Instituto de Estudios Avanzados en Desarrollo

Tracking the trend of quinoa price in Bolivia: Structural breaks and persistence of shocks

By:

Javier Aliaga Lordemann
Ignacio Garrón Vedia
María Cecilia Lenis Abastoflor

Series of Working Papers on Development
No. 10/2024

June 2024

Tracking the trend of quinoa price in Bolivia: Structural breaks and persistence of shocks*

Javier Aliaga Lordemann**
Ignacio Garrón Vedia***
María Cecilia Lenis Abastoflor****

La Paz, June 2024

Abstract

Quinoa has evolved considerably in the past decades, becoming consolidated as a fundamental pillar for Andean farming communities and emerging as a prominent actor in the global superfood market. Despite this, prices of this grain have been characterized by complex dynamics, with substantial fluctuations that directly affect smallholder income.

The goal of this research is to analyze Bolivian quinoa price dynamics, identifying both the main events and factors that caused structural breaks in the price trend and the persistence of shocks in time. The approach employed combines, on the one hand, an analysis of the structural breaks by means of the Bai and Perron contrast, together with estimates of long memory using the 2ELW estimator. Also evaluated was the influence of exogenous variables that affect prices, for which the world commodity activity index (Index of Global Real Economic Activity), the Oceanic Niño Index and world quinoa production were considered.

The findings show multiple structural breaks in the quinoa price series, related to certain key events. Among the latter are for example changes in research and development, the production and sales boom, and the boost prompted by State initiatives and international cooperation. These breaks are also related to different degrees of persistence in the shocks under the different regimes identified. Although the exogenous variables show no significant short-

* The research is part of the project titled *Creating Indigenous Women's Green Jobs Under Low-Carbon COVID-19 Responses and Recovery in the Bolivian Quinoa Sector*, presently being carried out by Fundación INESAD through the sponsorship of International Development Research Centre (IDRC) of Canada. Possible errors are entirely the responsibility of the authors.
** INESAD Associate Researcher (jaliaga@inesad.edu.bo)
*** INESAD Guest Researcher (ignaciogarron@gmail.com)
**** INESAD Junior Researcher (mlenis@inesad.edu.bo)

term effects, it is understood that they may have a relevant influence in different periods.
The present study shows the complexity of Bolivian quinoa price dynamics, characterized by several structural breaks. To take proper advantage of this market, producers and policy makers must implement flexible strategies, as well as continuous monitoring of the sector's progress, considering the key factors that induced price trend changes over the years.

Keywords: quinoa, prices, structural breaks, long memory, market dynamics, Andean region
JEL codes: Q10, Q11, Q17, O13, C22

Resumen

La quinua ha experimentado una notable transformación en las últimas décadas, consolidándose como un pilar fundamental para las comunidades agrícolas andinas y emergiendo como un actor prominente en el mercado global de los súper alimentos. Sin embargo, los precios de este grano han mostrado una dinámica compleja, con grandes fluctuaciones que han impactado directamente sobre los ingresos de los pequeños productores.
Esta investigación tiene como objetivo analizar la dinámica del precio de la quinua en Bolivia identificando los principales eventos y factores que han generado quiebres estructurales en su tendencia, así como también identificando la persistencia de los choques a lo largo del tiempo. Se empleó un enfoque que combina, por un lado, el análisis de quiebres estructurales por medio del contraste de Bai y Perron, y también está la estimación de la memoria larga a través del estimador 2ELW. Adicionalmente, se evaluó la influencia de variables exógenas que afectan sobre los precios. Para ello se contempló el índice de actividad mundial de materias primas, el índice oceánico de El Niño y la producción mundial de la quinua.
Los hallazgos revelan múltiples quiebres estructurales en la serie de precios de la quinua que se relacionan con ciertos eventos clave. Por ejemplo, están los cambios en la investigación y el desarrollo, el auge de la producción y la comercialización, y el impulso de las iniciativas gubernamentales y de la cooperación internacional. Estos quiebres también se asocian a distintos grados de persistencia de los choques en cada régimen identificado. Si bien las variables exógenas no muestran efectos significativos a corto plazo, se reconoce que podrían tener una influencia relevante en diferentes periodos.
Este estudio demuestra la complejidad en la dinámica de los precios de la quinua en Bolivia, que está caracterizada por múltiples quiebres estructurales. Para aprovechar las oportunidades en este mercado, los productores y formuladores de políticas deben implementar estrategias flexibles y de monitoreo constante de la evolución del sector, tomando en cuenta los factores clave que han impulsado los cambios en la tendencia de precios a lo largo del tiempo.

Palabras clave: Quinua, precios, quiebres estructurales, memoria larga, dinámica de mercado, región andina.
Código JEL: Q10, Q11, Q17, O13, C22

Introduction

For Andean producers, quinoa production prospects were promising for many years, with attractive export prices and growing demand. In this scenario, in 2013, prices reached a maximum of approximately USD 8/kg, USD 7/kg and USD 6/kg for Bolivia, Peru and Ecuador, respectively. This encouraging context was attributable, among other factors, to growing demand in the United States[1]. Notwithstanding, in 2014 prices collapsed as a result of the closing of markets and the emergence of new competitors, causing a negative impact on small farmer income in the Andean region (Alandia *et al.*, 2020).

At 2022, both export prices and production levels of quinoa in the region remained at levels similar to those of 2014, representing stagnation in the market. Given this, understanding the quinoa price dynamics is a topic relevant both for small producers and for policy makers in the Andean region. With this in mind, as far as the authors know, the present analysis may be the first done on quinoa price characteristics.

Hence, this work analyzes the role of different events that affected changes in quinoa export price trends from January 1992 to December 2022. It is observed that the structural breaks in the time series analyzed coincide with national and international events and projects carried out to promote quinoa production.

