2012). Following these methods, this study investigated the connection of tea markets across continents. Specifically, the study analyzed the price series of tea exported from Asia and Africa to European countries and the Middle East, respectively.

4. Results and discussion

4.1. Connection among tea markets in India, Sri Lanka and Kenya

Indian tea markets India produces leaf tea (also known as orthodox tea or loose leaf tea) and dust tea. The former is processed by traditional practices, while the latter by a standard CTC processing method. As discussed above, even though there are seven tea auction markets in India, tea sold in the Kolkata, Guwahati and Cochin markets was 364.63 thousand tons, which accounted for 62.82% of total tea sold in 2019 (Tea Board of India e-Auction Project 2019).

The dynamics of the dust tea and leaf tea prices in India's three largest markets — Kolkata, Guwahati and Cochin — are shown in Fig. 1-A. Leaf tea prices (solid lines) and dust tea prices (dashed lines) moved together in a given market. Further observations also found that the dynamics of the price series of the three markets seemed to be connected, even though solid statistical analyses are required to confirm this finding.

Before testing the relationships between these price series, their stationarity was tested. The results of the stationary test are shown in Table 2.[3] All leaf tea and dust tea price series in Kolkata, Guwahati and Cochin were stationary (rows 1–6, Table 2). The stationarity of price series in India was also found in previous studies (e.g., Dharmasena and Bessler 2004). Then, the VAR and vector Granger causality test were used to investigate their relationships. Lag length selection for the VAR model showed that FPE and AIC preferred an optimal lag length of 4, while SBIC and HQIC preferred a maximum optimal lag length of 1. Considering the parsimony rule, this study used the lag length of 1 for this VAR model.[4] The Granger causality test results are shown in Table 3.[5]

Tea auction markets in India were connected (Table 3). Leaf tea prices and dust tea prices were affected by each other in the same market, which confirms the finding of Fig. 1-A. For example, leaf tea prices and dust tea prices were affected by each other in Kolkata (rows 1 and 7), Guwahati (rows 15 and 27), and Cochin (row 29).

More interestingly, the Granger causality test results showed that the Kolkata market was an information sink in India. As shown in Table 3, both the Guwahati and Cochin markets had a significant impact on the leaf tea price (rows 2–5) and dust tea price (rows 8–11) in the Kolkata market. In this regard, tea price changes in either the Guwahati or Cochin markets could be transferred into the Kolkata market, making Kolkata an information sink in India.

Table 2 Stationary test of price series and their first difference

Tea type	Price level		First difference of price	
	z-value	*P*-value	*z*-value	*P*-value
Kolkata leaf	–3.32	0.01	–18.20	0.00
Kolkata dust	–4.38	0.00	–20.70	0.00
Guwahati leaf	–4.13	0.00	–18.58	0.00
Guwahati dust	–4.44	0.00	–18.59	0.00
Cochin leaf	–4.93	0.00	–25.02	0.00
Cochin dust	–2.59	0.09	–14.78	0.00
High-grown	–2.10	0.24	–17.99	0.00
Mid-grown	–1.96	0.30	–19.30	0.00
Low-grown	–2.23	0.20	–23.05	0.00
Kenya	–1.95	0.31	–16.40	0.00
Uganda	–2.07	0.26	–17.89	0.00
Rwanda	–2.94	0.04	–20.95	0.00
Tanzania	–5.62	0.00	–28.23	0.00
Burundi	–1.95	0.31	–18.88	0.00
Mozambique	–3.96	0.00	–22.74	0.00

This finding is consistent with expectation, as Kolkata is India's largest tea auction market with a total of 168 million kg of tea sold in 2019, which represents approximately 30% of India's tea trade (Tea Board of India e-Auction Project 2019). As the first tea auction market established in India, Kolkata also has a reputation for high-quality and hence high-price tea. Previous studies showed that high-quality Assam and Darjeeling teas from Guwahati were shipped to Kolkata at a high price (Hazarika 2008). The same is applicable to Cochin tea. As these high-quality teas have special characteristics (e.g., distinctive flavor and taste) and usually target high-income consumers, price variation in the source markets (i.e., Guwahati and Cochin) might transfer to the destination market (i.e., Kolkata).

