Revista de Historia Económica / Journal of Iberian and Latin American Economic History
(2024), **42**, 243–268
doi:10.1017/S0212610924000107

ARTICLES/ARTÍCULOS

Prices, wages and living standards in Spain in the modern era

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(Received 27 April 2022; accepted 20 February 2023)

Abstract

This study relies on a linear programming model to estimate welfare ratios in Spain between 1600 and 1800. This method is used to find the food basket that guaranteed the intake of basic nutrients at the lowest cost. The estimates show that working families in Toledo had higher welfare ratios than in those in Barcelona. In addition, the welfare ratios of Spain were always below those of London and Amsterdam. The divergence between Northern Europe and Spain started before the Industrial Revolution and increased over time.

Keywords: Living costs; prices; wages; Spain; Europe

JEL: N36; I32; J31; C61

Resumen

Este estudio se basa en un modelo de programación lineal para estimar ratios de bienestar en España en 1600-1800. Usando un modelo de programación lineal, se halla la canasta de consumo que garantizó la ingesta de nutrientes básicos al mínimo costo posible. Las estimaciones muestran que las familias de bajos ingresos en Toledo tenían mayores ratios de bienestar que en Barcelona. Asimismo, los ratios de bienestar en España estuvieron siempre por debajo de los ratios de Londres y Ámsterdam. La divergencia entre Europa del Norte y España se inició antes de la Revolución Industrial y aumentó a lo largo del tiempo.

Palabras clave: Costos de vida; precios; salarios; España; Europa

1. Introduction

For a long time, economists and economic historians have analysed living standards from the past. Starting with Allen (2001), several studies have estimated welfare ratios for a large number of countries. By doing so, it has been possible to determine the capacity of families to cover their basic needs, the differences in living standards across countries and their evolution over time.

To estimate welfare ratios, it is necessary to make a number of assumptions. Allen (2001) relied on the consumption habits of modern London to make assumptions about the food basket in several European cities. He also assumed that only one man worked per family and that he did so for 250 days per year. Allen (2009) subsequently made some adjustments to the earlier (2001) basket in order to obtain a subsistence basket. Bread was replaced by a cheaper cereal and the amounts of meat and other expensive items were reduced; the assumptions regarding the number of people who worked per family and the number of workdays remained unchanged.

For many years, most studies used Allen's methodology (2009) to estimate welfare ratios. Recently, however, some of the traditional assumptions have been questioned. Some criticisms refer to the food basket.[1] López and Piquero (2021), for instance, questioned the exclusion of bread from the basket of Spain, arguing that bread was an important part of the diets of Spanish families.[2] Meanwhile, Humphries (2023) and Horrell (2023) were of the opinion that the living costs should change in response to changing consumption habits. Rather than assuming a fixed basket, as Allen did, Humphries used board and lodging costs as a measure of living costs in order to include changing habits in England, whereas Horrell constructed a chained-Laspeyres price index in England based on changing expenditure patterns.

Consumption habits have largely been used to make assumptions about the subsistence food basket. However, using historical diets to estimate welfare ratios may be problematic. First, historical diets could have provided a deficient amount of some nutrients and an excessive amount of others. Consequently, it is necessary to adjust the historical diets to obtain a subsistence basket.[3] Second, if the subsistence baskets (corresponding to historical diets) were different across cities or over time, the resulting welfare ratios may not be comparable. For instance, using a different basket may not be appropriate if income or tastes influenced consumption habits.[4] In addition, using the same basket may not be appropriate if relative prices were different.[5]

Linear programming, a common optimisation method, can also be used to select the subsistence basket (Allen, 2017, 2020; Zegarra, 2021, 2022). Linear programming relies on information on prices, the chemical composition of foods and nutritional requirements to find the lowest-cost food basket. Linear programming has several advantages compared to the use of consumption habits. First, whereas historical diets need to be adjusted to obtain a subsistence basket, no adjustment of the lowest-cost basket is necessary. In addition, unlike historical diets, the lowest-cost basket is not affected by income or tastes. Instead, it is affected by the prices of goods, the chemical composition of foods and nutritional requirements. Finally, the method allows for substitution in response to changes in relative prices.[6]

[1] Some studies have also questioned Allen's assumptions regarding the number of people who worked per family and the number of workdays, whereas others questioned the use of salaries paid by institutions as representative of salaries in the whole economy.

[2] Meanwhile, Liu (2022) argues that the food basket used by Allen *et al.* (2011) to estimate the welfare ratio in China did not reflect the consumption habits of the poor in the country.

[3] Kumon (2022) argues that subsistence baskets could be arbitrary.

[4] For instance, assume prices in cities A and B are the same and salaries in A are twice as much as in B. Since people in city A have higher incomes than those in B, it is likely that people in A consumed more expensive items than those in B. If the cost of the typical diet in A is twice as much as in B, then the welfare ratio in A will be the same as in B, even though real incomes are higher in city A.

[5] For instance, assume the salaries are the same in A and B, the price of a kilogram of bread is one dollar in A and two dollars in B and the price of a kilogram of beans is two dollars in A and one dollar in B. In addition, assume people only consume bread in A and only consume beans in B. If the subsistence basket of both cities is equal the typical diet of A, the welfare ratio will be higher in A than in B. However, if the subsistence basket in both cities is equal to the typical diet in B, the welfare ratio will be higher in B.

[6] However, the lowest-cost basket does not change in response to changing consumption habits, unless habits respond to relative prices.

https://doi.org/10.1017/S0212610924000107 Published online by Cambridge University Press

Several studies have relied on linear programming to estimate welfare ratios. Allen (2017) used linear programming to determine poverty lines in the 21st century. Later, other studies used linear programming to determine food baskets and welfare ratios prior to 1900 in London and other European cities (Allen, 2020; Zegarra, 2022).[7] However, there are still many countries for which no linear programming model has been estimated to find the lowest-cost basket and calculate welfare ratios. For instance, no study has used a linear programming model for Spain.

Three studies have estimated welfare ratios for pre-1800 Spain (Allen, 2001; Allen *et al.*, 2012; López and Piquero, 2021). According to Allen (2001), the respectability welfare ratio in Spain in the 1600-1800 period was around the same as in France, Germany and Italy, but below that of Northern Europe. Allen's estimations suggest that the divergence in welfare ratios between Northern Europe and Spain started in the 16th century.[8] Later, Allen *et al.* (2012) estimated subsistence welfare ratios for several countries, including Spain, using a cheaper food basket.[9] An important finding of this study is that Toledo and Valencia had lower ratios than London in the period 1525-1800. More recently, López and Piquero (2021) found new welfare ratios for Spain. According to their estimates, Madrid had similar welfare ratios to Northern Europe in the 17th century. Over time, however, the welfare ratio in Spain declined. Unlike the estimates of Allen and Allen *et al.*, those of López and Piquero suggest that the divergence in welfare ratios between Northern Europe and Spain only started in the 18th century.

The three studies used historical consumption habits to estimate welfare ratios. By relying on historical diets, the resulting welfare ratios measure the capacity of families to cover their consumption habits. However, these ratios do not necessarily measure the capacity of families to cover their basic needs; it is possible that there were alternative food baskets that provided nutrients at a lower cost and were available for people at the time. In order to determine the basket that provided the necessary nutrients at the lowest possible cost, it is possible to use linear programming.

In this article, I use a linear programming model to determine the lowest-cost food baskets and estimate welfare ratios in Toledo and Barcelona between 1600 and 1800. Some restrictions on the intake of several nutrients were imposed as part of the model. Food baskets were allowed to vary across cities and change over time. The cost of fuel, clothing, housing and other basic products was also added to estimate the total living cost. The welfare ratios were then calculated as the ratio between family income and the total living cost.

I used primary and secondary sources. Much of the information on prices and wages in Toledo and Barcelona comes from Hamilton (1934, 1947), the records of the Faithful Executors (*Juzgado de Ejecutores*) of Toledo and Feliu (1991). I complemented these sources with other sources.[10] In addition, I obtained information about the chemical composition of foods from McCance and Widdowson (1946) and Paul and Southgate (1978) and nutritional requirements from FAO (1985) and Rao (2009).