The price changes are analyzed using an algorithmic approach that identifies relevant events endogenously. This method, also employed by Prados de la Escosura and Rodríguez-Caballero (2022) for studying European economic growth in relation to pandemics and wars, is based on the contrast proposed by Bai and Perron (1998), which estimates both the number and the date of structural changes in a price series. The methodology proposed by Bai and Perron (2003a) is used for estimation and that of Bai and Perron (2003b) for the critical values of the test. This process implies dividing the sample into subsamples with a cut-off parameter ε that defines the minimum size of the segment relative to the sample size. The estimates are done with ordinary least squares in each segment, and then the estimated values of the structural breaks are determined based on a global minimization problem. The analysis allows observing that two events had the greatest impact on prices. Firstly, it is worth highlighting that in the period from 2007 to 2012 there was considerable progress in the fostering and development of quinoa in the Southern Altiplano (High Plateau) of Bolivia with the implementation of programs centered on improving the quality of life of smallholders and promoting sustainable production of the grain. However, the event that generated a more persistent effect in the price level was the *International Year of Quinoa* (2013). Worth noting is the fact that although during this regime prices increased, its effects were observed in later periods.

The remainder of the document is structured as follows: Section I presents a brief analysis of the quinoa economy in the Andean region. Sections II and III present the data and methodology, respectively. Finally, sections IV and V show the main work results and conclusions, respectively.

[1] See Alandia *et al.* (2020) for further discussion.

I The quinoa economy in the region

In recent decades, the economics of quinoa went through considerable changes. Quinoa developed into a crucial component for Andean agricultural communities and became a key player in the superfoods market globally[2]. The present section analyzes the economic trajectory of quinoa in the Andean region. For this, a presentation is made of how the production and market dynamics had an effect on regional prices and how they helped shape the strategies of local farmers.

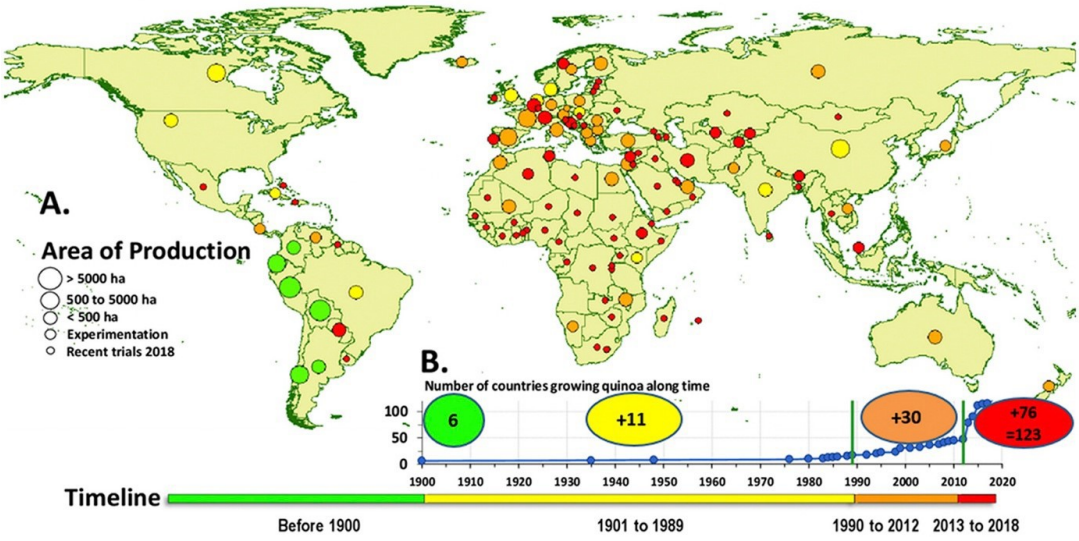
Jacobsen (2011) highlights quinoa's capacity to adapt to a diversity of agroecological conditions, making it possible to cultivate it beyond its traditional zones in the Andes. This adaptability has led to considerable geographic diversification, which in turn stimulated growing global interest in the crop. Quinoa's internationalization has transformed the grain from a basic local food into a product of high demand worldwide.

Ofstehage (2012) and Stevens (2017) observed that in the face of this increase in global demand, Andean producers have adopted new commercial strategies for becoming more effectively integrated in the international markets. These changes include a transition from subsistence practices to more commercial cultivation methods, as well as adaptation to international regulations and expectations, which imply professionalization and formalization of cultivation and commercialization techniques.
Figure 1 shows the evolution of distribution in the world's quinoa production since before 1900 to 2018. Prior to 1900, this grain's cultivation was exclusive to certain Andean countries. As of 1901, the experimentation period began, with other countries beginning to produce quinoa, reaching 123 in number in 2018. However, despite all of the new competition, the Andean countries continue to have an important presence in the market, possessing the largest production area.

The quinoa market's expansion had its challenges. Bazile and Baudrom (2015), Bazile *et al.* (2016) and González *et al.* (2015) discuss how growing global competition exerted pressure on prices, both at the local and international levels. This phenomenon directly affected the economic stability of small producers, who in addition faced significant price fluctuations.

[2] The term "superfood" refers to foods that provide numerous benefits for human health as a result of high nutrient density.

Figure 1: Worldwide distribution of quinoa production and evolution of plantations



Source: Alandia *et al.* (2020).

Hence stands out the importance of cooperation between farmers for accessing more lucrative markets and for applying sustainable agricultural practices. These collaborative networks have improved not only the economic conditions of producers, but have also fostered fairer and more equitable trade (Carimentrand *et al.*, 2015).

The quinoa boom also provided opportunities for exploring alternative markets and developing derivative products, thus creating new economic opportunities and helping to stabilize prices (Bellemare *et al.*, 2018). However, Benique Olivera (2021) and Jaikishun *et al.* (2019) also warn about market volatility and its potentially disruptive effects.

In terms of sustainability, Andreotti *et al.* (2022), Jacobsen (2011) and Liuhto *et al.* (2016) discuss how the need to adapt to international market demands led to investments in technology and training, which on the one hand increased productivity, but on the other created a dependency on some external inputs such as fertilizers and pesticides that could alter local ecological equilibrium. It is essential to carefully manage quinoa genetic resources to avoid the erosion of their biological and cultural diversity. These are critical aspects, given the historical and cultural significance of quinoa for the Andean peoples (Bazile and Baudrom, 2015).

