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The Quinoa Boom and the Welfare of Smallholder Producers in the Andes

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Abstract

The recent attention for quinoa as a highly nutritious “superfood” and the consequent increase in international quinoa trade is changing the production and consumption of quinoa among smallholder farmers in Andean regions, where the crop originates from. Quinoa is converting from a common staple and subsistence crop into a high-value cash crop. The rapid rise in international quinoa prices creates a concern about quinoa consumption – and consequent implications for nutrition – among Andean farm-households. In this paper, we estimate the own price elasticity of consumption of quinoa for quinoa-producing farm-households in the Peruvian Andes. We rely on the seminal Barnum-Squire farm-household model to explain the effects of food price changes that simultaneously affect farm-households’ consumption and production decisions. We apply the theoretical model to original farm-household survey data from Junín, a traditional quinoa producing region in Peru. The estimates show that a 1% increase in the quinoa price results in a 0.429% increase in quinoa production and a 0.238% increase in its consumption. Our finding of a positive own price elasticity of consumption of quinoa suggests that the global quinoa boom did not adversely affect the nutritional intake of smallholder quinoa producers.

Key Words: Quinoa, food consumption, farm-household model, Peru, price elasticity

JEL classification: D10, O1, O54, Q12

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1 Introduction

“Quinoa can play an important role in eradicating hunger, malnutrition and poverty”, FAO Director-General José Graziano da Silva said at the official launch of the ‘International Year of Quinoa’ at the UN Headquarters in February 2013. The traditional Andean crop is a so-called ‘superfood’ that receives increasing interest by consumers in high-income countries for its nutritious qualities and richness in proteins and micronutrients (Dobkin, 2008; Lester, 2006). Quinoa is put forward as part of the solution in the challenge of global food security, by providing nutritious food for a growing world population and income opportunities for smallholder farmers in the Andean region (FAO and CIRAD, 2015). As a result of the increased international attention, quinoa is increasingly being traded internationally with exports from the three main producing countries, Bolivia, Ecuador and Peru, increasing from 600 ton in 1992 to almost 68,000 ton in 2015. World market quinoa prices quadrupled from a rather stable FOB export price of around 1 USD/kg until 2007 to an average of 4 USD/kg in the last decade, with increased volatility and a peak of 5.5 USD/kg in 2014 (ALADI and FAO, 2014).

These international dynamics are profoundly changing the way quinoa is produced and consumed by local smallholder farmers in the Andean region. The crop is shifting from primarily being a common staple food in the Andean region and a subsistence crop for smallholder farmers in the past (Repo-Carrasco et al., 2003) to being a high-value cash crop that is increasingly consumed in high-income countries and urban market segments (Ofstehage, 2012). The rapidly rising international quinoa price creates a concern about the welfare of rural households in Andean regions, specifically about their quinoa consumption and the consequent implications for nutrition (Ayala Macedo, 2003). On the one hand, a higher quinoa price is beneficial to quinoa producers as it increases their income. On the other hand, consumers are negatively affected by a higher price and might substitute highly nutritious quinoa for other less nutritious food. Andean farm-households are at the same time consumers and producers of quinoa and understanding the effect of a price increase on their production and consumption decisions is not straightforward, cannot be derived from theory and remains an empirical question.

In this paper, we address this empirical question and reveal whether or not the worldwide quinoa hype and the increased utility high-income consumers derive from quinoa consumption comes at the expense of quinoa consumption and nutrition security of Andean

farm-households. Specifically, we assess the implications of exogenous changes in global quinoa prices on the production and consumption of quinoa among traditionally quinoa-producing farm-households in the Peruvian Andes. We underpin the empirical estimation of the own price elasticity of quinoa production and consumption with the Barnum-Squire farm-household model. This model accounts for the overall effect of farm-household behavior to changes in food prices, which simultaneously affect the consumption- and production decisions of utility maximizing farm-households (Barnum and Squire, 1979; Ellis, 1993). In its dual role as producer and consumer, the household makes interdependent production, labor allocation and consumption decisions. We apply the Barnum-Squire model using original household survey data from Junín in the Peruvian Andes.

By linking the seminal farm-household theory with quinoa production and consumption among Andean households during the quinoa price boom, our paper makes an important contribution. Some studies have analyzed the welfare implications of increasing staple food crop prices in other sectors, such as maize and rice, and have come to diverse conclusions. Some authors find a significant negative effect of higher staple food prices on food consumption (e.g., Alem & Soderbom, 2012; Attanasio et al., 2013), nutritional intake (e.g., Harttgen et al., 2016), poverty (e.g., Balagtas et al., 2013), and mental and physical health (e.g., Hadley et al., 2012). Others find no or, among rural households, even a positive effect of a price increase on staple food consumption (e.g., Hasan, 2016), self-reported food security (e.g., Verpoorten et al., 2013) and household welfare and poverty (Mghenyi et al., 2011). An older stream of literature has applied the Barnum-Squire farm-household theory to micro-survey data from different countries, including Korea (Ahn et al., 1981), Taiwan (Lau et al., 1978), Malaysia (Barnum and Squire, 1979), Sierra Leone (Strauss, 1984), Mexico (Taylor and Adelman, 2002) and Bangladesh (Quayes and Rashid, 2008). These studies demonstrate that the own price elasticity of supply of staple food crops is positive but that the own price elasticity of consumption of staple food crops can be positive or negative. They conclude that the structure of the markets in which the household operates is crucial in shaping household responses to price changes. This confirms the need for theoretically underpinned empirical research on the implications of increasing quinoa prices for Andean farm-households in order to fully understand the consequences of hyping this highly nutritious crop by international organizations and high-income consumers.

2 Background

As the worldwide trade of quinoa exploded, Peru has consolidated its position as world market leader in quinoa exports, bypassing Bolivia, the largest quinoa producer. The market share of Peru in quinoa exports to the US and the EU are 56% and 66% respectively in 2015 (UN Comtrade, 2015). Statistics for the last decade show an important increase in the harvested area, the production and export of quinoa, with particular sharp increases since 2012 (Figure 1). Production increased more sharply than the harvested area, pointing to increases in yields – yields grew with 3.45% annually in the period 1997-2015. The national farm-gate quinoa price in Peru follows the international price trend very closely and increased considerably, from 1.40 PEN/kg⁴ on average in 1997 to 5.13 PEN/kg in 2015, corresponding to an average annual price increase of 7.48% (Figure 2). The sharpest increase is observed between 2008 and 2013 when the price jumped from 3.78 to 7.56 PEN/kg. These figures clearly show that the international quinoa hype – consolidated in the declaration of 2014 as the National Year of Quinoa by FAO – translated into a quinoa production, export and price boom in Peru. Before 2013, quinoa was mainly a subsistence crop produced on small plots (see Table A1 in appendix; Keressen, 2015).

In 2015, quinoa was cultivated in 19 out of 24 regions in Peru but four regions account for 80% of the area: Puno (50% of the quinoa area), Ayacucho (15%), Arequipa (9%) and Junín (6%), which are the traditional smallholder quinoa-producing Andean regions. As a result of the international quinoa hype, new large-scale production areas are being taken into cultivation, particularly in the coastal agro-industrial zones in Ica, Lambayeque, Lima, Piura, and Tacna. The highest yields are observed in these coastal regions and in one of the traditional regions, Junín (1.91 ton/ha) (MINAGRI, 2015). In this paper we focus on smallholder quinoa farmers in the Junín region. Junín is one of the oldest quinoa-growing regions as well as one of the five sub-centers of genetic diversity of quinoa in Peru (Apaza et al., 2015). Junín is located in the central highland of Peru (Figure A1). Seven of the nine provinces produce quinoa, but only four provinces are specialized in quinoa production: Jauja (location ratios⁵ of 6.36), Huancayo (4.96), Concepción (2.21) and Chupaca (1.10). In Junín, the area harvested and the quinoa production increased during the late 1990s but decreased

⁴ The official exchange rate is 3.77 PEN/Euro in 2014 (Central Reserve Bank of Peru -BCRP)

⁵ The location ratios ($Q_{ij} = (V_{ij} / \sum_i V_{ij}) / (\sum_j V_{ij} / \sum_i \sum_j V_{ij})$) represent the relationship between the participation of sector "i" in region "j" and the participation of the same sector in the national total and therefore, it is used as a measure of "relative or interregional specialization". The relative specialization of a region in an activity (sector) would be associated with a $Q_{ij} > 1$; and it is measure with the harvested area between quinoa and total area cultivated (CEPAL, 2009).

sharply in 2000 and remained low until 2012 with the area fluctuating around 1,000 ha and the production around 1,500 ton (Figure 3). After 2012, the quinoa area as well as the production increased sharply, with a peak of more than 5,000 ha and 10,000 ton in 2014, and dropped slightly again in 2015. Yields increased steadily during the late 1990s and early years 2000; fluctuated around 1.3 ton/ha until 2012 and increased to 2 ton/ha in 2015. The average quinoa farm-gate price in Junín follows the same trend as the national price with an increase from 2007 onward and a peak of 7.52 PEN/kg in 2014 and a drop to 3.28 PEN/kg in 2015 (DRAJ, 2016).