According to my estimates, the welfare ratio in Toledo was usually above the ratio in Barcelona. In particular, the welfare ratio of a family of four members (two adults and two children) in Toledo was above 1.0 between 1600 and 1750, but below 1.0 in the period from

[7] In addition, I used linear programming to determine welfare ratios in Lima, Peru, in the 19th and 20th centuries (Zegarra, 2011, 2020, 2021).

[8] Allen (2001) calculated the welfare ratio using a basket that was later identified as a respectability basket by the same author (Allen, 2009).

[9] Allen (2009) assumed cheaper baskets than Allen (2001), which were later used by Allen *et al.* (2012). Allen *et al.* (2012) report welfare ratios in Madrid. All pre-1800 prices and wages, however, were obtained from Hamilton (1934, 1947) and thus correspond to Toledo.

[10] The appendix describes the data sources.

1750 to 1800, whereas in Barcelona the ratio ranged between 0.75 and 1.2 between 1600 and 1800. Families faced more difficulties to cover their basic expenses in Barcelona than in Toledo until the late 18th century. The estimates of this study differ from other studies. The welfare ratios in Spain estimated in this study are higher than the ratios of Allen (2001), far lower than those of Allen *et al.* (2012), and slightly lower than those of López and Piquero (2021). On the other hand, the estimations suggest that Spain had lower welfare ratios than Northern Europe between 1600 and 1800, especially after 1625. This study supports some of the findings of Allen (2001) and Allen *et al.* (2012), in particular the idea that Spain had lower welfare ratios than Northern Europe before the Industrial Revolution; however, the differences in welfare ratios between Northern Europe and Spain in the early 17th century were not as large as those found by those two studies. In addition, this study contradicts the argument of López and Piquero, who stated that the divergence between Spain and Northern Europe only started in the 18th century.

This article contributes to the literature on living standards in Spain. The main contribution is methodological; I use a different methodology to estimate welfare ratios compared to previous studies for Spain. Whereas previous studies estimated the capacity of families to cover their consumption habits, I estimated the capacity of families to cover their basic needs. In addition, the article contributes to the literature by showing that there were important differences in welfare ratios within Spain through the period of analysis, as well as between Northern Europe and Spain.

2. The literature

Two decades ago, Allen (2001) estimated welfare ratios for a large number of European cities. Allen relied on a food basket composed of bread, legumes, meat, eggs, butter, cheese and beer or wine. He did not consider this basket to be a subsistence basket. In fact, Allen (2009) indicated that this basket was a respectability one. In addition to the food basket, Allen (2001) also included fuel, linen, lamp oil, candles and soap in the subsistence basket. The cost of subsistence of a family was calculated as three times the cost of subsistence of an adult man. In addition, housing costs were assumed to represent 5 per cent of other costs.

According to Allen (2001), the respectability welfare ratios in Toledo and Valencia were usually below 1.0 in the 1600-1800 period (Table 1). The welfare ratios in Northern Europe were above those in the rest of Europe, including Spain. London had higher ratios than Toledo, Valencia, Paris, Leipzig, Vienna and other European cities. In the 16th century, welfare ratios in Northern Europe were already higher than in Spain. The differences in welfare ratios increased over time.

Later, Allen (2009) adjusted the food basket, making it cheaper. He replaced bread with cheaper cereals, eliminated eggs, cheese and beer (or wine) and reduced the quantity of legumes and meat in order to reflect the diets of the very poor. The basket provided around 1,940 kcal/day of calories for an adult man. Allen (2009) did not compute welfare ratios for Spain. However, Allen *et al.* (2012) used the same assumptions to estimate welfare ratios in Spain.

Allen *et al.* estimated welfare ratios for Toledo and Valencia, as well as for London and some cities in the Americas. The welfare ratios in Toledo and Valencia were lower than the ratios in London between 1525 and 1800. Therefore, Allen *et al.* (2012) reached a similar conclusion to Allen (2001): Spain had lower welfare ratios than London from the 16th century, long before the Industrial Revolution.

López and Piquero (2021) used a different basket to estimate welfare ratios in Madrid and Valencia. For both cities, the new food basket was composed of wheat bread, meat and

https://doi.org/10.1017/S0212610924000107 Published online by Cambridge University Press

Table 1. Welfare ratios in Europe

	Welfare ratios						Welfare ratio in New Castile with respect to:				Welfare ratio in Valencia with respect to:			
	NC	Val	Lnd	Ams	Par	Lpz	Lnd	Ams	Par	Lpz	Lnd	Ams	Par	Lpz
Allen (2001)														
1600–1650	0,71	0,84	1,10	1,27	0,81	0,58	0,64	0,56	0,87	1,21	0,76	0,66	1,04	1,45
1651–1700		0,72	1,32	1,36	0,84	0,76					0,55	0,53	0,87	0,95
1701–1750	0,82	0,71	1,51	1,48	0,76	0,72	0,54	0,55	1,07	1,14	0,47	0,48	0,93	0,99
1751–1800	0,61	0,56	1,34	1,34	0,70	0,61	0,45	0,46	0,87	1,00	0,42	0,42	0,80	0,93
Allen (2009), Allen *et al.* (2012)														
1600–1650	1,71	1,70	2,83	3,84	2,19	1,62	0,60	0,45	0,78	1,05	0,60	0,44	0,78	1,05
1651–1700	1,65	1,87	3,49	4,33	2,16	2,82	0,47	0,38	0,77	0,59	0,54	0,43	0,87	0,66
1701–1750	1,39	1,82	4,16	4,20	1,94	1,82	0,33	0,33	0,72	0,76	0,44	0,43	0,94	1,00
1751–1800	0,99	1,35	3,51	3,77	1,64	1,56	0,28	0,26	0,60	0,64	0,38	0,36	0,82	0,87
López and Piquero (2021)														
1600–1650	1,39	0,99	1,17	1,48			1,19	0,94			0,85	0,67		
1651–1700	1,32	1,20	1,39	1,49			0,95	0,88			0,87	0,81		
1701–1750	1,32	1,00	1,71	1,65			0,77	0,80			0,58	0,61		
1751–1800	0,83	0,75	1,49	1,50			0,55	0,55			0,50	0,50		

NC, New Castile; Val, Valencia; Lnd, London; Ams, Amsterdam; Par, Paris; Lpz, Leipzig.
Previous studies.
Notes: The table reports the welfare ratios of Allen (2001), Allen (2009), Allen *et al.* (2012) and López and Piquero (2021) for New Castile and Valencia. In the case of New Castile, the figures refer to Toledo (Allen, 2001; Allen *et al.*, 2012) or Madrid (López and Piquero, 2021). Allen (2009) and Allen *et al.* (2012) used the same method (including the composition of the food basket) to compute welfare ratios. The table also reports the relative ratios of welfare ratios of New Castile and Valencia with respect to other European cities. These relative welfare ratios are calculated as the welfare ratio of one city divided by the welfare ratio of another city. The welfare ratios of Allen (2001) were obtained from https://gpih.ucdavis.edu/Datafilelist.htm. The welfare ratios of López and Piquero (2021) were obtained from https://addi.ehu.es/handle/10810/40426?show=full. The original ratios of Allen *et al.* (2012) for Toledo, Valencia, London and Amsterdam are reported in the appendix of the study; I estimated the ratios in Paris and Leipzig using the same prices and wages as Allen (2001).

olive oil. The basket also included legumes in Madrid and rice in Valencia. In addition, the basket provided 2,100 kcal/day of calories for an average person (not for an adult man) and the subsistence cost of a family was calculated as four times the subsistence cost of an average person.

The welfare ratios of López and Piquero were higher than the estimates of Allen (2001) and lower than the ratios of Allen *et al.* (2012).[11] In addition, López and Piquero reached a different conclusion about the divergence of welfare ratios between Northern Europe and Spain compared with previous studies. According to López and Piquero, the differences in welfare ratios between Northern Europe and Spain were not as large as previously shown. In fact, the welfare ratio in Madrid was similar to the ratios in London and Amsterdam until 1700. The welfare ratios in Northern Europe only differed from the ratio in Madrid from the early 18th century.