Colombo market in Sri Lanka Sri Lanka produces mainly orthodox tea. Its tea-producing areas can be classified into three types according to elevation: (1) low-grown areas (e.g., Ratnapura/Balangoda, Deniyaya, Matara, and Galle) with high production in southern; (2) mid-grown areas (e.g., Uva Province, and Nuwara Eliya, Dimbuala and Dickoya); and (3) high-grown areas in the Central Highlands. According to the Tea Exporters

[3] In alternative scenarios, we considered the impact of seasonality and time trend on stationarity for all price series used in this study. The results show seasonality and adding time trend have no significant impact on stationarity.

[4] We also estimated the model with a lag length of 4 and the Granger causality test yields very similar results.

[5] For simplicity, the detailed estimation results of the vector autoregression are shown in Appendix D.

Table 3 Granger test for tea price series in India

Equation	Excluded	Chi^2	P-value
Kolkata leaf	Kolkata dust	23.58	0.00
	Guwahati leaf	23.01	0.00
	Guwahati dust	18.75	0.00
	Cochin leaf	5.50	0.02
	Cochin dust	7.52	0.01
	All	175.33	0.00
Kolkata dust	Kolkata leaf	7.06	0.01
	Guwahati leaf	3.03	0.08
	Guwahati dust	41.88	0.00
	Cochin leaf	0.12	0.73
	Cochin dust	4.50	0.03
	All	178.45	0.00
Guwahati leaf	Kolkata leaf	0.04	0.84
	Kolkata dust	1.28	0.26
	Guwahati dust	0.50	0.48
	Cochin leaf	0.64	0.42
	Cochin dust	0.01	0.93
	All	4.34	0.50
Guwahati dust	Kolkata leaf	0.14	0.70
	Kolkata dust	0.56	0.45
	Guwahati leaf	15.33	0.00
	Cochin leaf	0.04	0.84
	Cochin dust	0.32	0.57
	All	18.00	0.00
Cochin leaf	Kolkata leaf	3.03	0.08
	Kolkata dust	3.31	0.07
	Guwahati leaf	1.03	0.31
	Guwahati dust	1.43	0.23
	Cochin dust	12.32	0.00
	All	19.07	0.00
Cochin dust	Kolkata leaf	0.35	0.56
	Kolkata dust	2.09	0.15
	Guwahati leaf	0.33	0.57
	Guwahati dust	3.97	0.05
	Cochin leaf	0.00	0.97
	All	8.15	0.15

Association of Sri Lanka (2019b), the total production of low-grown tea was 189.8 million kg in 2019, 63.3% of the country's total tea production. The production of medium-grown and high-grown tea were 45.9 million kg (15.3%) and 61.7 million kg (20.6%), respectively. The dynamics of the tea price series of the low-grown, mid-grown and high-grown tea are shown in Fig. 1-B. Generally, the three price series were very similar and moved together.

Different from the tea price series in India, all three tea prices in Sri Lanka (i.e., low-grown, mid-grown and high-grown) were nonstationary (rows 7–9, Table 2). Further study showed that they were all integrated of order one, or I(1) (third and fourth columns, Table 2). Hence, the study further tested whether the three data series are cointegrated using the Johansen methodology (Johansen 1995). Bivariate cointegration tests showed that the trace statistic value for the low-grown and mid-grown tea prices was 21.79, with a *P*-value of less than 1%. The trace statistic values for the low-grown and high-grown tea and for the mid-grown and high-grown tea were 15.88 and 18.86, respectively, with both *P*-values of less than 5%. The vector test showed that the trace statistic value for the low-grown, mid-grown and high-grown tea was 45.91, with a *P*-value of less than 1%. That is, the three tea prices were cointegrated.