3 Application of the Barnum-Squire Model

We base our analysis on the Barnum-Squire farm-household model (Barnum and Squire, 1979; Ellis, 1993), which considers the household as an economic unit of production and consumption who trades-off the utility of consumption and the disutility of labor. In its dual role, the farm-household makes production, labor allocation and consumption decisions that are interdependent. The non-separability of production and consumption decisions stems from market imperfections and can resolve an apparent paradox of a positive own price elasticity of demand for food in farm-households. The household budget is endogenous and, in contrast to a pure consumer model, depends on production decisions that contribute to income through farm profits (Taylor and Adelman, 2002). The model provides an appropriate theoretical framework to analyze the response of quinoa-producing households in the Peruvian Andes to exogenous changes in quinoa prices, and reflects the behavior and institutional characteristics of the Peruvian highlands.

We slightly simplify the original Barnum-Squire model that considers four agricultural inputs (land, labor, capital and other variable production inputs) and consider only three inputs (land, labor and capital) as in Ellis (1993) and Quayas and Rashid (2008). Other specifications and assumptions remain as in the original Barnum-Squire model: presence of a labor market and participation of farm-households in the labor market either as net buyers or net sellers of labor; no sharecropping or other contractual arrangements; a time horizon of one agricultural cycle with land availability fixed. These assumptions are consistent with the situation of farmers in the Peruvian highlands who produce quinoa both for own consumption and for the market, use both family and hired labor for production, and partly sell their labor force in the local labor market. Quinoa is grown on non-irrigated land, such that changes in the cultivated area are only possible from one agricultural season to the other.

The farm-household is assumed to maximize utility (U), a function of leisure (L), quinoa consumption (C), consumption of other (market-purchased) goods (M) and a vector of household characteristics (a_i) (eq. 1); subject to a Cobb-Douglas quinoa production function with production (F) a function of quinoa area (A), labor in quinoa production (D), including both household and hired labor, capital inputs (K), and a vector of parameters (α_j) of the j^{th} inputs in the Cobb-Douglas production function (eq. 2); a time constraint (eq. 3); and an income constraint (eq. 4). This is formulated as follows:

$$U = U(L, C, M, a_i) \quad (1)$$

$$F = \alpha_0 A^{\alpha_1} D^{\alpha_2} K^{\alpha_3} \quad (2)$$

$$T = H + L + D \quad (3)$$

$$qM + pC = wH + R + pF - w_k K \quad (4)$$

The time constraint indicates that labor in quinoa production (D), farm-household time (L) and net labor hired in or out (H) cannot exceed total available time of working household members (T). The income constraint indicates that consumption of other goods bought at price q cannot exceed the income derived from quinoa production, which equals $p(F - C) - w_k K$ with p quinoa price and w_k capital cost; from other sources (R); and from hiring out labor at wage w , which equals wH and can be negative. It is assumed that both constraints are always binding.

In line with the original Barnun-Squire model, we specify the household utility function using the Linear Expenditure System (LES) with four arguments, C , M , L and functions of a variety of household characteristics (a_i), including number of dependents (n_2), number of workers (n_1) and education (e) and age (a) of the household head (eq. 5). As in the original Barnum-Squire model, farm-household time L includes leisure, reproductive and productive work in the farm-households, apart from time allocated to quinoa production. Due to data limitations, we modify the specification of M . Instead of ‘all other (market-purchased) goods’, M refers to other food products that are consumed in lunch meals. The utility function is expressed in per capita terms to differentiate between dependents (n_2), allocating all time to L , and workers (n_1), allocating time to L and household labor in quinoa and non-farm activities (S). Dependents and workers are assumed to consume the same quantities of goods. The utility function is assumed identical and additive across individuals; and can be expressed in per capita terms by dividing by $n (= n_1 + n_2)$ and expressing the proportion of workers in the family with $k (= n_1 / (n_1 + n_2))$ (eq. 6):

$$U = \sum \beta_i \ln(x_i - \gamma_i) \dots x_i = C, M, L \quad (5)$$

$$U = k\beta_1 \ln(t - s + \gamma_1) + (1 - k)\beta_1 \ln(t - \gamma_1) + \beta_2 \ln(c - \gamma_2) + \beta_3 \ln(m - \gamma_3) \quad (6)$$

with c , m , and s being per capita consumption of quinoa (C/n), per capita consumption of other food products (M/n) and labor supply per worker (S/n_1); β_i parameters to be estimated for each consumption item i (C , M and L); and γ_i functions of a variety of household characteristics including dependents (n_2), workers (n_1), education (e) and age (a) of the household head.

We combine the time and income constraints (eq. 3 and 4); express the equation as total household expenditures (E) on three consumption goods (C , M and L) (eq. 7); and divide by n to obtain an expression in per capita terms (eq. 8) with $t-s=L/n_1$:

$$pC + qM + wL = wT + R + \pi \quad (7)$$

$$wk(t - s) + pc + qm = E/n \quad (8)$$

The farm-household constrained utility maximization problem then becomes the maximization of the utility function (eq. 6), subject to the total household expenditure constraint (eq. 8). The Lagrange function of this maximization problem is defined by:

$$\begin{aligned} \mathcal{L} = & k\beta_1 \ln(t - s - \gamma_1) + (1 - k)\beta_1 \ln(t - \gamma_1) + \beta_2 \ln(c - \gamma_2) + \beta_3 \ln(m - \gamma_3) \\ & - \lambda(wk(t - s) + pc + qm - E/n) \end{aligned} \quad (9)$$

The first order conditions of the Lagrange maximization problem are derived in appendix C and result in the following set of equations of household consumption of quinoa (eq. 10), consumption of other food products (eq. 11) and allocation of labor (eq. 12):

$$\begin{aligned} \ln(pC) = & \beta_2 (\ln(E) - \ln(w) \ln(t) \ln(n_1)) + \beta_2 \ln(w) \ln(n) [\delta_{10} + \delta_{11} \ln(n_1) + \delta_{12} \ln(n_2) + \delta_{13} \ln(a)] \quad (10) \\ & + (1 - \beta_2) p \ln(n) [\delta_{20} + \delta_{21} \ln(n_1) + \delta_{22} \ln(n_2) + \delta_{23} \ln(a)] \\ & - \beta_2 q \ln(n) [\delta_{30} + \delta_{31} \ln(n_1) + \delta_{32} \ln(n_2) + \delta_{33} \ln(a)] \end{aligned}$$

$$\begin{aligned} \ln(qM) = & \beta_3 (\ln(E) - \ln(w) \ln(t) \ln(n_1)) + \beta_3 \ln(w) \ln(n) [\delta_{10} + \delta_{11} \ln(n_1) + \delta_{12} \ln(n_2) + \delta_{13} \ln(a)] \quad (11) \\ & - \beta_3 p \ln(n) [\delta_{20} + \delta_{21} \ln(n_1) + \delta_{22} \ln(n_2) + \delta_{23} \ln(a)] \\ & + (1 - \beta_3) q \ln(n) [\delta_{30} + \delta_{31} \ln(n_1) + \delta_{32} \ln(n_2) + \delta_{33} \ln(a)] \end{aligned}$$

$$\begin{aligned} \ln(wS) = & -k\beta_1 (\ln(E) - \ln(w) \ln(t) \ln(n_1)) \quad (12) \\ & + (1 - k\beta_1) \ln(w) \ln(n) [\delta_{10} + \delta_{11} \ln(n_1) + \delta_{12} \ln(n_2) + \delta_{13} \ln(a)] \\ & + k\beta_1 p \ln(n) [\delta_{20} + \delta_{21} \ln(n_1) + \delta_{22} \ln(n_2) + \delta_{23} \ln(a)] \\ & + k\beta_1 q \ln(n) [\delta_{30} + \delta_{31} \ln(n_1) + \delta_{32} \ln(n_2) + \delta_{33} \ln(a)] \end{aligned}$$