Allen (2001), Allen *et al.* (2012) and López and Piquero (2021) have made important contributions to the study of living standards in Spain. However, some of the assumptions in their studies are questionable. Consider the assumptions regarding the provision of calories. The food baskets of Allen (2001) and Allen *et al.* (2012) provided around 1,940 kcal of calories per day. As Humphries (2013) pointed out, people needed more than 1,940 kcal/day of calories to survive. In response to criticisms, Allen (2014, 2015) modified the food basket for the United States and England, including a higher quantity of cereals, thus providing around 2,100 kcal/day for an average person. Spanish men certainly needed far more calories than 1,940 kcal/day for subsistence. Since Spanish men weighed around 60 kg prior to 1900, an adult man of 18-30 years of age would have needed 3,450 kcal per day if he did heavy work (FAO, 1985).[12] On the other hand, López and Piquero (2021) used a basket of 2,100 kcal/day for an average person. I argue that 2,100 kcal/day were also not enough for subsistence; according to my calculations, an average person in modern Spain required at least 2,384 kcal/day.[13]

For their estimations of welfare ratios in Spain, Allen (2001), Allen *et al.* (2012) and López and Piquero (2021) used food baskets that provided certain amounts of calories and proteins. Calories and proteins are important for subsistence. People, however, require a variety of nutrients for a healthy life. People also require minerals, vitamins and fat. The lack of minerals and vitamins may lead to a variety of serious diseases (FAO, 2004).[14] Based on other studies, I assume that a balanced nutrition required fat, iron, thiamine, niacin, vitamin B12, folate and vitamin C, besides calories and proteins (Allen, 2017, 2020; Zegarra, 2020, 2021, 2022).

According to my calculations, the baskets of Allen (2001), Allen *et al.* (2012) and López and Piquero (2021) did not provide enough quantities of some nutrients. For instance, they did not provide vitamin C. In addition, the baskets of López and Piquero (2021) provided 0.1-0.2 μg/day of vitamin B12, far less than the requirement for an average person.

[11] The differences between López and Piquero (2021) and Allen (2001) are not surprising as López and Piquero estimated subsistence ratios, whereas Allen estimated respectability ratios.

[12] The height of an average male adult in Spain was around 1.63 m in the late 18th century (Dobado-Gonzalez and Garcia-Montero, 2014). For a height of 1.63 m, a weight of 60 kg implies a BMI of 20.7, which shows regular values.

[13] I calculated the requirements of nutrients for an average person using the distribution of population by age in Spain and the requirements of nutrients for different age categories. See the appendix for a further description of the method.

[14] For instance, the lack of iron may cause anaemia. The evidence shows that iron deficiency reduces physical working capacity (FAO, 2004). The lack of vitamin B12 may lead to «demyelination of the peripheral nerves and the spinal column, giving rise to the clinical condition called subacute combined degeneration» (FAO, 2004, p. 282). The lack of folate may contribute to neural tube defects, cardiovascular disease and colorectal cancer and the lack of vitamin C and niacin may lead to the diseases of scurvy and pellagra, respectively (FAO, 2004).

Other studies have estimated welfare ratios for a number of cities in the past assuming that people needed calories, proteins, vitamins and minerals (Allen, 2020; Zegarra, 2020, 2021, 2022), but no study has made this assumption for Spain.

It is possible to achieve a greater intake of important nutrients by increasing the consumption of certain items. For instance, increasing the consumption of meat would increase the intake of vitamin B12. Increasing the consumption of vegetables would allow people to meet their requirements of vitamin C. However, it is still not clear which items should be included in the food basket. All foods provide calories; most foods provide proteins and several provide vitamins and minerals. Thus, should bread or legumes be included in the food basket? Should beef, mutton, codfish or other animal-derived foods be included as a source of vitamin B12?

Another important issue for the calculation of welfare ratios refers to the use of historical consumption habits. Allen (2001), Allen *et al.* (2012) and López and Piquero (2021) used information about historical diets to make assumptions about the food basket. Historical diets contain valuable information for the study of nutrition. However, it is important to be aware of potential problems when estimating the food cost based on historical diets.

Consider, for example, the variety of diets across the population (even within groups with similar incomes) and, especially, across cities. Different cities had different diets due to climatic and cultural differences. Consequently, some studies have assumed different food baskets for different cities.[15] Although it is reasonable to consider different baskets for different cities, it is not clear whether those baskets should be used to compute comparable welfare ratios. Those baskets may provide similar calories, but do they provide similar quantities of other nutrients, such as vitamins and minerals? Should the researcher use those baskets to calculate welfare ratios if the quantities of vitamins and minerals are not the same?[16]

On the other hand, it is important to be careful when using historical diets, if the differences in diets across countries respond to income, and not only to availability or relative prices. If the differences in food baskets across cities reflect differences in income (and not only differences in relative prices), it might be argued that the differences in welfare ratios do not really reflect differences in the capacity to cover basic needs. Meanwhile, if diets are different across cities because of relative prices, using the same basket for all cities may not be appropriate to compute comparable welfare ratios.

In general, the selection of the food basket should depend on what we intend to measure. If the intention is to measure the capacity of families to cover their actual diets, it is useful to reconstruct historical diets. However, if the intention is to measure the capacity of families to cover their nutritional needs (in addition to other basic needs), and to make cross-sectional and over-time comparisons of welfare ratios, the computation of welfare ratios should not rely on historical diets. It is preferable to find the basket that allowed people to cover their basic needs at the lowest possible cost. By doing so, it will be possible to determine whether low-income families earned enough to satisfy their basic needs.

[15] Allen (2001), Allen *et al.* (2012) and López and Piquero (2021), for instance, used different cereals for different cities. López and Piquero assumed that the food basket in Amsterdam included rye bread, whereas the basket in Spain included brown bread. Other studies for Italy, the Habsburg Empire and Russia have also assumed different food baskets due to differences in common diets (Cvrcek, 2013; Malamina, 2013; Allen and Khaustova, 2019).

[16] In addition, within the same city and within the same economic group, there could also be differences in habits. Diets probably also varied over time in response to changes in relative prices and tastes. If the intention is to measure the capacity of families to afford their changing consumption habits, using the same basket for several decades will not be appropriate.

https://doi.org/10.1017/S0212610924000107 Published online by Cambridge University Press

3. Methodology

In this study, the welfare ratio measures the capacity of families to cover their basic needs, which are not necessarily the same as consumption habits. In order to obtain a reliable estimate of this capacity, it is necessary to pay attention to the alternative ways of satisfying those basic needs and choose the most efficient one. People require a variety of nutrients and there are different combinations of foods to obtain those nutrients.

I use linear programming to find the lowest-cost basket in Toledo and Barcelona. In order to find the optimal basket, it is important to determine the nutritional requirements. Calories and proteins are important for subsistence, but a healthy life requires much more than only calories and proteins; people also require fat, iron and vitamins. Nutritional requirements depend on age, height, weight and on the type of occupation. I relied on FAO (1985) to obtain the calorie requirements. I assumed adult men and women weighed 60 and 50 kg, respectively. In the basic model, I assumed a daily energy requirement of 2.2 BMR for men and 1.8 BMR for women, considering heavy work for men and moderate work for women. Following Allen (2017), I considered Indian dietary requirements of proteins, fat, iron and vitamins (Rao, 2009). These requirements were calculated assuming a weight of 60 kg for men, so they may be very similar to the nutritional needs of people in modern Spain.[17]

According to my calculations, an average adult man of 18-55 years old in modern Spain needed at least 3,428 kcal of calories and 60 g of proteins per day for subsistence.[18] In addition, for a balanced nutrition, an adult man also required at least 40 g of fat, 17 mg of iron, 1.7 mg of thiamine, 21 mg NE of niacin, 1.0 µg of vitamin B12, 200 µg of folate and 40 mg of vitamin C per day.

I assumed people could purchase the following foodstuffs: wheat bread, barley bread,[19] rice, dried beans, mutton, hens, dried codfish, eggs, sugar, honey, olive oil and wine. I considered these foodstuffs, because they are the only ones for which price information for both Toledo and Barcelona is available.