Then, a VECM was established to investigate the relationships between the three price series.[6] As shown in Table 4, in the mid-grown and low-grown tea price equations, the estimated coefficients of the cointegrating equation had correct signs, while these signs were incorrect in the high-grown tea price equation. However, it should be noted that it is common for the estimated coefficient of the cointegrating equation to have an incorrect sign in the VECM. For example, the example introduced in the STATA manual shows that both the estimated coefficients of the cointegrated vector are negative (for details, please refer to https://www.stata.com/manuals13/tsvec.pdf).

The VECM estimation results showed that the low-grown tea price series was the central price in the Colombo market in Sri Lanka. The estimated coefficient of the low-grown tea price was statically significant in both the mid-grown and the high-grown tea price equations (rows 6 and 7, Table 4). In other words, a price change for the low-grown tea affected the price series of both mid-grown and high-grown tea. The central position of the low-grown tea in the Colombo market is under expectation, as the low-grown region is Sri Lanka's largest production region, accounting for 60% of the total tea production in the country (Tea Exporters Association of Sri Lanka 2019b).

Mombasa market in Kenya In the Mombasa market, three tea price series (i.e., Kenya, Uganda and Burundi) were nonstationary, while the other three tea price series (i.e., Rwanda, Tanzania and Mozambique) were stationary (Table 2). As shown in Fig. 1-C, the three nonstationary tea price series (solid lines) seemed to move together. Further studies showed that all three nonstationary price series were I(1). Vector tests showed that the trace statistics for Kenya, Uganda and Burundi were 44.80, with a *P*-value of less than 1%. That is, the three nonstationary tea price

[6] An optimal lag length of 3 was selected according to the majority rule (i.e., both PFE and AIC prefer lag length of 3). Further study shows that similar results are obtained if a lag length of 2 was selected.

Table 4 Relationship between price series in the Colombo market

	First difference of tea price of[1)]		
	High-grown	Mid-grown	Low-grown
Co-integrating equation (*t*–1)	0.0324***	0.0174*	–0.0268**
	(2.98)	(1.86)	(–2.40)
Difference of high-grown (*t*–1)	–0.0495	0.0425	–0.0616
	(–0.64)	(0.63)	(–0.77)
Difference of high-grown (*t*–2)	0.1894**	0.0821	0.0841
	(2.48)	(1.25)	(1.07)
Difference of mid-grown (*t*–1)	0.2516**	–0.0185	0.0860
	(2.23)	(–0.19)	(0.74)
Difference of mid-grown (*t*–2)	0.0009	–0.0083	–0.0683
	(0.01)	(–0.09)	(–0.60)
Difference of low-grown (*t*–1)	–0.1971***	–0.0497	–0.1815**
	(–2.81)	(–0.82)	(–2.51)
Difference of low-grown (*t*–2)	–0.0381	0.0730	0.1721**
	(–0.56)	(1.24)	(2.44)
Constant	0.0005	–0.0002	0.0004
	(0.10)	(–0.04)	(0.09)
Observations	343	343	343

[1)] *z*-statistics in parentheses.
***, $P<0.01$; **, $P<0.05$; *, $P<0.1$.

series were cointegrated.[7] Hence, a VECM was used to investigate the relationships between the tea prices in Kenya, Uganda and Burundi.

The VECM estimation results showed that tea price change in Kenya had a significant impact on that of Uganda and Burundi.[8] As shown in Table 5, the estimated coefficients of the lagged difference in Kenya's tea prices were statistically significant in both the Uganda and Burundi equations. That is, a tea price change in Kenya in the previous time period could affect the current tea price in both Uganda and Burundi. This result is could be explained by at least two reasons. First, Kenya is the largest tea producer in the Mombasa market. Second, more than 90% of the tea from Uganda and Burundi was exported to Kenya (FAO 2019).