Understanding the complexity of the quinoa economy in the Andean region is vital for also comprehending how the changes in production and the global market dynamics directly influenced the price structure and local economic strategies. An understanding of these and other possible associated factors is fundamental for specifically dealing with the changes and events that had an impact on the price dynamics of the golden grain.

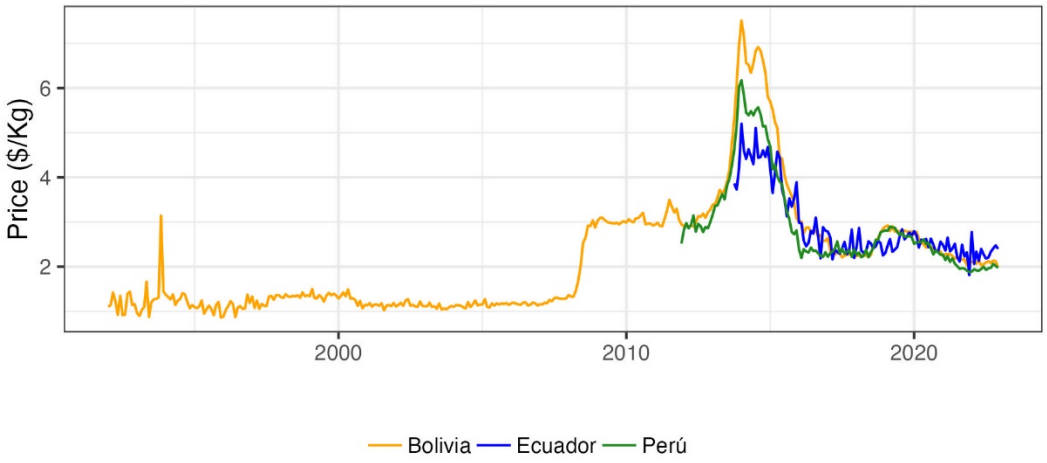
II Data

II.1 Quinoa prices

The data compiled includes monthly historical export price series, free on board (FOB), of the main producer countries of the Andean region: Peru, Bolivia and Ecuador. Given that Bolivia has a historical monthly series with more availability of data (from 1992 to 2022, $T = 372$), this is used as a benchmark price for quinoa at the global level. This is to say that although Peru and Ecuador are also among the main exporters presently, the choice was made to exclusively use Bolivian data due to the greater length of its time series.

It is important to indicate that Bolivia was the main world quinoa exporter until 2013, and that it has patterns of price evolution similar to those of the other two countries, as may be observed in Figure 2. This approach is essential for mitigating the limitations imposed by less coverage of data in certain time intervals for Peru and Ecuador. The resulting series is used for identifying key characteristics such as stationarity and the presence of trends and structural breaks. The analyses indicate that the price series are not stationary and that the trends observed may be attributed both to stochastic factors and significant structural changes in the market (Alandia *et al.*, 2020).

Figure 2: Price of quinoa exported in the Andean region



Source: Own preparation, based on the *Instituto Nacional de Estadísticas* (2022) and International Trade Centre (2022).

II.2 Factors associated with the quinoa price

In the analysis of the exogenous factors that influence the export price, different fundamental variables are considered for understanding both market behavior and the environmental conditions affecting production. Concretely, the following variables are considered: i) the world commodity activity index (Index of Global Real Economic Activity – IGREA), ii) the Oceanic Niño Index (ONI), and iii) world quinoa production.

Table 1: Variable Definition

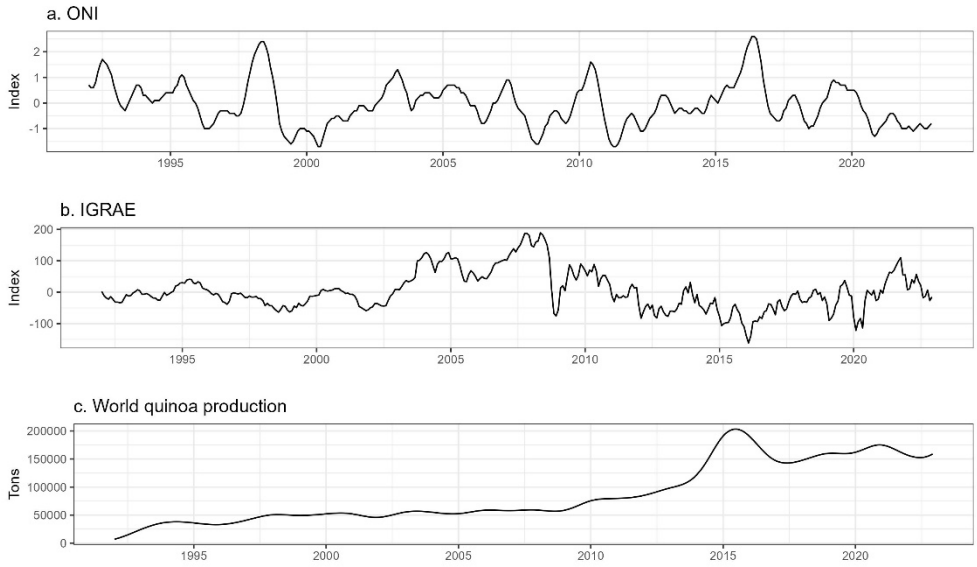
Variable	Description	Source
Export Price of quinoa	Quinoa price in USD/Kg. for Bolivia	Instituto Nacional de Estadístias de Bolivia and International Trade Centre (2024)
Index of Global Real Economic Activity (IGREA)	Index of economic cycle expressed in percentage deviations from trend (Kilian, 2009 & 2019)	Federal Reserve Bank of Dallas
Oceanic Niño Index (ONI)	Index measuring the development and intensity of El Niño	National Oceanic and Atmospheric Administration (NOAA, 2024)
Global quinoa production	Monthly global quinoa production in tons	Own elaboration based on FAO (2022)

Source: Own preparation

The world commodity activity index (IGREA), originally proposed by Lutz Kilian (2009), is a significant indicator for measuring real economic activity in commodities markets. The index is particularly relevant for quinoa, given that global shocks, both of supply and of demand, may considerably influence its price. Increases or falls in this index tend to anticipate changes in commodity prices (Carimentrand et al., 2015).