People obtained some foods from the market. Some foods could have been obtained through other means. The evidence suggests that some workers in modern Spain received an in-kind compensation besides their salaries (Drelichman and Gonzalez-Agudo, 2020). Some families could also obtain foods, especially vegetables and fruits, from the garden.[20]

[17] I assume that people should ingest at least the recommended dietary allowanced (RDA) of nutrients from Rao (2009). Gazeley and Horrell (2013), however, argue that ingesting less than the RDA does not necessarily mean deficiency. To determine deficiency, the minimum requirement could be set at 50% of the RDA.

[18] I calculated the requirements of nutrients for an average adult man using the distribution of population by age in Spain in 1787 and the nutritional requirements for different ages.

[19] The evidence suggests that the very poor in Spain consumed barley bread (Ministerio de Fomento, 1861; Riera, 1994). However, barley bread prices were not available. I estimated these prices using the prices of barley, the wages of skilled workers and the equation for bread prices from Allen (2001). As with any price, the price of barley bread may have reflected the cost of production, including the cost of barley and the cost of milling and baking, as well as profit margins. Since the prices of barley bread were not available, it might be argued that the product was not sold in the market. If barley bread was not sold in the market, families could purchase barley, mill the grain and bake it. In this case, the estimated price of barley bread would be a proxy of all costs associated to obtaining barley bread, including the price of barley and the costs of processing it. In the appendix, I consider the case in which families purchased barley to make barley pearl at home. In this case, I include barley in the linear programming model, instead of barley bread. The new welfare ratios are practically the same as in the basic model. In the appendix, I also consider the case in which people did not consume barley bread or barley. The results show that the welfare ratios remain practically the same.

[20] Garden provision of foods was possible. For instance, the evidence for La Mancha, in Southern Castile, suggests that some women in the mid-18th century worked in the family orchards and that most women worked in the fields during harvest (Sarasúa, 2019).

https://doi.org/10.1017/S0212610924000107 Published online by Cambridge University Press

It is possible to consider the in-kind compensation or garden provision of foods in the model, reducing the quantity of nutrients that a person would need to obtain from food markets.

None of the foods included in the linear programming model provided vitamin C.[21] If it is assumed that people obtained foods only from the market, the model would have no solution. Recently, Allen (2020) assumed that people obtained vitamin C at no pecuniary cost. For the linear programming model, I assumed that families in Toledo and Barcelona obtained vegetables as an in-kind compensation (besides their pecuniary wages) or from the garden in sufficient quantities to cover their needs of vitamin C at no pecuniary cost.[22] In particular, I assumed that an average adult man obtained 271 g/day of fresh vegetables at no pecuniary cost, composed of 136 g/day of onions, 45 g/day of garlic, 45 g/day of lettuce and 45 g/day of cabbage.[23] These vegetables provided not only vitamin C, but also other nutrients (except vitamin B12). Their provision of calories, however, only represented 2 per cent of the minimum requirement for an adult man.[24]

I relied on secondary sources to obtain the chemical composition of foodstuffs.[25] It is important to distinguish between the purchased quantity of an item and the consumed quantity. For instance, people purchased meat with bones, but discarded the bones. In the model, I included the price of a purchased kilogram and the intake of nutrients per purchased kilogram. If a portion of the food was not edible, the content of nutrients per purchased kilogram was lower than the content of nutrients per edible kilogram.

In this study, I estimated two types of food baskets: the calorie-protein basket (CP basket) and the balanced-nutrition basket (BN basket). For the CP basket, I only imposed restrictions on calories and proteins, not on other nutrients. If it is assumed that calories and proteins guarantee subsistence and that other nutrients are not necessary, the CP basket would be a subsistence basket. This basket, however, does not necessarily guarantee a balanced nutrition. Fat, minerals and vitamins are also important for a healthy life, so I estimated the BN basket including them.[26] For this basket, I imposed the same restrictions on calories and proteins as the CP basket, and added restrictions on fat, iron, thiamine, niacin, vitamin B12, folate and vitamin C.

Linear programming is useful to determine the quantities of foodstuffs that a person should purchase in order to satisfy their nutritional needs at the lowest possible cost. However, linear programming is not exempt from criticism. In particular, it is possible to argue that the lowest-cost basket does not necessarily reflect consumption habits. In addition, families did not have access to complete information about nutritional

[21] Price information about foods that provided vitamin C was available for Toledo, but not for Barcelona. The appendix reports the estimates for Toledo when including extra foods that provided vitamin C.

[22] Similarly, in another study, I assumed that families in other European cities obtained vegetables from the garden at no cost (Zegarra, 2022). Assuming that vegetables were obtained at no cost has an impact on welfare ratios (see the appendix).

[23] The evidence suggests that onions were an important part of the diets in New Castile and Catalonia. Garlic, lettuce and cabbages, among other vegetables, were also part of their diets. Palacio (1998, p. 48), for example, indicated that onions were popular in the diets of people in Madrid in the 18th century, but that other vegetables were also consumed, such as asparagus, garlic, cabbages, lettuces, chards, celery and peppers. Meanwhile, Bages-Querol (2019) indicates that onions and garlic were largely consumed in Catalonia in the 18th century, besides tomatoes, pumpkins, lettuce, artichokes and cabbages, among others.

[24] In 1922, the average yield of these products was more than 3,000 kg/acre (U.S. Secretary of Agriculture, 1952). In the period 1600-1800, yields were lower. Assuming an average yield of only 3,000 kg/acre for vegetables, a total output of 271 g/day of onions, garlic, lettuce and cabbage was possible with 0.03 acres.

[25] The appendix describes the method and sources to obtain the content of nutrients per purchased kilogram.

[26] In previous studies, I used the term «balanced-nutrition» basket or BN basket (Zegarra, 2021, 2022).

https://doi.org/10.1017/S0212610924000107 Published online by Cambridge University Press

requirements and the chemical composition of foodstuffs. Furthermore, they did not use a mathematical tool to select their diets.[27]

These criticisms do not invalidate linear programming as a methodology to estimate welfare ratios. I do not use linear programming to determine the actual consumption habits in the past. Rather I use the method to find the combination of foods people needed to consume to satisfy their needs at the minimum possible cost. As such, the corresponding welfare ratios do not measure whether people earned more than enough to pay for their consumption habits, but rather whether they earned enough to cover their basic needs.

4. Food baskets

I relied on a linear programming model to estimate the composition of the food basket in Toledo and Barcelona for the 1600-1800 period. Food baskets were allowed to vary over time. In particular, I estimated food baskets for each decade. I assumed p_j was equal to the average prices for each decade.[28] I estimated two baskets for an adult man, the calorie-protein basket (CP basket) and the «balanced-nutrition basket» (BN basket).

4.1. Calorie-protein basket (CP basket)

The CP basket guarantees a minimum provision of calories and proteins. Table 2 shows the optimal CP baskets of an adult man. The basket in Toledo is only composed of cereals. The large participation of cereals, in particular wheat bread and barley bread, is consistent with the differences in the cost of calories and proteins. On average, in the 1600–1800 period, the two types of bread were relatively cheap sources of calories and proteins.[29] Beans provided proteins at a low cost, but also provided calories at a higher cost compared to wheat bread and barley bread. The composition of the food basket changed over time. For instance, barley bread increased in importance, due to the decline in its relative price with respect to wheat bread.

The CP basket for Barcelona is composed of cereals, beans and olive oil. It has some important differences compared to that of Toledo. In particular, the Barcelona basket includes beans and olive oil, unlike that of Toledo. These differences in the composition of the food basket can be explained by relative prices: beans and olive oil were relatively cheaper in Barcelona than in Toledo.

4.2. Balanced nutrition basket (BN basket)

Table 2 also shows the balanced-nutrition baskets of an average adult man in Toledo and Barcelona. The basket is largely composed of cereals, but also includes animal-derived foods and olive oil. Cereals are an important component of the food basket in Toledo and Barcelona. Animal-based foods are also included in the food basket, though in far smaller quantities than cereals. In Barcelona, beans are also part of the food basket. The basket satisfies all restrictions and the binding constraints are those for calories, vitamin B12 and vitamin C.