A vector Granger causality test was then used to investigate the relationships between stationary price series in the Mombasa market.[9] In addition, the cointegrating equation (which includes Kenya, Uganda and Burundi) was also added to the vector Granger causality test. Tanzania's tea prices were affected by those of Rwanda and Mozambique (rows 10 and 11, Table 6). The effect from Rwanda (the second largest tea producer in Africa) might be due to similarity between Tanzanian and Rwandan tea (Hall 2003). The effect from Mozambique might be because Tanzania and Mozambique are both major suppliers of low-quality tea used for tea blends (Hall 2003).

4.2. Connection among tea markets across continents

European Union countries and the Middle East are two major tea consumption markets but they have few or no tea plantations. Total imports by the European Union and the Middle East reached 0.79 million tons in 2017, which are from Asian and African markets and account for more than 40% of the world's total imports (FAO 2019).

European Union market The European market imports tea from India (i.e., Kolkata, Guwahati and Cochin), high-grown areas of Sri Lanka, and African countries such as Kenya, Burundi, Rwanda, Tanzania and Mozambique (FAO 2019). As shown in Table 2, the price series of high-grown tea, Kenyan tea and Burundian tea were I(1), while the price series of other tea were stationary. Hence, this study first tested the cointegration of three nonstationary price series. The vector test showed that the trace statistics was 32.28, with a *P*-value of less than 5%. That is, the three tea prices were cointegrated. Then, the cointegrating equation, which includes high-grown tea

[7] Bivariate cointegration tests show that trace statistics for Kenya and Burundi are 25.45, with a *P*-value of less than 1%. On the other hand, the trace statistics for Kenya and Uganda, Uganda and Burundi are 14.55 and 14.52, respectively, which are slightly lower than the corresponding 5% critical value (i.e., 15.41).
[8] A lag length of 4 is chosen based on majority rule (both PFE and AIC prefer a lag length of 4).
[9] An maximum optimal lag length of 2 was selected based on FPE, AIC and SBIC.

Table 5 Relationship between non-stationary price series in the Mombasa market

	First difference of tea price of[1)]		
	Kenya	Uganda	Burundi
Co-integrating equation (*t*–1)	–0.0380	–0.0301	0.1493***
	(–1.07)	(–0.96)	(3.54)
Difference of Kenyan (*t*–1)	0.0552	0.2744***	0.2534***
	(0.81)	(4.58)	(3.13)
Difference of Kenyan (*t*–2)	0.0787	0.1179*	0.2034**
	(1.12)	(1.91)	(2.45)
Difference of Kenyan (*t*–3)	–0.0949	–0.1203**	–0.0206
	(–1.42)	(–2.04)	(–0.26)
Difference of Uganda (*t*–1)	0.1583**	–0.0747	0.0636
	(2.38)	(–1.27)	(0.80)
Difference of Uganda (*t*–2)	–0.0955	–0.0572	–0.0764
	(–1.43)	(–0.97)	(–0.96)
Difference of Uganda (*t*–3)	–0.0134	–0.1518***	–0.0151
	(–0.21)	(–2.69)	(–0.20)
Difference of Burundi (*t*–1)	0.0650	–0.0317	–0.1307**
	(1.24)	(–0.68)	(–2.10)
Difference of Burundi (*t*–2)	0.0715	–0.0389	0.0145
	(1.38)	(–0.86)	(0.24)
Difference of Burundi (*t*–3)	0.0452	0.0562	0.1211**
	(0.92)	(1.30)	(2.07)
Constant	–0.0027	–0.0016	–0.0010
	(–0.67)	(–0.45)	(–0.21)
Observations	342	342	342

[1)] *z*-statistics in parentheses.
***, $P<0.01$; **, $P<0.05$; *, $P<0.1$.