The Oceanic Niño Index is essential for measuring anomalies in ocean temperature, which are directly related to the El Niño phenomenon and can have devastating effects on weather conditions (*e.g.* extreme drought or floods), which directly impact agricultural production. When understanding these events, farmers may take preventive measures for protecting their crops and hence their economic stability and production (Bazile and Baudrom, 2015; Jacobsen, 2011)

Figure 3: Block of exogenous variables



Source: Own preparation based on the data described in Table 1.

The quinoa world production variable is considered for identifying how changes in demand, be it due to adverse climate conditions, changes in agricultural policies or due to technological innovation may affect global prices. Analyzing and considering this variable can contribute towards better understanding the supply and demand dynamics and their effect on price dynamics (Andreotti *et al.*, 2022; Bazile and Baudrom, 2015).

The variables described in the previous paragraph, studied jointly, allow a more complete perspective of the factors that have the potential to affect quinoa availability in the global market, and hence also the prices of this grain. Figure 4 graphically shows the block of exogenous variables mentioned.

III Econometric methodology

III.1 Contrasts of structural breaks

For analyzing the historic events that produced a change in the quinoa price trend, we use an algorithm that estimates the dates of these events endogenously; that is, without assuming the existence or location of these dates. Recently, Prados de la Escosura and Rodríguez-Caballero (2022) used the same approach for studying the modern economic growth of Europe and its relation to episodes of pandemics and wars. Similarly, we employ the Bai and Perron (1998) contrast to estimate both the number and the date of the structural breaks in the quinoa price series. As to the estimation algorithm, we remit to Bai and Perron (2003a); and for calculating the critical values of the test, to Bai and Perron (2003b).

For modelling the structural breaks in the price of quinoa, we consider the following specification that contains a constant and a linear trend,

$$y_t = \beta_{0,j} + \beta_{1,j} t + u_t \quad , \quad t = T_{j-1} + 1 \ldots, T_j \tag{1}$$

for regime $j = 1, \ldots, m+1$ and where the convention $T_0 = 0$ and $T_{m+1} = T$. In this model, y_t is the logarithm of the quinoa price, and $\beta_{0,j}$ and $\beta_{1,j}$ are the parameters that correspond to the intercept and to the slope of the linear trend estimated for the j^{th} regime, respectively. The purpose is to estimate the unknown parameters together with the structural break dates when we have information up to *T*.

Bai and Perron (2003b) propose a test called $F(\ell + 1|\ell)$, which sequentially tests the null hypothesis of the existence of ℓ structural breaks versus an alternative of $\ell + 1$ structural breaks. The general idea of the procedure is to divide the sample into subsamples based on a cut-off parameter, denoted by ε, which defines the minimum size of the segment that can be given as a fraction relative to the sample size[3].

The method of estimation is based on least ordinary squares. For each segment $m, T_1, \ldots, T_m$, the estimates by least ordinary squares associated, $\beta_{0,j}, \beta_{1,j}$ are obtained by minimizing the sum of the squared residuals,

$$S_t(T_1, \ldots, T_m) = \sum_{j=1}^{m+1} \sum_{t=T_{i-1}+1}^{T_i} (y_t - \beta_{0,j} - \beta_{1,j} t). \tag{2}$$

We will denote $\hat{\beta}_0(\{T_j\})$ and $\hat{\beta}_1(\{T_j\})$to the estimates based on the partition $T_1, \ldots, T_m$. $(\{T_j\})$. Then, when substituting these parameters estimated in equation 2, we obtain the estimated value of the structural breaks $S_t(\widehat{T_1}, \ldots, \widehat{T_m}) = arg\ min_{T_1}(S_t(T_0, \ldots, T_m))$, where the values estimated come from the problem of global minimization of the objective function. We refer to Bai and Perron (2003a) for the problem of dynamic programming and to Zeileis *et al.* (2002) for its application in programming environment *R*.

III.2 Long memory approach

In the previous section we have assumed that the quinoa price series follows a stationary process around a determinist trend, which implies that the shocks have temporary effects. Alternatively, we may suggest that this series has a stochastic trend, and therefore may have a certain structural trend of dependency on its past. In this case, the shock could have a permanent effect on the series. When this shock is sufficiently persistent but ends up being "forgotten" at a certain point in time, it is said that it has "long memory". Particularly, we follow the application of Prados de la Escosura and Rodríguez-Caballero (2022), which are based on Beran (2017). In the long memory models, persistence is measured by a parameter (fractional) denoted by *d*. According to Beran (2017), we may have different interpretations

[3] For example, the asymptotic critical values provided by Bai and Perron (2003a) employ a base cut-off parameter of $\varepsilon = 5$. However, depending on the characteristics of the sample, the researcher may choose to calibrate ε for other values.

depending on the value of d:

a) If $d = 0$, the series is stationary, implying that any disruption affecting the series only has short-term repercussions.

b) A process shows long memory if $0 < d < 1$. In this case, the external shock has a temporary effect on the series, though depending on the value of d, this shock can have a more persistent effect. Specifically, the process is stationary if $0 < d < 0.5$, and it is not when $d \geq 0.5$.

c) A process with $d \geq 1$ is not stationary and not reversible to the mean. Thus, an external shock has permanent effects on the series.

In our analysis, we estimate the fractional memory d by means of the two-step exact local Whittle (2ELW) method proposed by Shimotsu (2010) for each of the regimes previously estimated by the Bai-Perron methodology. In our context, this non-parametric estimator is important, as it can deal with unknown means and polynomial trends, covering both stationary and non-stationary zones. For example, Prados de la Escosura and Rodríguez-Caballero (2022) show the convenience of this methodology for analyzing long memory of GDP per capita growth for different European countries.