In matrix notation, the household consumption and labor allocation can be written as:

$$\begin{bmatrix} \ln(pC) \\ \ln(qM) \\ \ln(wS) \end{bmatrix} = (\ln(E) - \ln(w) \ln(t) \ln(n_1)) \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & k \end{bmatrix} \begin{bmatrix} \beta_2 \\ \beta_3 \\ -\beta_1 \end{bmatrix} \quad (13)$$

$$+ \ln(n) \begin{bmatrix} \beta_2 \ln(w) & (1 - \beta_2)p & -\beta_2 q \\ \beta_3 \ln(w) & -\beta_3 p & (1 - \beta_3)q \\ (1 - k\beta_1) \ln(w) & k\beta_1 p & k\beta_1 q \end{bmatrix} \begin{bmatrix} \delta_{10} & \delta_{11} & \delta_{12} & \delta_{13} \\ \delta_{20} & \delta_{21} & \delta_{22} & \delta_{23} \\ \delta_{30} & \delta_{31} & \delta_{32} & \delta_{33} \end{bmatrix} \begin{bmatrix} 1 \\ \ln(n_1) \\ \ln(n_2) \\ \ln(a) \end{bmatrix}$$

The impact of the production side on consumption decisions is transmitted through farm profits appearing in the income constraint (eq. 7). The farm-household maximize the following profit function (eq. 14):

$$\pi = p(\alpha_0 A^{\alpha_1} D^{\alpha_2} K^{\alpha_3}) - wD - w_k K \quad (14)$$

For which the first order conditions are:

$$\frac{\partial \pi}{\partial D} = p\alpha_0 A^{\alpha_1} \alpha_2 D^{\alpha_2-1} K^{\alpha_3} - w = 0 \quad \rightarrow \quad D = pF \frac{\alpha_2}{w}$$

$$\frac{\partial \pi}{\partial K} = p\alpha_0 A^{\alpha_1} D^{\alpha_2} \alpha_3 K^{\alpha_3-1} - w_k = 0 \quad \rightarrow \quad K = pF \frac{\alpha_3}{w_k}$$

These input demand equations are used to derive the production (eq. 15) and the profit function (eq. 16) in terms of the fixed factors (A) and the relative prices of D , K and C .

$$F = \frac{\alpha_0^{1/(1-\alpha_2-\alpha_3)} \alpha_2^{\alpha_2/(1-\alpha_2-\alpha_3)} \alpha_3^{\alpha_3/(1-\alpha_2-\alpha_3)} A^{\alpha_1/(1-\alpha_2-\alpha_3)} p^{(\alpha_2+\alpha_3)/(1-\alpha_2-\alpha_3)}}{w^{\alpha_2/(1-\alpha_2-\alpha_3)} w_k^{\alpha_3/(1-\alpha_2-\alpha_3)}} \quad (15)$$

$$\pi = \frac{\alpha_0^{1/(1-\alpha_2-\alpha_3)} \alpha_2^{\alpha_2/(1-\alpha_2-\alpha_3)} \alpha_3^{\alpha_3/(1-\alpha_2-\alpha_3)} A^{\alpha_1/(1-\alpha_2-\alpha_3)} p^{1/(1-\alpha_2-\alpha_3)}}{w^{\alpha_2/(1-\alpha_2-\alpha_3)} w_k^{\alpha_3/(1-\alpha_2-\alpha_3)}} \quad (16)$$

As a result, the total household expenditure (E) can be expressed as:

$$E = \frac{(1 - \alpha_2 - \alpha_3) \alpha_0^{\frac{1}{(1-\alpha_2-\alpha_3)}} \alpha_2^{\frac{\alpha_2}{(1-\alpha_2-\alpha_3)}} \alpha_3^{\frac{\alpha_3}{(1-\alpha_2-\alpha_3)}} A^{\frac{\alpha_1}{(1-\alpha_2-\alpha_3)}} p^{\frac{1}{(1-\alpha_2-\alpha_3)}}}{w^{\frac{\alpha_2}{(1-\alpha_2-\alpha_3)}} w_k^{\frac{\alpha_3}{(1-\alpha_2-\alpha_3)}}} + wnt + R \quad (17)$$

From the households' farm-good demand function (eq. 13) and the total household expenditure function (eq. 17), we can derive the total proportional change in any endogenous variable Y (such as C , M or S) as response to a proportional change in an exogenous variable X (such as w , p or q). In general, these total response elasticities are given by (eq. 18):

$$\frac{\partial Y}{\partial X} \cdot \frac{X}{Y} (\pi \text{ variable}) = \frac{\partial Y}{\partial X} \cdot \frac{X}{Y} (\pi \text{ constant}) + \left(\frac{\partial Y}{\partial E} \cdot \frac{E}{Y} \right) \cdot \left(\frac{\partial E}{\partial \pi} \cdot \frac{\pi}{E} \right) \cdot \left(\frac{\partial \pi}{\partial X} \cdot \frac{X}{\pi} \right) \quad (18)$$

Specifically, the total effect of a change in quinoa price (p) on the own-consumption of quinoa (C) or the own price elasticity of quinoa consumption η_p^C is given by (eq. 19):

$$\eta_p^C = \eta_{p,\pi}^C + \eta_E^C \eta_p^\pi \cdot \frac{\pi}{E} \quad \rightarrow \quad \frac{dC}{dp} \cdot \frac{p}{C} = \frac{\delta C}{\delta p} \cdot \frac{p}{C} + \frac{\delta C}{\delta E} \cdot \frac{E}{C} \cdot \frac{\delta \pi}{\delta p} \cdot \frac{p}{\pi} \cdot \frac{\pi}{E} \quad (19)$$

The own price elasticity of quinoa consumption consists of two opposing effects (assuming that quinoa is a normal good). The first effect (first right-hand side term in eq. 19) is the direct effect of a change in quinoa price on the consumption of quinoa, keeping farm profits constant. This encompasses a 'real income' effect stemming from a change in real income with changing quinoa prices and a 'substitution effect' stemming from substitution between quinoa and other food products if quinoa prices change. This direct effect will be negative as an increase in the quinoa price decreases real income and results in substitution of quinoa for other products. The second effect (second right-hand side term in eq. 19) is the indirect effect of a change in quinoa price on the consumption of quinoa, or the 'farm profit' effect. The farm-household benefits from a higher quinoa price as farm profits and total household income increase. This indirect effect is the product of two elasticities: the income elasticity of consumption (η_E^C) and the price elasticity of income or profits (η_p^π). The indirect effect is positive as (with quinoa assumed to be a normal good) the income elasticity of consumption and the effect of an increase in quinoa price on farm profits are both positive. Depending on the magnitude of the two opposing effects, the positive indirect 'farm profit' effect may dampen or counterbalance the negative direct 'real income' and 'substitution' effects. The own price elasticity of consumption of quinoa (η_p^C) ultimately remains an empirical question. In what follows we estimate the price elasticity of consumption of quinoa empirically using survey data from Junín region in Peru. As robustness check, we additionally estimate price elasticities of production and labor demand and supply and elasticities with respect to wages.

4 Data

We use data from an original cross-sectional farm-household survey that was conducted in Junín between February and March 2015. We used a three-stage sampling design with purposive selection in the first stage and stratified random selection in the second and third stage. In the first stage, and based on statistics collected from *Regional Direction of Agriculture of Junín* (DRAJ, 2016), we identified 61 districts where quinoa was produced in 2014 and selected 25 which were more specialized in quinoa cultivation (with the median of the localization ratios in the last 3 years more than one). In the second stage, and based on reports and personal communication with employees from the agricultural agencies of Concepción, Chupaca, and Jauja, we identified the largest villages in terms of population density (154 in total), from which we randomly sampled 47 villages. In the third stage we randomly selected 518 farm-households, with the number of households in each village proportional to the population of quinoa producers.