Table 6 Granger test for tea price series in the Mombasa market

Equation	Excluded	Chi^2	*P*-value
K&U&B[1)]	Rwanda	2.71	0.26
	Tanzania	0.56	0.75
	Mozambique	0.51	0.78
	All	4.73	0.58
Rwanda	K&U&B	1.52	0.47
	Tanzania	2.55	0.28
	Mozambique	1.06	0.59
	All	7.55	0.27
Tanzania	K&U&B	0.94	0.63
	Rwanda	15.59	0.00
	Mozambique	19.18	0.00
	All	34.45	0.00
Mozambique	K&U&B	1.47	0.48
	Rwanda	1.89	0.39
	Tanzania	2.11	0.35
	All	6.64	0.36

[1)] K&U&B stands for Kenya, Uganda and Burundi.

from Sri Lanka, Kenyan tea and Burundian tea, was added into a vector Granger causality test for stationary price series. The test results are shown in Table 7.[10]

The connection of markets in the same region was confirmed again. For example, The tea price series of the Kolkata market was affected by those of the Guwahati and Cochin markets, which is the same as the finding shown in Table 3. Similarly, the price series of Rwandan and Mozambique tea affected those of Tanzania tea, confirming the findings shown in Table 6. In other words, the estimation results in Table 7 confirmed the findings in regional markets, indicating that the findings are robust.

Interestingly, Table 7 also shows that the Indian market, through Cochin, was associated with the markets in Colombo and Mombasa. As shown in rows 46–49 (third and fourth columns), the leaf tea price in Cochin was affected by the cointegrating equation (which includes high-grown tea prices in Colombo and the prices series for Kenyan and Burundian tea in Mombasa), and prices of tea from Tanzania and Mozambique. In addition, Table 7 shows that the price of Rwandan tea and the dust tea price in Cochin were affected by each other (rows 7 and 26, the last two columns). But the other two Indian markets (i.e., Kolkata and Guwahati) had no clear relationship with the Colombo or Mombasa markets.

The results are consistent with our expectations. Major tea sold in the Kolkata and Guwahati markets are from North and Northeast India. Due to the special

[10] The cointegrated equation is estimated with a lag length of 3, while the VAR model including the cointegrated equation is estimated with a lag length of 2 based on based on PFE and AIC. Estimation results of the VAR model is shown in Appendix E.

Table 7 Granger test for price series exported to European market1)

Equation	Excluded	Chi²	*P*-value	Equation	Excluded	Chi²	*P*-value
Kolkata L	Kolkata D	23.70	0.00	Cochin D	Kolkata L	0.10	0.75
	Guwahati L	19.50	0.00		Kolkata D	1.19	0.28
	Guwahati D	16.36	0.00		Guwahati L	3.35	0.07
	Cochin L	7.21	0.01		Guwahati D	9.25	0.00
	Cochin D	7.46	0.01		Cochin L	0.60	0.44
	H&K&B	0.57	0.45		H&K&B	0.83	0.36
	Rwanda	1.24	0.27		Rwanda	2.36	0.12
	Tanzania	0.01	0.92		Tanzania	4.09	0.04
	Mozambique	0.62	0.43		Mozambique	0.04	0.84
	All	178.97	0.00		All	24.39	0.00
Kolkata D	Kolkata L	8.29	0.00	H&K&B	Kolkata L	0.24	0.62
	Guwahati L	3.46	0.06		Kolkata D	0.38	0.54
	Guwahati D	34.89	0.00		Guwahati L	0.41	0.52
	Cochin L	0.91	0.34		Guwahati D	0.04	0.85
	Cochin D	5.55	0.02		Cochin L	2.79	0.09
	H&K&B	2.42	0.12		Cochin D	0.08	0.77
	Rwanda	1.17	0.28		Rwanda	0.01	0.92
	Tanzania	0.02	0.88		Tanzania	1.25	0.26
	Mozambique	1.59	0.21		Mozambique	4.01	0.05
	All	185.88	0.00		All	10.70	0.30
Guwahati L	Kolkata L	0.04	0.85	Rwanda	Kolkata L	0.35	0.55
	Kolkata D	1.20	0.27		Kolkata D	2.35	0.13
	Guwahati D	0.82	0.36		Guwahati L	0.77	0.38
	Cochin L	0.98	0.32		Guwahati D	0.03	0.86
	Cochin D	0.01	0.91		Cochin L	4.98	0.03
	H&K&B	0.05	0.83		Cochin D	6.53	0.01
	Rwanda	1.47	0.22		H&K&B	0.57	0.45
	Tanzania	0.07	0.79		Tanzania	0.90	0.34
	Mozambique	0.07	0.79		Mozambique	0.32	0.57
	All	6.20	0.72		All	18.20	0.03
Guwahati D	Kolkata L	0.52	0.47	Tanzania	Kolkata L	0.38	0.54
	Kolkata D	1.07	0.30		Kolkata D	0.08	0.78
	Guwahati L	18.12	0.00		Guwahati L	0.58	0.45
	Cochin L	0.00	0.95		Guwahati D	1.85	0.17
	Cochin D	0.04	0.85		Cochin L	0.71	0.40
	H&K&B	1.27	0.26		Cochin D	6.51	0.01
	Rwanda	0.02	0.89		H&K&B	0.00	1.00
	Tanzania	1.25	0.26		Rwanda	19.16	0.00
	Mozambique	0.30	0.58		Mozambique	24.69	0.00
	All	21.67	0.01		All	58.12	0.00
Cochin L	Kolkata L	2.46	0.12	Mozambiq	Kolkata L	0.00	0.99
	Kolkata D	3.49	0.06		Kolkata D	0.32	0.57
	Guwahati L	1.25	0.26		Guwahati L	0.66	0.42
	Guwahati D	1.87	0.17		Guwahati D	0.05	0.83
	Cochin D	8.84	0.00		Cochin L	0.09	0.77
	H&K&B	7.26	0.01		Cochin D	1.63	0.20
	Rwanda	1.56	0.21		H&K&B	0.02	0.88
	Tanzania	3.09	0.08		Rwanda	0.84	0.36
	Mozambique	5.22	0.02		Tanzania ue	1.13	0.29
	All	37.06	0.00		All	8.55	0.48