IV Results

IV.1 Structural breaks and persistence of quinoa prices

There are several factors and events that may have influenced changes in quinoa prices over the period studied. The growing popularity of the grain in recent decades has had an important role in the fluctuations of both supply and demand. Changes in climate conditions, such as extreme temperatures and drought also had a considerable effect on production in the region, and hence on price.

Chart 2 provides information by structural breaks for each regime and sub-regime[4] doing analysis with confidence intervals (CI) and rates of growth of the trend for the quinoa price in Bolivia according to each regime. Also, the chart provides the fractional memory parameter d of each regime estimated by means of the 2ELW method.

The estimate of the breaks depends on the cut-off parameter $\varepsilon = 0.05$, which has been calibrated for each individual case[5]. The long-term memory parameter is estimated with band widths $m = T^{0.70}$, where T is the duration of each regime. This parameter if often chosen in the econometric literature to avoid other components of the time series (such as the level or stationary components) from interfering with a correct estimate of persistency. Thus, the following describes the possible reasons that generated the structural breaks.

[4] The sub-regimes are defined as periods included between two successive structural changes estimated endogenously, which coincide with episodes of changes in quinoa production and trade. Additionally, the regimes are proposed in relation to important events that may have influenced production or trade, or significant changes in policies, the economy or technology that may have affected the price of quinoa. The details of the regimes are in Chart 2.

[5] To find this value, a seeking of $\varepsilon = [0.05; 0.012]$ values was done.

Table 2: Structural Breaks, Regimes, and Persistence of Quinoa Price in Bolivia

Regime	Structural Breaks	Period	Duration (months)	95 % CI	2ELW	Growth Rate (%)
1	1993(10)	1992(01) - 1993(10)	22	1992(11) - 1993(11)	1,15	0,24
2	1995(05)	1993(11) - 1995(05)	19	1995(04) - 1995(09)	2,32	-2,83
	1997(07)	1995(06) - 1997(07)	26	1997(04) - 1997(11)	0,31	0,57
3	2000(08)	1997(08) - 2000(08)	37	2000(07) - 2000 (09)	-0,08	0,02
	2006(12)	2000(09) - 2006(12)	76	2006(09) - 2007(01)	0,29	0,04
4	2008(06)	2007(01) - 2008(06)	18	2008(05) - 2008(07)	0,05	2,14
	2012(11)	2008(07) - 2012(11)	53	2012(10) - 2012(12)	0,88	0,13
5	2014(05)	2012(12) - 2014(05)	18	2014(04) - 2014(06)	2,21	5,48
6	2016(02)	2014(06) - 2016(02)	21	2016(01) - 2016(03)	0,20	-4,58
	2018(08)	2016(03) - 2018(08)	30	2018(07) - 2018(09)	1,25	-0,90
		2018(09) - 2022(12)	50		0,84	-0,77

Source: Own preparation

1. **First regime:** In the time series analyzed, it is observed that in the first regime the price of quinoa had a positive rate of growth (0.24% from January 1992 to October 1993). This growth may be attributed to the considerable boost in research and experimentation of this crop at the international level in that decade. In this regard, the European Union became interested in production and research of the grain in the mentioned period. From 1992 to 1997, the IBTA-WB Project[6], financed by the World Bank played an essential role in strengthening research in quinoa in Bolivia. The project, focused on improving food security in the country, led to obtaining improved varieties. This interest may have generated changes in the perception and demand of the grain at the global level, which in turn may have influenced price. The progress mentioned had a considerable and lasting effect on the export price, which is reflected in parameter $d = 1.146$, indicating that the process is not stationary and is not reversible to the mean (Bazile and Baudrom, 2015; Gandarillas *et al.*, 2013).

2. **Second regime:** In response to growing global interest in quinoa, the European Union implemented a project within the AIR1 program, called *Quinua: Un cultivo múltiple para la diversificación agrícola de la CE, 1993-1997 (Quinoa: A multiple crop for agricultural diversification of the EC, 1993-1997)* (IICA, 2015).

   The data indicates that in the second period, from November 1993 to July 1997, two distinct subperiods were present. The first, from November 1993 to May 1995, had a negative growth rate and a non-stationary behavior not reversible to the mean ($d = 2.315$).

[6] Project between Instituto Boliviano de Tecnología Agropecuaria and the World Bank. Included the main fields of food security in Bolivia: potatoes, wheat, quinoa, legumes, maize, livestock, and forage.

The second subperiod, which went from June 1995 to July 1997, was stationary (d = 0.314), with a slight recovery in prices. In this way, following a considerable increase in October 1993, prices stabilized and then fell in the mentioned period. These changes in the series had – in the first subperiod – lasting effects, showing a downward trend that suggests lack of reversibility towards the mean; however, in the second subperiod, the structural break identified did not have a persistent effect.

3. **Third regime:** The third regime identified is from August 1997 to December 2006, and is made up of two subperiods. In 1997, government policies led to closing Instituto Boliviano de Tecnología Agropecuaria (IBTA) and transferring responsibilities to the department governments. Thus, the universities and organizations such as Fundación PROINPA took on a fundamental role in the continuity of research and the development of the crop (Carimentrand *et al.*, 2015; IICA, 2015). This event did not have a major effect on quinoa prices, which increased by 0.02% in the subperiod that went from August 1997 to August 2000.

   The creation of PROINPA in 1999, with the support of several international organizations, constituted a joint effort for conserving and progressing in quinoa research in the country. PROINPA's decision to recruit recognized professionals and experienced researchers from the former IBTA Quinoa Research Program was essential for preserving the accumulated knowledge and the genetic heritage associated with quinoa. The second subperiod was likely influenced by this event, as a growth rate of 0.04% is observed from September 2000 to December 2006 (Bazile and Baudrom, 2015; Bazile *et al.*, 2016).

   The consolidation of Banco Nacional de Granos Altoandinos under the tutelage of PROINPA and later of Instituto Nacional de Innovación Agropecuaria y Forestal (INIAF) ensured the long-term preservation of germplasm of quinoa and other Andean crops. This transition period represented a considerable change in the governance and financing of agricultural research in Bolivia, with a renewed approach in international cooperation and the strengthening of institutional capacities for the sustainable development of the agricultural sector (IICA, 2015).