Data were obtained using a quantitative structured questionnaire with the following modules: (1) household socio-demographic characteristics; (2) land ownership; (3) quinoa production and marketing; (4) other crop production and marketing; (5) livestock and animal production; (6) off-farm activities and other income; and (7) quinoa consumption. The reference period for production and consumption data is the harvest season in 2014. The primary survey information was complemented with secondary information from the *Regional Direction of Agriculture of Junín* (DRAJ, 2016), including statistics for regional input and output prices.

5 Descriptive Analysis

5.1 Household demographic characteristics

Household demographic characteristics are summarized in Table 1. Thirteen percent of households in the sample are female headed; the average age of the household head is 50 years; and 49% of household heads have completed secondary education, 22% have completed high education (technical institute and university) and only less than 10% have not completed primary school. The average household size (n) is 3.6 members, the average number of workers (n_1) 2.07 and the number of dependents (n_2) 1.54 - resulting in a workers' ratio of 0.64.

5.2 The farm-household as an economic unit of production

Information on the production side of the farm-household is summarized in Table 2. Figures indicate that land and livestock holdings are rather small, with on average 4.62 hectares (ha) of land and 4.59 livestock units per household. The average quinoa area is 1.84 ha and the average quinoa yield 2,050.59 kg/ha. Farmers sell on average 76% of the total quinoa production in the harvest seasons, 13.1% is commercialized in the off season, 7.61% is retained for household consumption, and 3.27% is saved as seeds for the next season. Households diversify crop production and cultivate on average 3.56 other crops, with the most common crops being potato (68% of households), corn (45%), barley (42%), broad beans (33%), wheat (19%), pea (18%), carrot (8%) and alfalfa (4%).

Farmers use on average 127.5 labor days (with one labor day equivalent to eight hours) in quinoa production, out of which 85% is hired labor and only 15% is household labor. This corroborates our assumption of an active labor market in the underlying theoretical model. The average input and capital costs (K) in quinoa production is 1,574.34 PEN, including cost for fertilizers (45.74% of the total capital cost), machines (42.37%) and seeds (11.89%). Profits from quinoa production are on average 25,894.11 PEN, calculated as gross revenue (pF) minus the cost of labor (D) and capital (K) inputs.

5.3 The farm-household as an economic unit of consumption

Information on the consumption of quinoa, the consumption of other food products, and the allocation of labor is summarized in Table 3. The survey data include information on the physical quantity of quinoa consumed each month for the past 12 months. The average monthly per capita quinoa consumption of households in the sample is 8.02 kg in physical terms or 134.10 PEN in monetary terms, calculated using quinoa price (p) information from official regional statistics (DRAJ, 2016). Due to data limitations, the consumption of other food products is proxied for by a variable measuring the consumption of other food products during lunch meals. As lunch is the main meal in the Peruvian Andes and as, apart from small quantities at breakfast, quinoa is mainly consumed during lunch, focusing on lunch meals can proxy for consumption of other food products and capture the substitution of quinoa for other food products. Based on information from the survey, 81 typical lunch dishes were identified. Using information from focus group discussions with farm-households and from interviews with nutritional specialists, the average amount of other food products in these dishes was determined. Multiplying this with price data for different food products from

official statistics (DRAJ, 2016) and adding up, a proxy variable for consumption of other food products was obtained. This proxy variable of food consumption (qM) is on average 1,199.57 PEN. The budget share of quinoa relative to other food used in an average meal is relatively small and corresponds to around 10% of the budget for the meal.

The total labor time available of working household members (T) in the 2014 harvest season (Oct 2013 – May 2014) is 1,506 labor days on average. For comparability with the household reliance on hired labor, this was measured as the household labor force (n_1) multiplied by the labor days in the above agricultural cycle; where the agricultural cycle corresponds to 243 days and 1 day equals 3 labor days (i.e. eight hours). The average household labor supply (S) is 101.44 labor days, where 18.80% of the labor supply is used in quinoa production and 81.20% of the household labor was destined to other non-farm activities. For the quinoa production, the households recur to hired labor (H) for an average of 26.05 labor days and at a daily wage of 37.22 PEN. This indicates that the farm-household is a buyer of quinoa-farm labor. The remaining household time ($T-S$) is dedicated to productive and reproductive work and leisure in the farm-household (L). It includes the activities associated with daily maintenance of the household, childcare, sleep and the production of other non-quinoa crops. The household expenditure (E) is 54,171.38 PEN and it is the sum of the monetary value of consumption of quinoa (pC), of other food products consumed together with quinoa (qM), and of productive and reproductive work and leisure (wL) within the household. The net income of any other activities of the household is 9,698.22 PEN (R); it includes income from livestock, processed products, sub products, money transfer by NGOs, remittances and conditional transfers by the government of Peru.

6 Model Results

We use the survey data to estimate the Barnum-Squire model described in section 3, which explains short-run production and consumption behavior of quinoa farm-households and can be used to estimate the own price elasticity of consumption of quinoa. First, the Cobb-Douglas production function is estimated by Ordinary Least Squares (OLS). From the estimated parameters the quinoa production (F), profit (π) and quinoa labor demand (D) functions are obtained and the elasticities of production, profits and labor demand with respect to the price of quinoa are calculated. Second, we estimate the parameters of the expenditures equations which are nonlinear in the parameters by Feasible Generalized Nonlinear Least Squares (FGNLS) and present the estimated parameters for the three consumption goods. We use the estimated parameters to calculate price elasticities of

consumption of quinoa (C), of consumption of other food products (M) and of household labor supply in quinoa farm and non-farm activities (S). Elasticities with respect to wages are estimated in both the production function and expenditure system analyses to corroborate our findings.

6.1 The Production Side

The Cobb-Douglas quinoa production function (eq. 2) is derived (eq. 20) using the estimated production coefficients of the farm-household model that are reported in table 4:

$$F = 1363.568A^{0.781}D^{0.066}K^{0.234} \quad (20)$$

All coefficients are significant at the 10% level. The returns to scale are decreasing: the null hypothesis of $\alpha_1 + \alpha_2 + \alpha_3 = 1$ is rejected at the 5% significance level. The estimated coefficient for quinoa labor (D), 0.066, is relatively low. Capital (K) and area (A) are more important inputs for quinoa production, which is in line with the increasing mechanization of quinoa production.

The quinoa production (eq. 21), profit (eq. 22) and labor demand (eq. 23) are expressed as functions of the quantity of the fixed factor (area) and the relative price of labor and capital:

$$F = 1363.568A^{1.116}p^{0.429}w^{-0.094}w_K^{-0.335} \quad (21)$$

$$\pi = 954.432A^{1.116}p^{1.429}w^{-0.094}w_K^{-0.335} \quad (22)$$

$$D = 95.45A^{1.116}p^{1.429}w^{-1.094}w_K^{-0.335} \quad (23)$$

These equations are used to provide estimates of the elasticities of production, labor demand and profits of quinoa with respect to price and daily wage (Table 5). The table shows that a 1% increase in quinoa price results in a 0.429% increase in quinoa production. A 1% increase in quinoa price also has a positive impact on both the demand for labor and profits, increasing both more than proportionally by 1.429%. The daily wage elasticity of quinoa production is negative. A one percent increase in the daily wage results in a 0.094% decrease in the quinoa production, and a 1.094% decline in quinoa labor demand.

6.2 The Consumption Side

We estimate the household demand function for quinoa, other food products, and household labor defined by eq. 10, 11 and 12 respectively. Parameters with coefficients not significant at the 5% significance level were dropped and the system was re-estimated. Specifically, none of the coefficients on education was found to be significant, such that in the final estimation we use three household characteristics: household labor force (n_1), dependents (n_2) and age of the household head (a)⁶. The final parameter estimates to be used for the response analysis are presented in Table 6; all coefficients are significant at 1% level.