Wheat bread and barley bread have a large participation in the BN food basket in Toledo and Barcelona. This result is not surprising as these two items were relatively

[27] Although families did not use a mathematical tool to select their diet, relative prices probably influence consumption habits, especially those of low-income families. On the other hand, there are only a few long series of historical prices (Calderon *et al.*, 2017). It could be argued that the limited information on prices does not allow us to find the true lowest-cost basket.

[28] See the appendix for a description of the data sources.

[29] Table A.3 in the appendix reports the cost of nutrients.

Table 2. Comparison between the CP and BN baskets and other studies' baskets

		CP basket		BN basket		Allen (2001)	Allen *et al.* (2012)	López and Piquero (2021)	
		Toledo	Barcelona	Toledo	Barcelona	Toledo and Valencia	Toledo and Valencia	Madrid	Valencia
Wheat bread	kg	351,0	70,2	374,1	163,8	182,0	0,0	271,0	271,0
Barley bread	kg	110,4	348,5	62,2	225,3	0,0	0,0	0,0	0,0
Oats	kg	a/	a/	a/	a/	0,0	155,0 b/	0,0	0,0
Rice	kg	0,0	0,0	0,0	0,0	0,0	0,0	0,0	19,5
Beans	kg	0,0	4,7	0,0	17,5	0,0	0,0	0,0	0,0
Chickpeas	kg	a/	a/	a/	a/	52,0	20,0	19,0	0,0
Beef	kg	a/	a/	a/	a/	0,0	0,0	5,0	0,0
Mutton	kg	0,0	0,0	21,7	9,7	26,0	5,0	0,0	5,0
Hens	kg	0,0	0,0	0,0	0,0	0,0	5,0	0,0	0,0
Codfish	kg	0,0	0,0	0,0	3,8	0,0	0,0	0,0	0,0
Eggs	kg	0,0	0,0	0,0	4,9	2,9	0,0	0,0	0,0
Cheese	kg	a/	a/	a/	a/	5,2	0,0	0,0	0,0
Butter	kg	a/	a/	a/	a/	0,0	0,0	0,0	0,0
Sugar	kg	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Honey	kg	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Olive oil	kg	0,0	5,3	1,6	8,8	5,2	3,0	2,7	2,7
Wine	kg	0,0	0,0	0,0	0,0	68,3	0,0	0,0	0,0

(*Continued*)

Table 2. (*Continued.*)

		CP basket		BN basket		Allen (2001)		Allen *et al.* (2012)		López and Piquero (2021)			
		Toledo	Barcelona	Toledo	Barcelona	Toledo and Valencia		Toledo and Valencia		Madrid		Valencia	
Nutrients (as % of the minimum requirement)													
Calories	kcal	100,0	100,0	100,0	100,0	66,5	68,6	40,2	42,4	92,0	95,2	93,6	96,8
Proteins	g	150,2	131,0	156,4	150,4	130,6	139,0	76,5	85,0	131,6	141,9	115,5	125,8
Fat	g	52,4	77,7	100,0	124,0	136,0	136,9	95,7	96,5	78,4	79,4	75,9	77,0
Iron	mg	153,0	70,3	161,9	113,6	132,2	141,1	84,0	92,8	108,8	116,8	95,0	102,9
Thiamine	mg	194,3	90,0	202,1	131,9	126,0	133,3	92,4	99,7	208,2	218,7	195,2	205,7
Niacin	mg NE	219,7	126,6	230,0	156,7	123,9	126,5	20,0	22,6	210,6	214,2	209,5	213,1
Vitamin B12	µg	0,0	0,0	100,0	100,0	163,3	163,3	23,0	23,0	19,3	19,3	32,4	32,4
Folate	µg	148,2	113,6	151,1	201,8	345,5	374,8	190,6	219,9	205,3	237,5	99,4	131,6
Vitamin C	mg	100,0	100,0	100,0	100,0	0,0	100,0	0,0	100,0	0,0	96,9	0,0	96,9

Notes: The table reports the average composition of the CP and BN baskets and the baskets from Allen (2001, 2009) and López and Piquero (2021). The CP and BN baskets and those of Allen (2001) and Allen *et al.* (2012) refer to an adult man. López and Piquero's (2021) baskets refer to an average person. For some foodstuffs, the original quantities in Allen (2001) are in litres or in units; I converted those figures to kilograms. The table also reports the quantity of nutrients as a percentage of their minimum requirements. For CP and BN baskets and those of Allen (2001) and Allen *et al.* (2012), the minimum requirements refer to an average man. For López and Piquero (2021), to the average person. For Allen (2001, 2009) and López and Piquero (2021), I report two figures on the intake of nutrients as % of the minimum requirements. The first column assumes the person only consumed foodstuffs from the market; the second column assumes the person consumed foodstuffs from the market and from the garden (the same quantities as in the basic model in this study). a/ This item was not included in the linear programming model. b/ Allen *et al.* (2012) does not indicate the exact amount of cereals in the basket of Spain. They mention that the quantity of cereals was chosen to provide the same number of calories as 155 kg of oats. According to my estimates, the basket should then include 188 kg of wheat.

cheap sources of calories, proteins, fat, iron, thiamine, niacin and folate. Beans were also a relatively cheap source of nutrients in Barcelona. Not surprisingly, beans are included in the food basket of Barcelona. On the other hand, animal-derived foods (for instance, mutton) are included in the basket because they provided vitamin B12.

The composition of the food basket changed over time. Barley bread increased in importance, whereas wheat bread became less important. These changes in the food basket can be explained by the evolution of relative prices. Barley bread became relatively cheaper over time with respect to wheat bread. On the other hand, there were changes among animal-derived foods. In particular, in Barcelona mutton and codfish declined in importance compared to eggs.

4.3. Comparison with other food baskets

Allen (2001), Allen *et al.* (2012) and López and Piquero (2021) made assumptions about the food baskets in order to estimate welfare ratios in Spain.[30] How do the CP and BN baskets in Toledo and Barcelona compare to the baskets of those studies?

Table 2 shows all food baskets.[31] There are some important similarities between the CP and BN baskets and the baskets of the three previous studies on Spain. One of the similarities is the inclusion of cereals. Cereals represented an important portion of all food baskets. There are also similarities in the exclusion of some items. As with the baskets of the three previous studies, the CP and BN baskets did not include hens, sugar and honey.

However, there are also important differences in the composition of the food basket. One difference refers to the inclusion of barley bread. This item had an important participation in the CP and BN baskets. In contrast, Allen (2001), Allen *et al.* (2012) and López and Piquero (2021) did not include barley bread or barley. The second difference refers to animal-derived foods. In several decades, the BN basket included mutton; however, in some decades the BN basket in Barcelona also included codfish and eggs. In contrast, the three previous studies on Spain did not include fish or eggs. The third difference refers to the inclusion of legumes (beans or chickpeas). The BN basket in Toledo never included legumes. In contrast, the three previous studies included legumes in the food baskets of New Castile (Toledo or Madrid). The fourth difference refers to the evolution of the food basket. The CP and BN baskets were allowed to change over time. In contrast, the baskets in the three previous studies were assumed constant in spite of the changes in relative prices.

There are also differences in the provision of nutrients. By assumption, the BN basket provided more nutrients than the baskets of Allen (2001), Allen *et al.* (2012) and López and Piquero (2021). The basket of Allen provided fewer calories than the BN basket. In addition, the basket of Allen *et al.* provided fewer calories, proteins, fat, iron, niacin and vitamin B12 than the BN basket,[32] whereas the basket of López and Piquero provided fewer calories, fat and vitamin B12 than the BN basket.[33] Thus, the baskets of these three studies

[30] Those studies estimated welfare ratios for Spain and other countries.

[31] I compare the CP and BN baskets to those of Allen (2001), Allen *et al.* (2012) and López and Piquero (2021). Notice, however, that the basket of Allen (2001) is a respectability basket.

[32] The deficiency of nutrients in historical diets is consistent with the presence of a number of illnesses among the poor. For instance, the evidence from cranial porosities in medieval and modern Europe suggests more nutritional deficiencies among low-income families (Papathanasiou *et al.*, 2019). The evidence also suggests high frequency of porotic hyperostosis and criba orbitalia in medieval times, which could be caused by iron deficiency, vitamin B12 deficiency, among other reasons.