4. **Fourth regime:** The fourth regime is defined as going from January 2007 to November 2012, and is also made up of two subperiods. It may generally be said that this regime is characterized by significant progress in the promotion and development of quinoa in the Southern Altiplano of Bolivia. In the 2005-2008 period, Fundación de Apoyo a las Universidades de Tarija y Potosí (FAUTAPO), with the support of the Embassy of the Netherlands, executed what was called Programa Quinua Real del Altiplano Sur. The program focused on boosting royal quinoa as a main economic activity in the region, fostering its production and promoting its consumption at the national and international levels. It may be observed that in the first subperiod (from January 2007 to June 2008), the rate of growth of the series was 2.14%, but the activities mentioned previously did not have a lasting impact (IICA, 2015).

   Additionally, in the second subperiod, which went from July 2008 to November 2012, there was a positive growth rate trend (0.13%), but the value d = 0.880 suggests that the process has a

memory of shorter duration. It is however worth mentioning that 2008 marked a change towards organic quinoa production in the Southern Altiplano.

From 2009 to 2013, Phase II of Programa Complejo Productivo Altiplano Sur (COMPASUR) was implemented, with the aim of improving the quality of life of farmers by means of sustainable production of organic royal quinoa and through its promotion at the national and international levels. During this period, FAUTAPO achieved noteworthy results, increasing the level of competitiveness of the Southern Altiplano, particularly through the production of royal quinoa, livestock breeding and rural tourism (IICA, 2015). These efforts included activities from sustainable production to the industrialization of royal quinoa, thus contributing towards the comprehensive development of the region.

5. **Fifth regime:** The changes observed in the fifth regime, which went from December 2012 to May 2014, respond to the activities the International Year of Quinoa, 2013. This event was organized as an international initiative of the Food and Agriculture Organization of the United Nations (FAO), which sought to accentuate the value of this Andean crop. Global attention towards quinoa increased considerably following this event, with increased demand and visibility of production at the international level and in Bolivia, where the perception and approach towards quinoa improved both at the government level and within civil society (Muñoz Jáuregui, 2013).

   The relevance of this international event may be observed in the considerable increase in the price of Bolivian quinoa during this period, of 5.48%. It is also observed that this process is non-stationary and not reversible to the mean *(d* = 2,207), suggesting that the International Year of Quinoa had lasting effects on the price of this grain under these conditions.

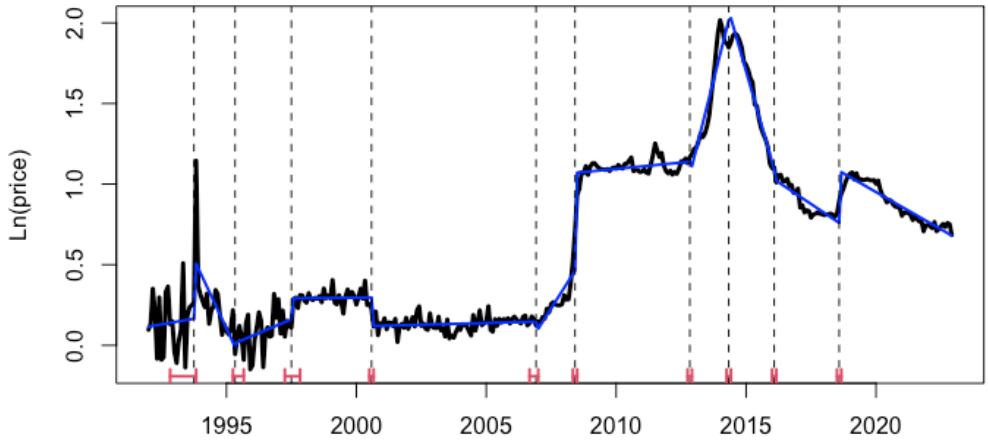
   The International Year of Quinoa acted as a catalyst for the development and promotion of policies and projects related to quinoa in Bolivia (Bazile *et al.*, 2019). The authorities took measures for fostering its production, promotion and sales at the national and international levels, and they implemented initiatives for improving the related agricultural infrastructure, strengthening producer capacities and fostering research and development. This initial boost translated into continuous growth in the years which followed, leaving a lasting impact in the industry, possibly attributable to greater public awareness of the benefits of the grain, as well as the implementation of strategies for improving its competitiveness, and its access to new markets.

6. **Seventh regime:** After 2016 a market response is observed in response to the price decrease of previous years and the entry of new competitors in the international market, which diversified supply and stabilized prices at lower levels. This trend reflects how external dynamics, such as climate changes, international policies and consumption trends can have a considerable effect on local agricultural markets.

   The dynamic nature of the quinoa market in the Andean region may be observed in the price analysis, revealing extreme sensitivity to a variety of external factors, underlining the importance of closely monitoring these elements so as to understand and adapt to market fluctuations.

The entry of new competitors and the stabilization of prices at lower levels after 2016 may have been the result of greater global supply, prompted by an increase in production and exports of the crop in different regions. The situation may have also been influenced by changes in climate conditions, trade policies and by consumer demand, indicating a need for timely and adaptive management by the agricultural market actors.

Figure 4: Identification of structural changes: Logarithm of quinoa price and trends



Source: Own elaboration based on Instituto Nacional de Estadística (2022). Note: Trend values were obtained according to Table 2.

V Relationship of quinoa prices with the other factors

This section analyzes the factors that may be related to changes in quinoa prices. For this, we employ the stationary transformation of the quinoa price logarithm, understood as the deviation of the series in relation to changes in the trend (see Figure 5). It is important to note that the residuals and all other variables are stationary[7].

The results of the analysis suggest that according to the regression using ordinary least squares with Newey-West robust errors, only the lag seems to have a considerable influence on quinoa price changes, though its effect is slight (see Chart 3). The coefficients of the remaining variables are statistically equal to zero, indicating that they have little or no effect on the price changes in the short-term.