The total elasticities of household consumption of quinoa (C), consumption of other food products (M) and the household labor supply (S) with respect to the price of quinoa (p) and the daily wage (w) are derived from the households' farm-good demand function (eq. 24) and the total household expenditure (eq. 25).

$$\begin{aligned} & \begin{bmatrix} \ln(pC) \\ \ln(qM) \\ \ln(wS) \end{bmatrix} \\ & = (\ln(E) - \ln(w) \ln(t) \ln(n_1)) \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0.64 \end{bmatrix} \begin{bmatrix} 0.30 \\ 0.45 \\ -0.38 \end{bmatrix} \\ & + \ln(n) \begin{bmatrix} 0.30 \ln(w) & 0.70p & -0.30q \\ 0.45 \ln(w) & -0.45p & 0.55q \\ (1 - 0.24) \ln(w) & 0.24p & 0.24q \end{bmatrix} \begin{bmatrix} 5.36 & -3.03 & -0.4 & 0.74 \\ 0 & 1.75 & 0.16 & -0.21 \\ 0 & 3.35 & 0.30 & -0.4 \end{bmatrix} \begin{bmatrix} 1 \\ \ln(n_1) \\ \ln(n_2) \\ \ln(a) \end{bmatrix} \end{aligned} \quad (24)$$

$$E = 954.432A^{1.116}p^{1.429}w^{-0.094}w_k^{-0.335} + wnt + R \quad (25)$$

Table 7 presents the estimated elasticities, calculated at the arithmetic means of the sample. Results indicate that a one percent increase in the quinoa price (p) results in a 0.238% increase in the own-consumption of quinoa (C). This implies that the negative 'real income' and 'substitution' effects of increasing quinoa prices are outweighed by a positive 'farm-profit' effect from quinoa production. A higher quinoa price is found to increase household labor supply, including the households' time in quinoa production and non-farm activities, by 0.292%. This likely stems from a re-allocation of farm-household time to on-farm quinoa production and a higher opportunity cost of farm-household time as the quinoa price increases. Moreover, we find that a one percent increase in the daily wage (w) results in an increase of own-consumption of quinoa (C) by 1.308% and in a strong effect on the

⁶ The original model by Barnum & Squire (1979) includes four variables on household characteristics: age, education, household labor force and number of dependents.

household labor supply (S) of 5.805%. The former two outcomes point to a positive off-farm wage-income effect while the latter reflects the higher opportunity cost of leisure due to the market wage increase.

Multicollinearity between the production factors could result in imprecise estimates of the production elasticities, which in turn could result in imprecise estimates of price elasticities. To test the robustness of the results to multicollinearity among production factors, the elasticity of own quinoa consumption with respect to price was calculated using two alternative Cobb-Douglas production functions, without capital input and without labor input. We find very similar results as in the baseline model, i.e., own price elasticities of quinoa consumption of 0.212 and 0.229 respectively, pointing to robustness of the results.

7 Discussion

The results reveal that traditional quinoa farm-households in the central highlands of Peru increase both quinoa production and consumption as a response to an increase in the price of quinoa. In terms of the Barnum-Squire model, this implies that the positive ‘farm profit’ effect due to the global quinoa price increase, offsets the negative ‘real income’ and ‘food substitution’ effects that would be predicted from a basic indifference-curve analysis. Our results do not support claims about decreasing quinoa consumption among Andean farmers (Blythman, 2013; Friedman-Rudovsky, 2012; Verner, 2013).

The estimated price elasticity of quinoa production of 0.429 is small in comparison with other estimates in the literature. For Bangladesh, Quayes and Rashid (2008) estimate a production elasticity of 2.03. The smaller effect we find is likely due to our focus on only one farm good, while Quayes and Rashid (2008) consider a combination of 33 food items. The sign and magnitude of the estimated price elasticity of quinoa consumption of 0.238, are consistent with estimates by Lau et al. (1978) and Barnum and Squire (1979). These authors point to a price elasticity of consumption of 0.221 for farm produce in Taiwan and of 0.380 for rice in Malaysia (see Table B in the appendix for a summary of results). Taylor and Adelman (2002) find a significantly larger positive price elasticity of consumption of 0.947 for staple food crops in Mexico. Other studies found significantly smaller or even negative elasticities of consumptions: Ahn et al. (1981) report an almost nil elasticity of 0.01 for rice in Korea, while both Strauss (1984) and Quayes and Rashid (2008) report respectively negative price elasticities for rice consumption in Sierra Leone (elasticity of -0.66) and for a combination of crops in Bangladesh (elasticity of -0.212). Differences in findings might be related to own price elasticities and profit effects being smaller at lower expenditure levels

(Strauss et al., 1984). Quinoa producers in Peru have higher expenditure levels than farmers in Bangladesh and Sierra Leone, and are likely more similar to farmers in upper-middle-income or high-income countries like Taiwan, Malaysia or Mexico. Moreover, quinoa is a staple crop in the Peruvian Andes, but, as compared to staples in other settings is consumed in relatively small quantities, representing a comparatively small share in households' food expenditures (Vega-Gálvez et al., 2010). In this setting, income effects from increased profits through price increases are more likely to outweigh negative 'real income' and 'food substitution' effects.

In our application of the Barnum-Squire farm-household model, we stick as closely as possible to the original model and its application by other scholars. While some applications have considered multiple farm outputs (e.g., Lau et al., 1978; Taylor and Adelman, 2002; Quayes and Rashid, 2008), we focus on farm-households' total consumption of one staple food product, quinoa, which is in line with the original model and applications by Ahn et al. (1981) and Straus (1984). Due to data limitations we only consider consumption of other food products in lunch meals instead of total consumption of market-purchased goods and constructed these data based on information about the type of meals consumed. While our data do capture changes in food consumption from changes in dish composition following quinoa price increases, this is only a proxy for consumption of non-quinoa food products or market-purchased goods. The original Barnum-Squire model and its applications, including our study, treat land as a fixed factor of production and consider only one agricultural season. Our result of a positive own price elasticity of quinoa consumption therefore has to be interpreted as a short term effect of the international quinoa boom. In the long run and across agricultural seasons, land allocated to quinoa production and other crops may become variable and substitution of land (and labor) between crops should be taken into account, which will likely increase the 'farm profit' effect and result in an even higher own price elasticity of quinoa consumption. On the other hand, increased volatility of international quinoa prices in the long may affect farm-households' consumption and production decisions in a way that cannot be predicted by the Barnum-Squire model, which does not take into account risk behavior.

8 Conclusion

The rapid increase in quinoa prices, following the increased international attention to quinoa as a 'superfood' and the increased international trade in quinoa, creates a concern about the welfare effects for (often poor) people in Andean regions, where quinoa originates from. With prices more than tripling in a couple of years, concerns have risen about Andean households'

ability to further afford quinoa consumption and the consequent impact on nutrition. In this paper we examine the impact of the exogenous increase in the quinoa price on the own-consumption of quinoa in farm-households in the Peruvian Andes who are at the same time producers and consumers of quinoa. Results suggest a positive impact of the increase in quinoa price on both production and consumption of this Andean crop in traditional quinoa-producing households.

With this paper, we make a contribution to the literature in three ways. First, we apply the seminal Barnum-Squire farm-household model with a focus on a specific staple food crop with highly nutritious characteristics, that are not only valued in the local but also in the global market. Previous applications of the model have focused on food aggregates or staple crops with high calorie content but lower nutritious value and limited international market demand. Quinoa differs from common staples like rice and maize for being consumed in smaller quantities, but being, at the same time, the principal source of nutritional value for smallholder farmers in the rural Andes (Vega-Gálvez et al., 2010). An increased consumption of quinoa affects farm-households' food intake both in terms of available food quantity as well as nutritious content. Second, we add to the emerging scientific evidence tackling the concerns about increasing quinoa prices and the welfare effects for households in Andean regions. Bellemare et al. (2016) point out that rising quinoa prices positively affect the total value of household consumption and household welfare. Stevens (2015) finds that cultural preferences for quinoa in certain areas of Peru do not lead to a worsening of nutritional outcomes. We add to this evidence by showing a positive own price elasticity of consumption of quinoa among traditionally quinoa-producing farm-households in the Peruvian Andes. This emerging evidence does not hold up the concerns that have risen about the welfare and nutrition effects of increased international demand and increasing prices for quinoa. Finally, our study is relevant in light of other global 'superfoods' that are important in traditional diets in developing countries but that are becoming increasingly popular for their nutritional value. Crops such as teff in Ethiopia, other Andean crops like kiwicha, kañiwa and tarwi, coconut oil in Sri Lanka or moringa in Tanzania are traditionally cultivated for subsistence and local consumption but international demand for these crops is increasing. This can lead to important welfare changes in areas where these crops are traditionally cultivated and understanding these welfare effects requires empirical research.