[33] The basket of López and Piquero only provided 0.1 μg/day of vitamin B12 in Madrid and 0.2 μg/day in Valencia, far less than the requirement of 0.7 μg/day for an average person.

did not provide enough calories to support the daily energy requirements of a labourer who did heavy work nor other nutrients important for a balanced nutrition.

5. Welfare ratios

In order to estimate welfare ratios, most studies assumed that the living cost of a family was a multiple of the cost for an adult man or of the cost for an average person. In the 2000s, most studies assumed a subsistence basket for an adult man and estimated the cost of subsistence of a family of four members (two adults and two children) as three times the cost for an adult man (Allen, 2001, 2009). Meanwhile, other studies assumed that the cost of subsistence of a family of four members was equal to four times the cost for an average person (Allen, 2014, 2020; López and Piquero, 2021; Zegarra, 2022).

It is not appropriate to assume that the living cost of a family was three times the cost for an adult man. According to the calculations for Spain, the total requirement of calories for a family of two adults and two children was less than three times the requirement of an adult man who did hard work, whereas the requirements of iron and vitamin C were more than four times. On the other hand, assuming that the cost of living of a family was four times the cost for an average person is also questionable. Such a method would be valid for a family of four members as long as the average structure of the family reflected the distribution of the Spanish population.[34]

In this study, I followed a different approach to estimate the cost of living of a family. I first computed the total nutritional requirements for a family based on its structure and then used linear programming to estimate the lowest-cost basket. There were different types of family structures. This section shows the welfare ratio for an average family of four members, two adults and two children. The next section shows the welfare ratio for alternative family structures.

In order to find the lowest-cost basket for the family of four members, I assumed that the two adults ranged between 18 and 55 years old and that the two children were up to 15 years old. I used the distribution of the population in Spain in the late 18th century to calculate the average nutritional requirements for each family member. To obtain the requirements of calories, I assumed that the husband did hard work and that the wife did moderate work, so the daily energy requirements were 2.2 BMR for the husband and 1.8 BMR for the wife. The total daily nutritional requirements for the entire family were 9,207 kcal of calories, 181 g of proteins, 130 g of fat, 74 mg of iron, 4.5 mg of thiamine, 59 mg NE of niacin, 2.5 μg of vitamin B12, 682 μg of folate and 163 mg of vitamin C. I also assumed that the family obtained vegetables at no pecuniary cost.[35]

For the calculation of the total cost of living, I also considered fuel, linen, soap, candles, lamp oil and housing as basic needs. In particular, I assumed that on average a person required 2.0 M BTU of fuel, 3 m of cotton, 1.3 kg of candles, 1.3 kg of soap and 1.3 litres of lamp oil per year. In addition, following a standard assumption in the literature, I assumed that housing costs were equal to 5 per cent of the cost of other basic needs.

Figure 1 shows the daily living cost of a family in Toledo and Barcelona. The figure shows two series for each city. One series assumes that the cost of food was the cost of the CP basket. Another series assumes that the cost of food was the cost of the BN basket.

[34] In 18th-century Spain, around 25% of the population was composed of men of more than 24 years old, 25% were women over the age of 24 and around 50% were young children, adolescents and young adults (up to 24 years of age). Therefore, on average, the cost of living of a family of four members, including a man of more than 24 years of age, a woman over the age of 24 and two people younger than 24 (young children, adolescents or young adults) would be four times the cost of an average person.

[35] I assume that a family obtained vitamin C from a free provision of vegetables. I assume the same vegetables and the same proportions as in the previous section.

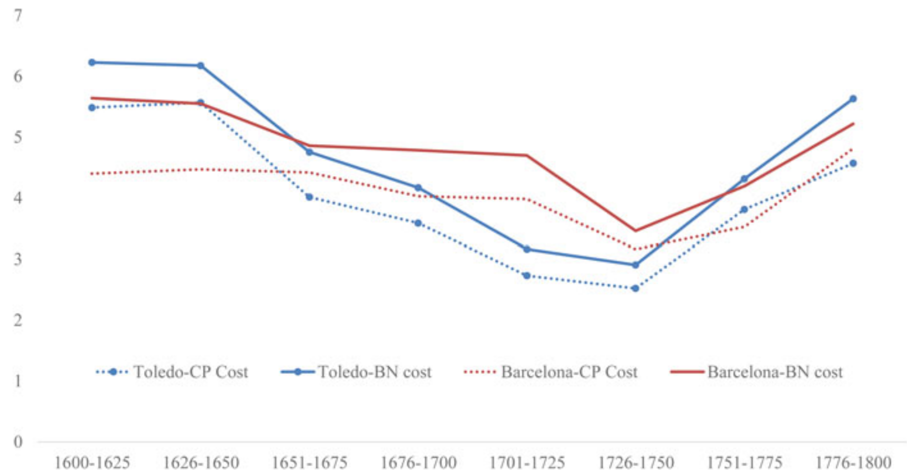

Figure 1. Cost of living in Spain, 1600–1800 (grams of silver/day).
Notes: The figure depicts the evolution of the daily living cost of a family in Toledo and Barcelona in the period 1600-1800 in grams of silver, including food and non-food expenses. CP cost is the living cost if the food cost was equal to the cost of the CP basket. BN cost is the living cost if the food cost was equal to the cost of the BN basket.

The living costs in Toledo and Barcelona followed a similar pattern, although the growth rates were different.

The data on salaries of low-skilled workers were retrieved from secondary sources, especially from Hamilton (1934, 1947) for Toledo and Feliu (1991) for Barcelona.[36] The information refers to payments to male labourers for a day of work. Following most of the literature, I assumed that only one male adult worked per family and that he did so for 250 days per year.[37]

Figure 2 shows the evolution of daily family income in grams of silver. I calculated the daily family income as the annual labour income divided by 365, assuming that labourers worked 250 days in a year. Family income in Toledo declined between 1600 and 1725 and remained relatively constant subsequently. In the case of Barcelona, family income increased in the mid-17th century, but then declined in the period 1676-1725. Income then increased in the second half of the 18th century.

I calculated two types of welfare ratios using the two types of food baskets. The two types of welfare ratios are labelled as CP welfare ratios and BN welfare ratios.[38] The CP welfare ratio measures the capacity of families to cover their most basic needs, including calories and proteins, but not necessarily other nutrients. Meanwhile, the BN welfare ratio measures the capacity of families to cover their basic needs, including having a balanced nutrition. If the CP ratio is less than 1.0, the family could not even afford subsistence. If the BN is greater than 1.0, the family could cover their basic needs, including a balanced

[36] The data sources are included in the appendix.

[37] Allen (2001, 2009), for instance, made the same assumptions. Stephenson (2018), however, questioned the assumption of 250 days of work per year for London. Other studies have also questioned this assumption: the time worked could have been fewer than 250 days (Humphries and Weisdorf, 2019; Gary and Olsson, 2020). In addition, Humphries and Weisdorf (2015) showed that women in England and Wales worked for a salary. Meanwhile, several studies showed that women in Spain worked for a salary in the 18th, 19th and early 20th centuries (Llopis and García, 2011; Borderias, 2012; Muñoz-Abeledo, 2012; Agua and Lopez, 2018; Sarasúa, 2019).

[38] For the calculation of the CP welfare ratio, I measure the cost of food as the cost of the CP basket. For the calculation of the BN welfare ratio, I measure the cost of food as the cost of the BN basket.