It is however important to consider that these variables could have effects on quinoa prices in different periods, and these effects could be captured by the deterministic trend. For example, the increase in world production had a similar evolution during the boom period and the quinoa price decrease period (from 2014 to 2016), suggesting a relationship between these variables.

In summary, although the additional variables do not seem to significantly affect changes in quinoa

[7] We reject the null hypothesis of the augmented Dickey-Fuller test with a constant, and lag selection with Akaike.

prices in the short-term, it is possible that they may have effects on the price series in different periods. This highlights the importance of considering the narrative of the structural breaks for explaining the different regimes.

VI Conclusions

Due to its nutritional value and sustainability, quinoa has become increasingly popular at the global level in recent decades. However, the prices of this Andean grain have shown complex dynamics, with several structural breaks that reflect the underlying factors that affected its evolution. This study concentrates on the quinoa price dynamics in Bolivia, employing a methodological approach that combines structural break analysis and an evaluation of the persistence of shocks through long memory.

Applying the Bai and Perron contrast allowed identifying multiple structural breaks in the quinoa price series, suggesting that a variety of events and factors had an effect on the trends of these prices over time. The long memory analysis, done with the 2ELW estimator complement these findings by revealing different degrees of persistence of the shocks in each of the regimes identified.

The results show that the structural breaks of 1993 and 1997 are related to significant changes in research and development of the crop in Bolivia, such as the introduction of international projects and the institutional transition of IBTA to other entities. This reflects the importance of innovation and capacity strengthening in the sector for boosting competitiveness.

Following this, the boom in quinoa production and sales was reflected in the break in 2000, when processing organizations were created in response to high international prices and access to projects and financial resources. Similarly, the breaks of 2006 and 2008 coincide with periods of quinoa promotion and development in the Southern Altiplano, with an emphasis on sustainable and organic production. The break of 2014 is related to the impact of the International Year of Quinoa, which served as a catalyst for developing and fostering policies and projects related to this crop in Bolivia, thus giving the industry a boost that endured in time.

The analysis of additional factors, such as the increase in world production, shows that although these factors or variables do not seem to have a significant effect on price changes in the short-term, they may have a relevant influence in different periods, which is captured by the deterministic trend identified.

Given the complexity of the price dynamics, characterized by multiple structural breaks, quinoa producers must adopt a strategic and adaptive approach in relation to price policies and forecasts. Continuous monitoring of the key factors, as well as progress in research and development, and changes in the market structure and consumption trends will be essential for anticipating and adequately responding to market fluctuations.

This study demonstrates the importance of understanding the evolution of and the factors which determine quinoa prices in Bolivia, given this crop's economic and social importance. The application

of a robust approach that combines structural break analysis and long memory has allowed identifying the main events and elements that led to changes in the trends of these prices over time. The findings may be valuable for producers and policy makers to design effective strategies allowing them to adapt to and take advantage of opportunities in this dynamic market.

References

Alandia, G., Rodriguez, J. P., Jacobsen, S. E., Bazile, D. & Condori, B. (2020). Global Expansion of Quinoa and Challenges for the Andean Region. *Global Food Security*, *26*, 100429.

Andreotti, F., Bazile, D., Biaggi, C., Callo-Concha, D., Jacquet, J., Jemal, O. M., King, O. I., Mbosso, C., Padulosi, S., Speelman, E. N. & van Noordwijk, M. (2022). When Neglected Species Gain Global Interest: Lessons Learned from Quinoa's Boom and Bust for Teff and Minor Millet. *Global Food Security*, *32*, 100613.

Bai, J. & Perron, P. (2003a). Computation and Analysis of Multiple Structural Change Models. *Journal of Applied Econometrics*, *18*. https://doi.org/10.1002/jae.659.

Bai, J. & Perron, P. (2003b). Critical Values for Multiple Structural Change Tests. *The Econometrics Journal*, *6*. https://doi.org/10.1111/1368-423x.00102.

Bai, J. & Perron, P. (1998). Estimating and Testing Linear Models with Multiple Structural Changes. *Econometrica*, *66*. https://doi.org/10.2307/2998540.

Bazile, D. & Baudrom, F. (2015). The Dynamics of the Global Expansion of Quinoa Growing in View of its High Biodiversity (C. N. Didier Bazile, Daniel Bertero, Ed.). *State of the Art Report on Quinoa Around the World in 2013*, 478-491.

Bazile, D., Biaggi, M. C. & Jara, B. (2019). Cinco años después de la celebración del año internacional de la quinua. *Libro de resúmenes, VII Congreso mundial de la quinua y otros granos andinos,* Chile.

Bazile, D., Jacobsen, S. E. & Verniau, A. (2016). The Global Expansion of Quinoa: Trends and Limits. *Frontiers in Plant Science*, *7*, 184730. www.frontiersin.org.

Bellemare, M. F., Fajardo-Gonzalez, J. & Gitter, S. R. (2018). Foods and Fads: The Welfare Impacts of Rising Quinoa Prices in Peru. *World Development*, *112*, 163-179.

Benique Olivera, E. (2021). Impacto económico del cambio climático en el cultivo de quinua (chenopodium quinoa willd) orgánica en la región del altiplano: un enfoque ricardiano. *Revista de Investigaciones Altoandinas*, *23*(4), 236-243.

Beran, J. (2017). *Statistics for Long-Memory Processes*. https://doi.org/10.1201/9780203738481.

Carimentrand, A., Baudoin, A., Lacroix, P., Didier, B. & Chia, E. (2015). Quinoa Trade in Andean Countries: Opportunities and Challenges for Family. https://agritrop.cirad.fr/575498/1/document%7B%5C_%7D575498.pdf

FAO (2024). FAOSTAT: Datos sobre alimentación y agricultura [Base de datos]. Recuperado el 15 de marzo de 2024 de www.fao.org/faostat/es/#home

Gandarillas, A., Rojas, W., Bonifacio, A. & Ojeda, N. (2013). La quinua en Bolivia: perspectiva de la Fundación PROINPA. *Estado del arte de la quinua en el mundo*, 410-431.