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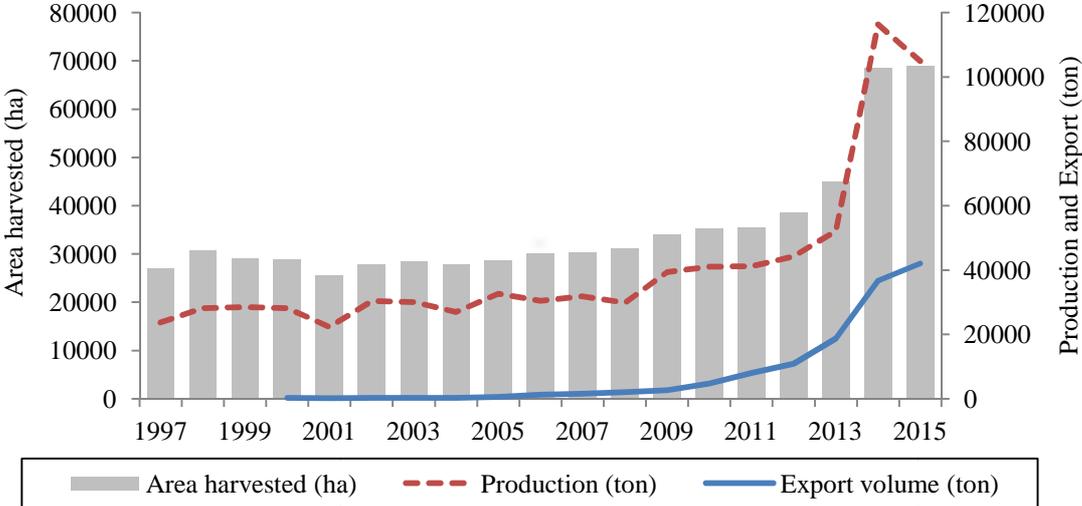
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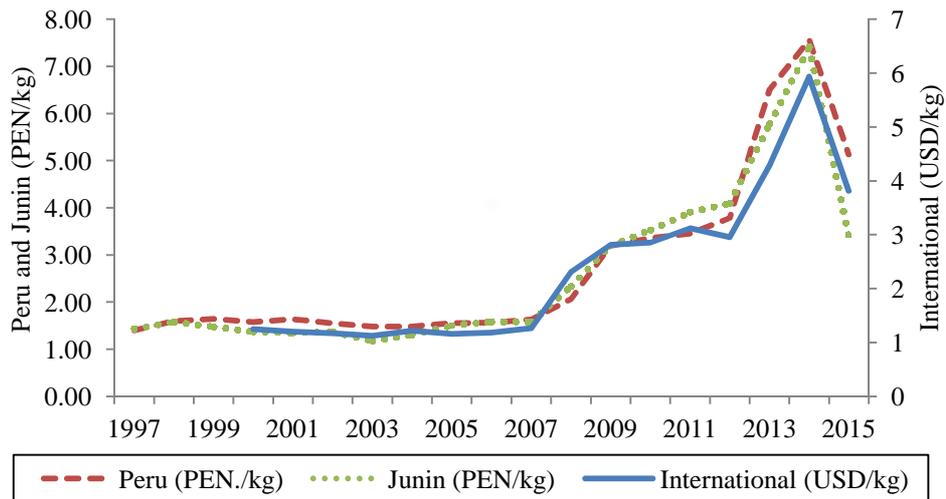
Figures

Figure 1: Evolution of quinoa area harvested, production and exports in Peru.



Source: Authors' elaboration from MINAGRI, over 1997 – 2015
Note: Data on international export volumes are only available from the year 2000

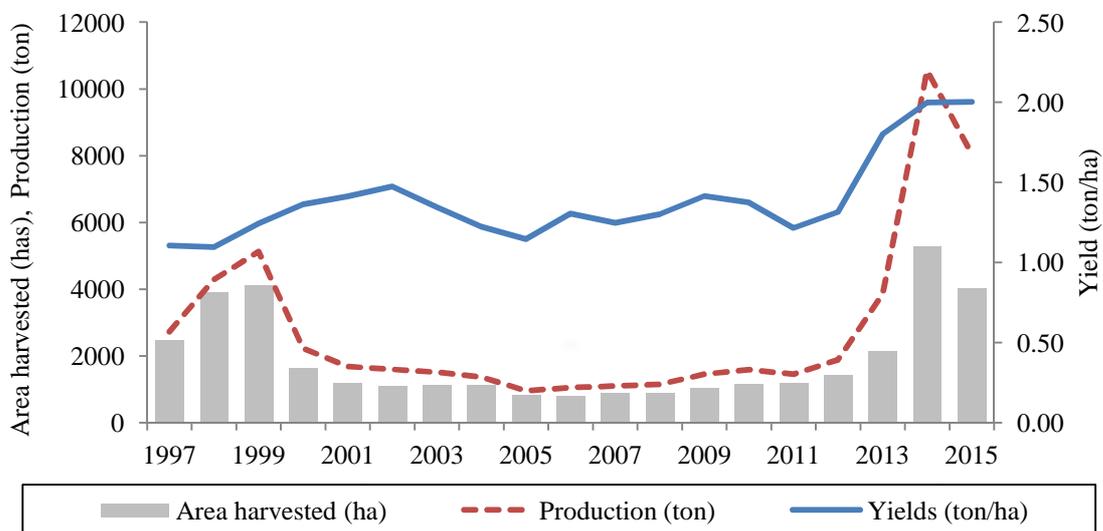
Figure 2: Evolution of quinoa price at international, Peru and Junín level



Source: Authors' elaboration from MINAGRI, DRAJ, ADEX and INE, over 1997 – 2015

Note: The official exchange rate in 2014 is 3.77 PEN/Euro (Central Reserve Bank of Peru); Data on international export volumes are only available from the year 2000

Figure 3: Evolution of quinoa area harvested, production and yield in Junín region.



Source: Authors' elaboration from DRAJ, over 1997 – 2015

Tables

Table 1: Household characteristics of quinoa producers

Variable	Description	Unit	Mean N=518	Standard deviation
Household female	head The share of female household heads	%	12.93	
Age (<i>a</i>)	Age of the household head (HH)	year	50.43	13.43
Education (<i>e</i>)	Education of the household head is expressed in terms of consecutive integer codes based on the level of formal education received			
Primary school	Percentage of HH heads that completed primary education	%	20.08	
Secondary school	Percentage of HH heads that completed secondary education	%	49.61	
Institute	Percentage of HH heads that completed technical institute	%	9.46	
University	Percentage of HH heads that completed university	%	12.16	
Incomplete education	Percentage of HH heads with an incomplete primary education	%	6.95	
No education	Percentage of HHs heads without education	%	1.74	
Family size (<i>n</i>)	The sum of dependents (n_2) and working family members (n_1)	#	3.6	1.46
Workers (n_1)	Members of the family that work, either on-farm or off-farm	#	2.07	0.87

Dependents (n_2)	The household members that fall in the category of student, job seeker, disabled or sick, housewife and children under the age of 8	#	1.54	1.34
Proportion of workers (k)	The ratio between workers (n_1) and the family size (n)	#	0.64	0.26

Source: Calculations based on household survey data collected by the authors in 2015

Note: HH = Household

Table 2: Household as an economic unit of production

Variable	Description	Unit	Mean N=518	Standard deviation
Area cultivated	Total surface cultivated by the farmer	ha	4.62	5.93
Livestock (TLU)	The number of tropical livestock units owned by the household	#	4.59	5.60
Crops	The number of crops cultivated by the farm in the agricultural season 2013-2014	#	3.56	1.49
Area (A)	The surface area that the farm devotes to crop quinoa in the agricultural season 2013-2014	ha	1.84	2.89
Production (F)	Quinoa production by the farmer in the agricultural season 2013-2014	kg	4,194.47	7,974.77
Self-consumption	Percentage of quinoa production destined to self-consumption	%	7.61	
Seed	Percentage of quinoa production that is maintained as a seed for the next season	%	3.27	
Storage	Percentage of quinoa production destined to storage. It is sold in the next season	%	13.10	
Sale	Percentage of quinoa production that is sold in the season	%	76.04	
Yield	Total quinoa production divided by quinoa area cultivated (F/A)	kg/ha	2,050.59	979.58