1) H&K&B stands for high-grown (in Sri Lanka), Kenya and Burundi. "D" stands for dust tea, while "L" stands for leaf tea.

tea varieties produced and environmental and climate conditions, tea from North India is so special that it has no substitute in the market (Luo 2010a). The varieties and flavors of tea sold in Cochin however are very similar to those grown in Sri Lanka and African countries (Luo 2010b). In addition, most tea sold in Cochin, Sri Lanka and African countries is processed using the CTC method, which might be the reason why the Cochin market is associated with the Colombo and Mombasa markets.

Middle East market The Middle East market imports tea from the Kolkata and Guwahati markets, low- and mid-grown areas from Sri Lanka, and African countries – Kenya, Uganda, Tanzania and Mozambique (FAO 2019). Following the method specified in the section of "European Union market", this study first tested the cointegration of four I(1) price series of low-grown and mid-grown tea from Sri Lanka, Kenya tea, and Burundi tea. The vector test showed that the trace statistics for the four price series was 56.43, with a *P*-value of less than 1%. That is, the four tea prices were cointegrated.[11]

The VECM estimation results showed that tea price change in the Colombo market had a significant impact on that of the Mombasa market.[12] As shown in Table 8, the estimated coefficients of the prices of the low- and mid-grown tea were statistically significant in both the Kenya and Uganda equations (rows 3, 6, 8 and 10). Similarly, the estimated coefficients of the tea prices of Kenya and Uganda were statistically significant in both the low- and mid-grown equations (rows 8, 10, 12 and 13). That is, tea price in the Colombo market could affect that in Mombasa, and *vice versa*.