González, J. A., Eisa, S. S., Hussin, S. A. E. S. & Prado, F. E. (2015). Quinoa: An Incan Crop to Face Global Changes in Agriculture. *Quinoa: Improvement and Sustainable Production*, 1-18.

Instituto Nacional de Estadística (2024). Datos de Comercio Exterior [Base de datos]. Recuperado el 15 de marzo de 2024 de www.ine.gob.bo/comex/

International Trade Centre (2024). Trade statistics for international business development [Base de datos]. Recuperado el 17 de marzo de 2024 de www.trademap.org/Index.aspx

Jacobsen, S. E. (2011). The Situation for Quinoa and Its Production in Southern Bolivia: From Economic Success to Environmental Disaster. *Journal of Agronomy and Crop Science*, *197*(5), 390-399.

Jaikishun, S., Li, W., Yang, Z. & Song, S. (2019). Quinoa: In Perspective of Global Challenges. *Agronomy 2019, 9*(4), 176.

Kilian, L. (2009). Not all oil price shocks are alike: Disentangling demand and supply shocks in the crude oil market. *American economic review*, *99*(3), 1053-1069.

Liuhto, M., Mercado, G. & Aruquipa, R. (2016). El cambio climático sobre la producción de quinua en el altiplano boliviano y la capacidad de adaptación de los agricultores. *Revista de investigación e innovación agropecuaria y de recursos naturales*, *3*(2), 166-178.

Muñoz Jáuregui, A. M. (2013). Año internacional de la quinua. *Revista de la Sociedad Química del Perú*, *79*(1), 1-2.

National Oceanic and Atmospheric Administration (2024). National Weather Service, Cold & Warm Episodes by Season. [Base de datos]. Recuperado el 14 de marzo de 2024 de origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php

Ofstehage, A. (2012). The Construction of an Alternative Quinoa Economy: Balancing Solidarity, Household Needs, and Profit in San Agustín, Bolivia. *Agriculture and Human Values*, *29*(4), 441-454.

Prados de la Escosura, L. & Rodríguez-Caballero, C. V. (2022). War, Pandemics, and Modern Economic Growth in Europe. *Explorations in Economic History*, *86*. https://doi.org/10.1016/j.eeh. 2022.101467.

Reserva Federal de Dallas (2024). Index of global real economic activity [Base de datos]. Recuperado el 15 de marzo de 2024 de www.dallasfed.org/research/igrea

Risi, J. Rojas, W. & Pacheco, M. (2015). Producción y mercado de la quinua en Bolivia. Instituto Interamericano de Cooperación para la Agricultura – IICA. La Paz, Bolivia.

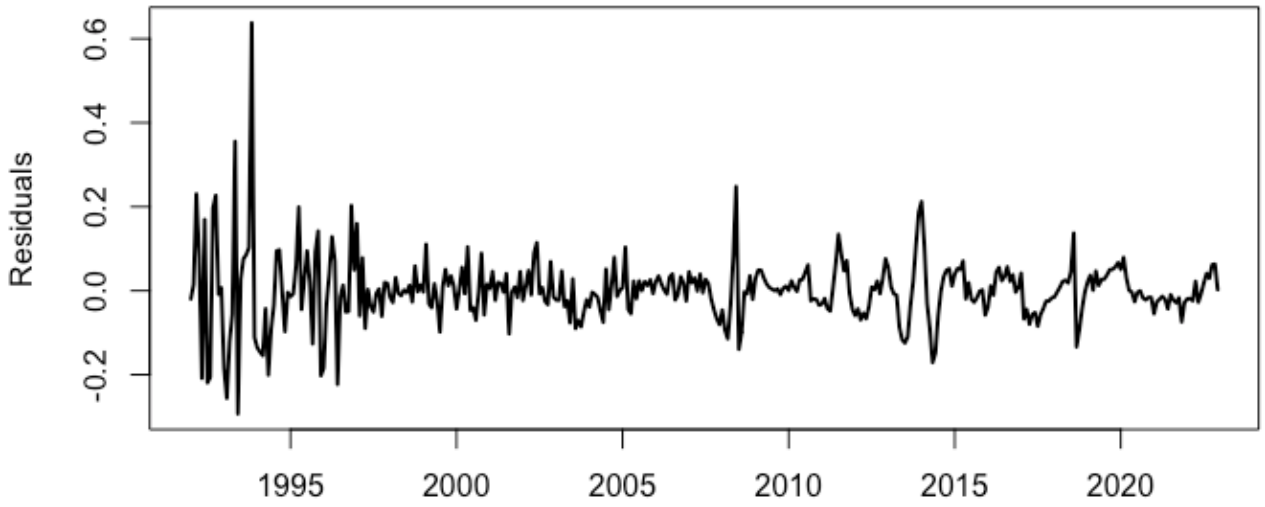
Shimotsu, K. (2010). Exact Local Whittle Estimation of Fractional Integration with Unknown Mean and Time Trend. *Econometric Theory*, *26*. https://doi.org/10.1017/S0266466609100075.

Stevens, A. W. (2017). Quinoa Quandary: Cultural Tastes and Nutrition in Peru. *Food Policy*, *71*, 132-142.

Zeileis, A., Leisch, F., Hornik, K. & Kleiber, C. (2002). Strucchange: An R package for Testing for Structural Change in Linear Regression Models. https://doi.org/10.18637/jss.v007.i02.

VII Apendix

Figure 5: Stationary transformation of quinoa price



Source: Own elaboration based on Instituto Nacional de Estadísticas (2022). Note: Values are obtained according to a regression that incorporates changes in trend according to Table 2 and Figure 3.

Table 3: Quinoa Price Associated Factors

	Dependent variable:
	Residuals
ONI Index	0.007
	(0.005)
ΔLog(Global Production)	0.099
	(0.323)
Kilian Index	−0.00002
	(0.0001)
Constant	−0.0004
	(0.005)
Observations	371
R^2	0.007
Adjusted R^2	0.001
Residual Std. Error	0.081 (df = 367)
F Statistic	0.851 (df = 3; 367)

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$. Newey-Wes standard errors.