Labor (D)	Labor input used in quinoa production. It includes family and hired labor. Male and female labor are weighted equally, and 1 labor day corresponds to 8 hours	labor day	127.49	341.89
Household labor	The share of labor that comes from the household	%	14.96	
Contract labor	The share of labor that is hired	%	85.04	
Capital (K)	Capital inputs used in quinoa production, which include: seed, fertilizers and machine in monetary terms	PEN	1,574.34	4,905.55
Seed	Percentage of capital spent in seeds	%	11.89	
Fertilizers	Percentage of capital spent in organic and synthetic fertilizers	%	45.74	
Machine	Percentage of capital spent in the rent of tractor, thresher, and combine harvester	%	42.37	
Farm profits (π)	Restricted farm profits. That is, gross revenue (pF) less the cost of labor (D) and capital (K) inputs	PEN	25,894.11	49,918.75

Source: Calculations based on household survey data, collected by the authors in 2015

Note: ha = hectares

Table 3: Household as an economic unit of consumption

Variable	Description	Unit	Mean N=518	Standard deviation
Quinoa consumption (pC)	Market value of quinoa consumption (in monetary terms)	PEN	134.1	96.14
Other food products (qM)	Market value of other food products that is consumed together with quinoa as a complement to prepare a quinoa dish (in monetary terms)	PEN	1199.57	636.48
Household labor supply (S)	Household labor supply destined to quinoa farming and other non-farm activities. Male and female labor are weighted equally; child labor is not considered	labor day	101.44	124.06
Quinoa activities	Percentage of household labor supply destined to quinoa activities	%	18.80	
Other activities	Percentage of household labor supply destined to non-farm activities	%	81.20	
Total time available of working household members (T)	The number of labor days in the period from October 2013 to May 2014 of the household labor force (n_l), in which in one agricultural cycle there are 243 days, and 1 day equals 3 labor days	labor day	1,505.85	634.59
Net labor time for quinoa production (H)	Net quantity of quinoa labor time sold if $H > 0$ and net quantity of quinoa labor time purchased if $H < 0$	labor day	-26.05	323.32
Productive and reproductive work and leisure (L)	Is obtained as a residual by subtracting total time worked (S) from total time available of the working household members (T)	labor day	1,404.41	621.48
Daily wage (w)	Daily wage	PEN	37.22	14.92
Net other income (R)	Net other income includes income from livestock, processed products, sub products, money transfer by NGOs, remittances and conditional transfers by the government of Peru	PEN	9,698.22	95,153.91
Total household expenditure (E)	It is obtained as the sum of the monetary value of consumption of quinoa (pC), of other food products consumed together with quinoa (qM), and of productive and reproductive work and leisure (wL) within the household	PEN	54,171.38	31,801.13

Source: Calculations based on household survey data, collected by the authors in 2015

Table 4: Estimates of the production side of the farm household model

Coefficient	Estimate	Standard errors
Ln(<i>D</i>)	0.066 [*]	0.038
Ln(<i>A</i>)	0.781 ^{***}	0.042
Ln(<i>K</i>)	0.234 ^{***}	0.036
_cons	5.571 ^{***}	0.254
N	513	
F	874.84	
p	0.00	
r2	0.846	

Source: Estimations based on household survey data collected by the authors in 2015

Notes: ^{*} p < 0.1, ^{**} p < 0.05, ^{***} p < 0.01

Table 5: Elasticities of quinoa production, labor demand, and profit with respect to selected variables

Variables	Elasticities		
	Production (F)	Labor demand (D)	Profit (π)
Quinoa price (p)	0.429	1.429	1.429
Daily wage (w)	-0.094	-1.094	-0.094

Source: Estimations based on household survey data collected by the authors in 2015

Table 6: Estimated parameters of the Linear Expenditure System for an agricultural household in Junín region - Peru

Coefficient	Estimate		Standard errors
β_1	0.382		
β_2	0.304	***	0.016
β_3	0.453	***	0.010
δ_{10}	5.359	***	0.439
δ_{11}	-3.030	***	0.171
δ_{21}	1.754	***	0.276
δ_{31}	3.348	***	0.400
δ_{12}	-0.339	***	0.059
δ_{22}	0.162	***	0.049
δ_{32}	0.303	***	0.085
δ_{13}	0.745	***	0.123
δ_{23}	-0.213	***	0.052
δ_{33}	-0.402	***	0.076

Source: Estimations based on household survey data collected by the authors in 2015

Notes: β_1 is derived from the restriction that $k\beta_1 + \beta_2 + \beta_3 = 1$. In calculating β_1 , k was set at its mean value of 0.637. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; N=518.

Table 7: Household response elasticities

Exogenous variables ($X = p, w$)	Total response elasticities	Own-consumption of quinoa "C"	Supply of labor "S"
Price of quinoa (p)	η_p^Y	0.238	0.292
Daily wage (w)	$\eta_{q,\pi}^Y$	1.308	5.805

Source: Estimations based on household survey data collected in 2015

Appendix

Figure A1: Study area. Peru country, Junin region and 25 districts selected: (1) Aco, (2) Acolla, (3) Ahuac, (4) Canchayllo, (5) Chambara, (6) Chongos bajos, (7) Colca, (8) Comas, (9) Concepción, (10) El Tambo, (11) Huachac, (12) Huertas, (13) Jauja, (14) Manzanares, (15) Marco, (16) Mito, (17) Orcotuna, (18) Paccha, (19) San Jose de Quero, (20) San Juan de Yscos, (21) Sapallanga, (22) Sicaya, (23) Sincos, (24) Tunanmarca, and (25) Yauyos.

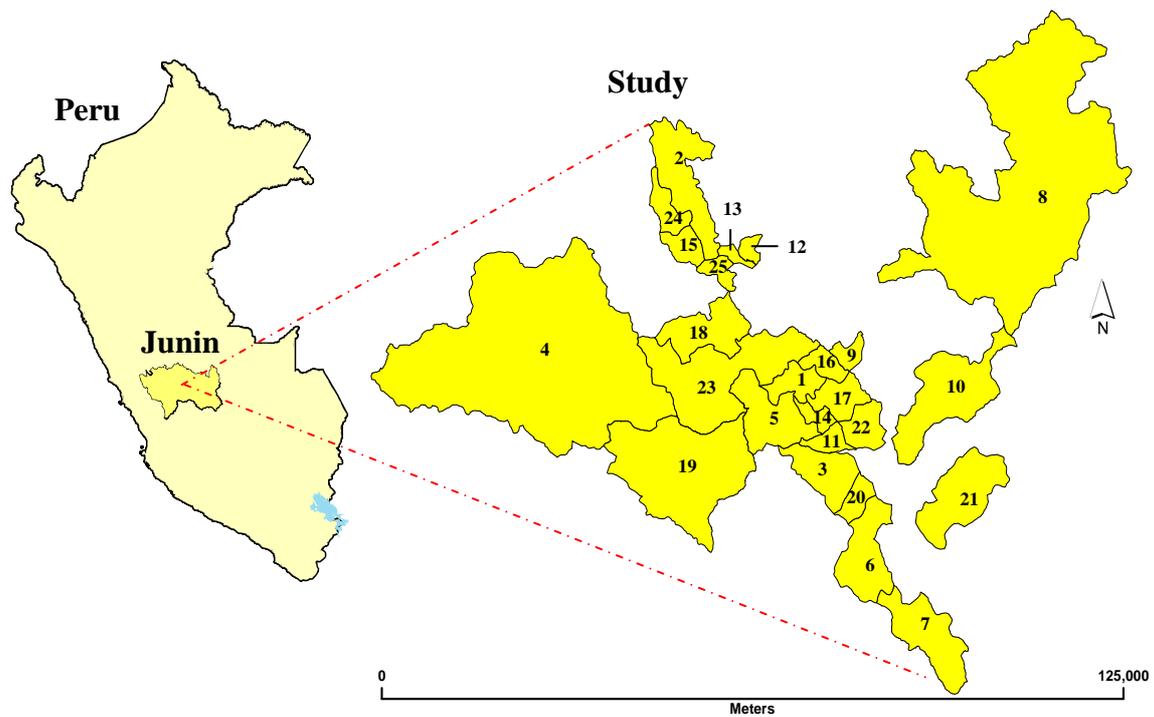


Table A1: Quinoa harvested area, production, yield and consumption in quinoa-producing farmers in Peru