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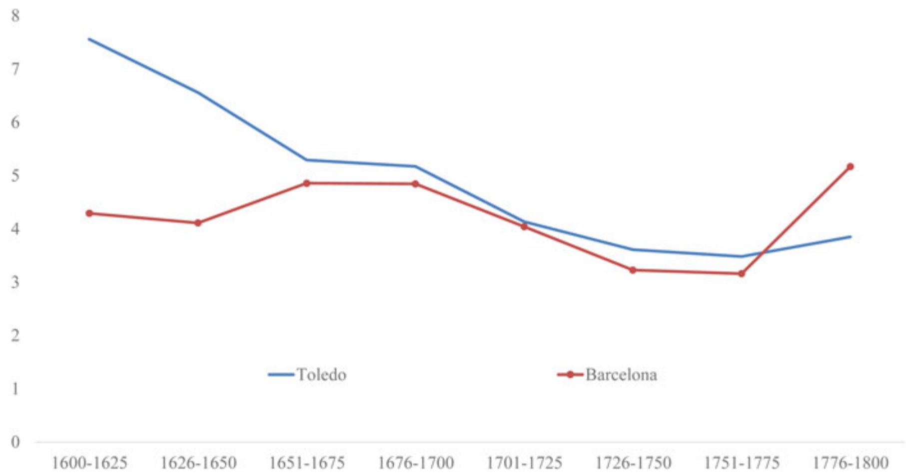

Figure 2. Family income in Spain, 1600–1800 (grams of silver/day).
Notes: The figure depicts the evolution of family income in Toledo and Barcelona in the period 1600-1800 in grams of silver per day. I assume male labourers were the only source of family income and that they worked 250 days per year. The daily family income was calculated as the wage of a day of work multiplied by 250/365.

nutrition. If the CP ratio is greater than 1.0 and the BN ratio is less than 1.0, a family could cover their needs of calories and proteins, but not the needs of other nutrients.

Figure 3 shows the evolution of the welfare ratios. As expected, the BN ratios were lower than the CP ratios. For each city, both welfare ratios followed a similar trend. In the case of Toledo, the CP welfare ratio declined from 1.4 between 1600 and 1625 to 1.2 in the period 1626-50, but then increased above 1.6 between 1701 and 1725. In the following decades, the ratio followed a downward trend. In the late 18th century, the ratio was 0.8. The BN ratio followed a similar trend, falling from almost 1.3 in the early 17th century to 1.1 between 1626 and 1650, increasing to 1.4 in the period 1701–25, and declining to 0.7 in the late 18th century. In the case of Barcelona, the two welfare ratios increased from 0.75–1.0 in the early 17th century to 1.0-1.2 in the period 1651–75, declined to 0.75–0.9 between 1751 and 1775, and increased to 0.9-1.1 in the late 18th century.

The CP and BN welfare ratios in Toledo were above 1.0 until the mid-18th century. Four-member families in the city were able to cover their basic needs, including a balanced nutrition. In the second half of the 18th century, however, both ratios were below 1.0. By then, four-member families were not able to satisfy their most basic needs. Meanwhile, the two ratios in Barcelona were below those of Toledo during most of the period. Compared to families in Toledo, families in Barcelona faced more difficulties to cover their basic needs.

How do my results compare with those from Allen (2001), Allen *et al.* (2012) and López and Piquero (2021)? Table 3 compares the CP and BN welfare ratios in Spain with those from the three previous studies. The CP and BN ratios in Spain are higher than the estimates of Allen (2001). For instance, the welfare ratio of Allen for Toledo was always below 1.0 for the period 1600–1800. In contrast, the CP and BN ratios in Toledo were above 1.0 between 1600 and 1750. The ratio of Allen for Valencia was around the same level as Toledo. In comparison, the CP and BN ratios in Barcelona were below those in Toledo. On the other hand, for New Castile and Barcelona/Valencia, the BN welfare ratios are far lower than the ratios of Allen *et al.* (2012) and slightly lower than those of López and Piquero (2021).

Compared with the three previous studies on Spain, I estimated the welfare ratios using a different methodology (linear programming vs. historical diets) and assuming different

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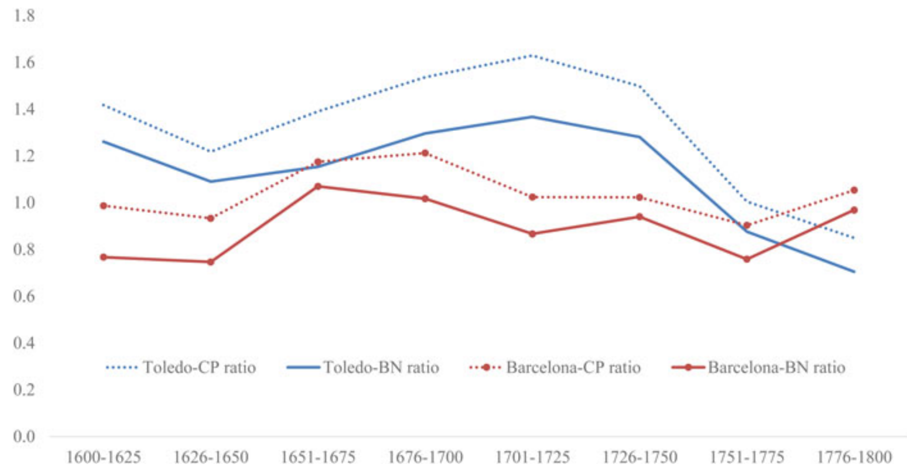

Figure 3. Welfare ratios in Spain, 1600–1800.
Notes: The figure depicts the evolution of welfare ratios in Toledo and Barcelona in the period 1600-1800. CP ratios are the welfare ratios under the assumption that the cost of food was equal to the cost of the CP basket. BN ratios are the welfare ratios under the assumption that the cost of food was equal to the cost of the BN basket.

nutritional requirements. The use of linear programming would produce a lower cost of subsistence than historical diets and so a higher welfare ratio. However, this study assumes a higher requirement of calories than the three previous studies on Spain. A higher calorie intake would produce a higher cost of subsistence and then a lower welfare ratio.

To determine the effect of linear programming on the results, I recalculated the welfare ratios of Allen (2001), Allen *et al.* (2012) and López and Piquero (2021) for Toledo and Madrid, maintaining the same proportions of foodstuffs as those studies, but using the same intake of calories as in this study. I also assumed that the cost of fuel, lamp oil, linen, soap and candles for a family was four times the cost for an average person.

The bottom section of Table 3 shows the results. Since the baskets of Allen (2001), Allen *et al.* (2012) and López and Piquero (2021) provided fewer calories than the minimum requirements, the cost of food of those studies increased after the adjustment.[39] The adjusted ratios are now lower than the CP ratios in all cases and all periods. The original welfare ratio of Allen (2001) was already lower than the CP ratio. After the adjustment, the ratio of Allen represented 60 per cent of the CP ratio.[40] The original ratio of Allen *et al.* (2012) was higher than the CP ratio in the 17th century and in the late 18th century. After the adjustment, however, the ratio of Allen *et al.* became 70-80 per cent of the CP ratio. Meanwhile, the original ratio of López and Piquero (2021) was slightly higher than the CP ratio. After the adjustment, however, the ratio became 80-90 per cent of

[39] For Toledo, I recalculated the ratios of Allen (2001) and Allen *et al.* (2012) using the same wages as in this study. For 1600-50 and 1701-50, the average wages used in this study are higher than those used by Allen (2001). Consequently, in this period the ratio of Allen (2001) increased after the adjustment, in spite of the increase in the food cost. For Madrid, I used the same prices and wages as López and Piquero (2021). Notice that Allen (2001) and Allen *et al.* (2012) used prices from Hamilton (1934, 1947), whereas I also recurred to other sources of information. I then re-estimated CP ratios of Toledo only using prices from Hamilton (1934, 1947) and compared them with the adjusted estimates from Allen (2001) and Allen *et al.* (2012). The results are very similar to those in the bottom section of Table 3.

[40] As mentioned previously, Allen (2001) did not assume a subsistence basket, but rather a respectability one. This basket was not intended to provide the cheapest method to grant subsistence.