The cointegrating equation was added in a vector Granger causality test for stationary price series. The test results are shown in Table 9.[13] As expected, the connection of the markets in the same country or region was confirmed again. For example, for tea from India, the

Table 8 Relationship between non-stationary price series exported to the Middle East market

	First difference of tea price of[1)]			
	Low-land	Mid-land	Kenya	Uganda
Co-integrating equation (*t*–1)	–0.1476***	–0.0075	0.0056	0.0309
	(–4.09)	(–0.24)	(0.18)	(1.13)
Difference of low-land (*t*–1)	–0.1437**	–0.0206	–0.0541	–0.0104
	(–2.07)	(–0.34)	(–0.91)	(–0.20)
Difference of low-land (*t*–2)	0.1758**	0.0918	–0.1446**	–0.1192**
	(2.54)	(1.53)	(–2.42)	(–2.26)
Difference of low-land (*t*–3)	–0.0873	0.0466	0.0553	–0.0123
	(–1.26)	(0.78)	(0.93)	(–0.23)
Difference of mid-land (*t*–1)	0.0240	–0.0207	0.0234	0.0776
	(0.29)	(–0.29)	(0.33)	(1.23)
Difference of mid-land (*t*–2)	–0.0320	0.0169	0.1638**	0.1576**
	(–0.39)	(0.24)	(2.29)	(2.50)
Difference of mid-land (*t*–3)	0.0040	–0.0898	0.0707	–0.0069
	(0.05)	(–1.25)	(0.99)	(–0.11)
Difference of Kenya (*t*–1)	0.1148*	0.0081	0.0815	0.2422***
	(1.70)	(0.14)	(1.40)	(4.70)
Difference of Kenya (*t*–2)	–0.0007	–0.0857	0.1316**	0.0868*
	(–0.01)	(–1.43)	(2.20)	(1.65)
Difference of Kenya (*t*–3)	0.1138*	0.0089	–0.0416	–0.1123**
	(1.67)	(0.15)	(–0.71)	(–2.16)
Difference of Uganda (*t*–1)	–0.0292	0.0789	0.1716***	–0.0716
	(–0.39)	(1.21)	(2.64)	(–1.25)
Difference of Uganda (*t*-2)	–0.1378*	0.0068	–0.1015	–0.0527
	(–1.79)	(0.10)	(–1.53)	(–0.90)
Difference of Uganda (*t*–3)	0.1118	0.1130*	–0.0306	–0.1389**
	(1.51)	(1.76)	(–0.48)	(–2.46)
Constant	–0.0003	–0.0001	–0.0024	–0.0012
	(–0.07)	(–0.01)	(–0.58)	(–0.33)
Observations	342	342	342	342

[1)] *z*-statistics in parentheses.
***, *P*<0.01; **, *P*<0.05; *, *P*<0.1.

[11] Even though the cointegrating equation includes four price series, the coefficients of low-grown and mid-grown tea are 1.00 and –1.15, respectively, while the coefficients for Kenya and Burundi are 0.18 and 0.05. That is, it seems that cointegration equation includes more information about low-grown and mid-grown tea. Hence, in the following, we consider it to represent low-grown and high-grown tea.

[12] A lag length of 4 is chosen based on majority rule (both PFE and AIC prefer a lag length of 4).

[13] The cointegrated equation is estimated with a lag length of 4 based on PFE and AIC, while the VAR model including the cointegrated equation is estimated with a lag length of 1 based on HQIC and SBIC. Estimation results of the VAR model is shown in Appendix F.

Table 9 Granger test for price series exported to the Middle East market[1)]