	2010		2011		2012		Average
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	
N° farmers	424		354		573		
Area harvested (has)	0.21	0.53	0.16	0.38	0.19	0.44	0.18
Yield (kg/ha)	1770.17	2250.82	1156.42	1066.71	1026.23	1736.02	1317.61
Production (kg)	228.91	763.98	163.56	489.56	234.51	1109.90	208.99
Sell (kg)	125.65	655.14	109.47	466.58	179.35	1102.95	138.16
Self-consumption (kg)	65.46	183.31	34.76	42.92	35.07	42.83	45.09
Seed (kg)	11.16	35.72	5.33	8.28	7.00	14.63	7.83
Sub products (kg)	12.62	27.30	6.87	22.86	5.50	17.74	8.33
Barter (kg)	0.40	4.73	0.32	2.27	0.11	1.19	0.28
Animal feed (kg)			0.08	1.23	0.36	2.80	0.22
Others (kg)	13.27	89.30	6.74	24.44	7.13	29.57	9.05
% of sell (Sale/Production)	0.18	0.30	0.17	0.30	0.15	0.29	0.16
% of Self-consumption (Self-consumption/Production)	0.56	0.31	0.60	0.33	0.60	0.34	0.59
Price (soles/kg)	3.71	1.02	3.74	0.84	4.12	1.10	3.86
Consumption per capita	19.98	41.93	15.02	18.72	15.70	22.33	16.90
Consumption per adult equivalent	31.63	71.48	20.65	24.94	21.40	27.74	24.56

Source: Author's calculation based on micro data from ENAPRES, over 2010-2012

Table B: Price elasticity of consumption of different agricultural commodities in different studies

Country	Agricultural commodity	Consumption of agricultural commodity	References
Taiwan	Farm output ¹	0.221	Lau et al. (1978)
Malaysia	Rice	0.380	Barnum and Squire (1979)
Korea	Rice	0.010	Ahn et al. (1981)
	Barley	0.060	
	Other farm produce	0.120	
Mexico	Staple foods	0.947	Taylor and Adelman (2002)
Sierra Leone	Rice	-0.660	Straus J. (1984)
Bangladesh	Farm good ²	-0.212	Quayes and Rashid (2008)

Note: ¹Farm output refers to commodities produced in agriculture. ²Farm good are goods that are consumed by a majority of the farmers. This include 33 food items.

Appendix C

The first order conditions of the Lagrange maximization model (eq. 9) are:

$$\frac{\partial \mathcal{L}}{\partial (t-s)} = k\beta_1 \frac{1}{t-s-\gamma_1} - \lambda wk = 0 \quad \rightarrow \quad w(t-s) = w\gamma_1 + \beta_1 \frac{1}{\lambda} \quad (\text{C.1})$$

$$\frac{\partial \mathcal{L}}{\partial c} = \beta_2 \frac{1}{c-\gamma_2} - \lambda p = 0 \quad \rightarrow \quad pc = p\gamma_2 + \beta_2 \frac{1}{\lambda} \quad (\text{C.2})$$

$$\frac{\partial \mathcal{L}}{\partial m} = \beta_3 \frac{1}{m-\gamma_3} - \lambda q = 0 \quad \rightarrow \quad qm = q\gamma_3 + \beta_3 \frac{1}{\lambda} \quad (\text{C.3})$$

$$\frac{\partial \mathcal{L}}{\partial \lambda} = wk(t-s) + pc + qm - \frac{E}{n} = 0 \quad \rightarrow \quad \frac{1}{\lambda} = \frac{E}{n} - wk\gamma_1 - p\gamma_2 - q\gamma_3 \quad (\text{C.4})$$

Where $k\beta_1 + \beta_2 + \beta_3 = 1$. Then, the equation C.5, C.6 and C.7 can be derived by manipulating C.1, C.2 and C.3 into C.4, and to avoid a data specification error, which could arise through the computation of leisure as the residual after time allocated to work activities (s) is subtracted from total discretionary time available (t). We adopt a modification suggested by Abbott and Ashenfetter, which involves substituting $t - \gamma_s = \gamma_1$.

$$-ws = \beta_1 b + w'(\beta_1 - 1/k)\gamma_s - \beta_1 p\gamma_2 - \beta_1 q\gamma_3 \quad (\text{C.5})$$

$$pc = \beta_2 b + \beta_2 w'\gamma_s + p(1 - \beta_2)\gamma_2 - \beta_2 q\gamma_3 \quad (\text{C.6})$$

$$qm = \beta_3 b + \beta_3 w'\gamma_s - \beta_3 p\gamma_2 + (1 - \beta_3)q\gamma_3 \quad (\text{C.7})$$

Where $b = -w's + pc + qm$. This transformation has the dual advantage that neither leisure nor total available hours are included as variables and we obtain a direct estimate of the household labor supply function (C.5). To simplify, we can write the system in matrix notation as

$$\begin{bmatrix} -ws \\ pc \\ qm \end{bmatrix} = \begin{bmatrix} b & 0 & 0 \\ 0 & b & 0 \\ 0 & 0 & b \end{bmatrix} \begin{bmatrix} \beta_1 \\ \beta_2 \\ \beta_3 \end{bmatrix} + \begin{bmatrix} (\beta_1 - 1/k)kw & -\beta_1 p & -\beta_1 q \\ \beta_2 kw & (1 - \beta_2)p & -\beta_2 q \\ \beta_3 kw & -\beta_3 p & (1 - \beta_3)q \end{bmatrix} \begin{bmatrix} \gamma_s \\ \gamma_2 \\ \gamma_3 \end{bmatrix} \quad (\text{C.8})$$

$$Y = B\beta + P\gamma \quad (\text{C.9})$$

In addition, the household characteristics are introduced by making the vector γ a linear function of a vector of household characteristics (G), in which δ are parameters to be estimated in the Linear Expenditure System demand function.

$$\begin{bmatrix} \gamma_s \\ \gamma_2 \\ \gamma_3 \end{bmatrix} = \begin{bmatrix} \delta_{10} & \delta_{11} & \delta_{12} & \delta_{13} \\ \delta_{20} & \delta_{21} & \delta_{22} & \delta_{23} \\ \delta_{30} & \delta_{31} & \delta_{32} & \delta_{33} \end{bmatrix} \begin{bmatrix} 1 \\ n_1 \\ n_2 \\ e \end{bmatrix} \quad (\text{C.10})$$

$$\gamma = \delta G \quad (\text{C.11})$$

Thus the final system of equation to be estimated can be written as $Y = B\beta + P\delta G$. Finally, the family expenditure functions may then be derived by multiplying the expenditure functions for quinoa (C.12) and other products (C.13) by n , and the labor supply function (C.14) by n_l .

$$pC = \beta_2(E - wtn_1) + \beta_2wn[\delta_{10} + \delta_{11}n_1 + \delta_{12}n_2 + \delta_{13}a] \\ + (1 - \beta_2)pn[\delta_{20} + \delta_{21}n_1 + \delta_{22}n_2 + \delta_{23}a] - \beta_2qn[\delta_{30} + \delta_{31}n_1 + \delta_{32}n_2 + \delta_{33}a] \quad (C.12)$$

$$qM = \beta_3(E - wtn_1) + \beta_3 \ln(w) n[\delta_{10} + \delta_{11}n_1 + \delta_{12}n_2 + \delta_{13}a] - \beta_3pn[\delta_{20} + \delta_{21}n_1 + \delta_{22}n_2 + \delta_{23}a] \\ + (1 - \beta_3)qn[\delta_{30} + \delta_{31}n_1 + \delta_{32}n_2 + \delta_{33}a] \quad (C.13)$$

$$wS = -k\beta_1(E - wtn_1) + (1 - k\beta_1) \ln(w) \ln(n)[\delta_{10} + \delta_{11}n_1 + \delta_{12}n_2 + \delta_{13}a] \\ + k\beta_1pn[\delta_{20} + \delta_{21}n_1 + \delta_{22}n_2 + \delta_{23}a] + k\beta_1qn[\delta_{30} + \delta_{31}n_1 + \delta_{32}n_2 + \delta_{33}a] \quad (C.14)$$

With the exception of the price of quinoa (p), other foods (q), and the proportion of working members (k), we employ the natural log of all the variables used in the consumption equations (eq. 11, 12 and 13).