Equation	Excluded	Chi^2	*P*-value
Kolkata L	Kolkata D	28.25	0.00
	Guwahati L	18.84	0.00
	Guwahati D	16.02	0.00
	L&M&K&U	0.30	0.59
	Tanzania	0.47	0.49
	Mozambique	0.01	0.91
	All	164.58	0.00
Kolkata D	Kolkata L	7.11	0.01
	Guwahati L	1.80	0.18
	Guwahati D	38.04	0.00
	L&M&K&U	0.68	0.41
	Tanzania	1.96	0.16
	Mozambique	0.54	0.46
	All	173.51	0.00
Guwahati L	Kolkata L	0.27	0.60
	Kolkata D	2.26	0.13
	Guwahati D	0.48	0.49
	L&M&K&U	0.07	0.80
	Tanzania	0.06	0.80
	Mozambique	0.10	0.75
	All	3.33	0.77
Guwahati D	Kolkata L	0.13	0.72
	Kolkata D	0.63	0.43
	Guwahati L	18.21	0.00
	L&M&K&U	0.35	0.55
	Tanzania	0.89	0.35
	Mozambique	0.25	0.61
	All	20.40	0.00
L&M&K&U	Kolkata L	0.04	0.83
	Kolkata D	0.24	0.63
	Guwahati L	0.21	0.64
	Guwahati D	0.05	0.83
	Tanzania	0.47	0.49
	Mozambique	0.70	0.40
	All	5.09	0.53
Tanzania	Kolkata L	0.00	1.00
	Kolkata D	0.32	0.57
	Guwahati L	0.35	0.55
	Guwahati D	1.43	0.23
	L&M&K&U	0.17	0.68
	Mozambique	25.34	0.00
	All	29.58	0.00
Mozambique	Kolkata L	0.07	0.78
	Kolkata D	0.10	0.75
	Guwahati L	0.58	0.45
	Guwahati D	0.06	0.81
	L&M&K&U	1.58	0.21
	Tanzania	5.39	0.02
	All	7.98	0.24

[1)] L&M&K&U stands for low-grown (in Sri Lanka), mid-grown (in Sri Lanka), Kenya and Uganda; "D" stands for dust tea, while "L" stands for leaf tea.

tea prices in Kolkata were affected by those in Guwahati (rows 2–3). For the African markets, tea prices in Tanzania and Mozambique were connected (rows 41 and 48). That is, the relationship between price series in the same country or region was again confirmed.

5. Conclusion and policy recommendations

Worldwide tea markets have not been systematically studied in the literature, though global tea consumption has grown rapidly in recent years, and is projected to keep rising in the coming decades. Using weekly data, this study shows that the world's major black tea markets are connected, even though heterogeneities vary widely. This finding holds not only for regional markets within a country but also for markets across countries. This study contributes to literature by showing that it is the Cochin market that connects India with Colombo and Mombasa tea markets, while the latter two are affected by each other.

The results of this study have important implications for tea farmers in major tea-producing countries. First, this study provides empirical evidence to predict tea price movement between regions and across countries. Tea prices in one market can transmit to other markets not only in the same region but also to international markets in other countries, which implies that local tea market prices are determined not only by local demand and supply but also by tea markets in other major tea production countries. Production decision of tea farmers in one country must respond to supply shocks or price changes in other major tea-producing countries.

Second, the integration of tea markets across countries implies that tea markets are becoming increasingly competitive, which forces tea producers to face production shocks on a global scale. On the one hand, any production shock due to climate and/or plant pests and diseases in one country or region will cause less price fluctuations than in nonintegrated markets. This helps all tea farmers in the world mitigate price risks due to local production shocks. On the other hand, local farmers may suffer increased price fluctuations due to any large production shock from other countries because price changes in these countries can easily transmit to local markets.

Last but not least, the results of this study also have important implications for rural employment and poverty alleviation. Tea production is highly labor intensive. Most tea production is located in mountainous or remote areas. Tea producers and hired laborers are relatively poor in many tea-producing countries (i.e., India, Sri

Lanka, African countries, and China). As discussed in the Introduction section, tea farmer's income comes mainly from tea production. This study shows that major tea markets are connected, and price changes in one market can transmit to other markets. Hence, expanding production may have a minor negative impact on local and global tea prices but a major positive impact on the income of millions of small tea producers.

This study has some limitations. First, it only investigated the auction price series of black tea. Hence, whether the price fluctuations in major green tea-producing countries without auction markets (e.g., China, Vietnam, and Japan) are connected remains unclear. In this sense, the integration of green tea markets deserves further study. Second, this study focuses only on the interaction of tea prices, but ignores the impact of other exogenous variables such as climate change and consumption substitution of different teas.

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Declaration of competing interest

The authors declare that they have no conflict of interest.

Appendices associated with this paper are available on http://www.ChinaAgriSci.com/V2/En/appendix.htm

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