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Table 3. Welfare ratios: a comparison

	1600–1650	1651–1700	1701–1750	1751–1800
A. Comparison of my estimates and the welfare ratios of previous studies				
CP ratios (my estimates)				
Toledo	1,32	1,46	1,56	0,93
Barcelona	0,96	1,19	1,02	0,98
BN ratios (my estimates)				
Toledo	1,18	1,22	1,32	0,79
Barcelona	0,76	1,04	0,90	0,86
Allen (2001)				
Toledo	0,71	1/	0,82	0,61
Valencia	0,84	0,72	0,71	0,56
Allen *et al.* (2012)				
Toledo	1,71	1,65	1,39	0,99
Valencia	1,70	1,87	1,82	1,35
López and Piquero (2021)				
Madrid	1,39	1,32	1,32	0,83
Valencia	0,99	1,20	1,00	0,75
B. Comparison of my CP estimates and the adjusted estimates from previous studies in Toledo and Madrid				
Comparison of CP ratios and the ratios of Allen (2001) for Toledo				
Original ratios of Allen (2001)	0,71	1/	0,82	0,61
With respect to the CP ratio	0,5		0,5	0,7
Adjusted ratios of Allen (2001)	0,86	0,85	0,90	0,56

With respect to the CP ratio	0,6	0,6	0,6	0,6
Comparison of CP ratios and the ratios of Allen *et al.* (2012) for Toledo				
Original ratios of Allen *et al.* (2012)	1,71	1,65	1,39	0,99
With respect to the CP ratio	1,3	1,1	0,9	1,1
Adjusted ratios of Allen *et al.* (2012)	1,03	1,09	1,14	0,64
With respect to the CP ratio	0,8	0,7	0,7	0,7
Comparison of CP ratios and the ratios of López and Piquero (2021) for Madrid				
Original ratios of López and Piquero (2021)	1,39	1,32	1,32	0,83
With respect to the CP ratio 2/	1,0	0,9	0,9	0,9
Adjusted ratios of López and Piquero (2021)	1,35	1,24	1,27	0,79
With respect to the CP ratio 2/	0,9	0,9	0,8	0,8

Notes: The table reports my estimates of welfare ratios in Spain, as well as the welfare ratios of Allen (2001), Allen *et al.* (2012) and López and Piquero (2021). My estimates refer to Toledo and Barcelona. Allen (2001) and Allen *et al.* (2012) report ratios in Toledo and Valencia, whereas López and Piquero report ratios in Madrid and Valencia. I also recalculated the welfare ratios from Allen (2001), Allen *et al.* (2012) and López and Piquero (2021) to make them comparable with my estimates. I adjusted the cost of food of those studies by multiplying the original cost of food by a factor *K*, where *K* is the ratio of the calories in the present study divided by the calories in the previous studies. I calculated the cost of food of the previous studies using their original prices. For Allen *et al.* (2012), I assumed that the basket was composed of 188 kg/year of wheat, instead of 155 kg/year of oats. I also assumed that the cost of fuel, lamp oil, linen, soap and candles for a family was four times the cost for an average person. The ratios, prices and wages of Allen (2001) were obtained from https://gpih.ucdavis.edu/Datafilelist.htm. The ratios of Allen *et al.* (2012) come from the appendix of the same study. The welfare ratios, prices and wages of López and Piquero (2021) were obtained from https://addi.ehu.es/handle/10810/40426?show=full. Wages and prices in Madrid come from López and Piquero. 1/ Allen (2001) did not report welfare ratios for this period. 2/ I estimated the CP ratios in Madrid using linear programming.

the CP ratio. Therefore, linear programming yielded important changes in the cost of food and so in the welfare ratio. Had poor families opted for consuming the lowest-cost basket instead of the typical diet, they would have had a better chance of covering their basic nutritional needs.

6. Family structures and life cycle

In the basic model, I calculated the cost of living for a family of four members (two adults and two children) and assumed that only a man worked in the family and that he did so for 250 days per year. These assumptions may have reflected the reality of some families, but not all. Women and even children could also have worked for a salary. In addition, the workload and the structure of the family may have changed over time.[41] At an early stage, before having children, both adult men and women could work. As people got married and started having children, one of the parents probably had to stay at home to raise the children. Eventually, however, children left the house. Families had different welfare ratios through life. How did welfare ratios vary depending on family size, the length of workdays and the number of people who worked?

Horrell *et al.* (2022) estimated welfare ratios in England and Wales for six life stages after young people left the home of their parents at the age of 15.[42] These stages are youth, young-family, peak-family, old-family, post-family and old-age. I follow Horrell *et al.* and make assumptions for each stage, regarding the ages in these stages, the number of people who worked, the time worked and the number of children. The first stage, called youth, began at the age of 15 and ended at 24. During this stage, men and women were independent and had no children. I assumed they worked full time during this stage, that is, 250 days per year. I assumed men and women got married and started a family at the age of 25. During the young-family stage (25-34 years), the family had two young children. I assumed the husband continued working 250 days/year and the wife reduced her workload to 50 days/year to raise children. During the peak-family stage (35-44 years), the family grew. I assumed the family now had three children (two adolescents and one young child), and that the couple maintained their workload. During the fourth stage, the old-family stage, the parents were between 46 and 55 years old. I assumed that two of the children had now left home, the husband worked 250 days/year and the wife worked 100 days/year. In the fifth stage, the post-family stage (55-64 years), the third child had also left home and both parents worked 250 days/year. In the sixth stage, the old age (65-75 years), the couple reduced their workload due to their advanced age. In particular, I assumed that the husband worked 125 days/year and the wife did so for 50 days/year.

I estimated welfare ratios for the six life stages. I assumed that people did not save or borrow. I calculated the nutritional requirements of the family for each stage. The requirements depended on gender, age and type of work. I assumed energy requirements of 2.2, 2.0 and 1.8 BMR when working 250 days/year, 100-125 days/year and 50 days/year, respectively. I then estimated the linear programming model and found the BN food basket for each life stage. The cost of other goods and services (fuel, linen, etc.) was calculated as the number of people in the family times the cost per person. I assumed the same quantities of fuel, linen, lamp oil, candles and soap per person as in the basic model. I assumed salaries of women were equal to 40 per cent of those of men.[43]

[41] In England and Wales, for instance, compared with married women, single women worked longer hours for a salary (Horrell *et al.*, 2021).

[42] Boter (2020) also relied on the life cycle to estimate welfare ratios in the Netherlands.

[43] Llopis and García (2011) provide information on women's salaries. Women made less than 50% of the salaries of men in Madrid in the period 1680-1800.

https://doi.org/10.1017/S0212610924000107 Published online by Cambridge University Press

Table 4. Welfare ratios in different life stages

	Basic model	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
Toledo							
1600–1625	1,26	2,84	1,40	1,09	1,70	2,83	1,35
1626–1650	1,09	2,45	1,21	0,94	1,47	2,44	1,16
1651–1675	1,15	2,65	1,28	1,00	1,57	2,60	1,22
1676–1700	1,30	2,98	1,44	1,12	1,77	2,94	1,38
1701–1725	1,37	3,15	1,51	1,18	1,87	3,11	1,47
1726–1750	1,28	2,92	1,42	1,11	1,74	2,88	1,36
1751–1775	0,88	1,99	0,98	0,76	1,19	1,99	0,94
1776–1800	0,70	1,60	0,79	0,60	0,95	1,63	0,77
Barcelona							
1600–1625	0,77	1,73	0,88	0,65	1,03	1,77	0,83
1626–1650	0,75	1,69	0,85	0,64	1,01	1,73	0,81
1651–1675	1,07	2,39	1,21	0,92	1,43	2,41	1,15
1676–1700	1,02	2,28	1,14	0,87	1,36	2,29	1,09
1701–1725	0,87	1,93	0,97	0,74	1,16	1,94	0,93
1726–1750	0,94	2,08	1,05	0,81	1,26	2,09	1,01
1751–1775	0,76	1,71	0,86	0,64	1,02	1,75	0,83
1776–1800	0,97	2,17	1,08	0,83	1,30	2,20	1,06

Notes: The table reports BN welfare ratios for six life stages in Toledo and Barcelona. In stage 1, men and women were between 15 and 24 years of age and had no children. In stage 2, men and women were between 25 and 34 years old. The two adults had two children. In stage 3, the two parents were between 35 and 44 years old. The family was composed of the father, the mother and three children. In stage 4, the two parents were between 45 and 54 years of age. In addition, two children had moved out. In stage 5, the two parents were between 55 and 64 years and the family was only composed of the two parents. In stage 6, the two parents were between 65 and 75 years of age. The adult man worked 250 days/year in stages 1-5 and 125 days/year in stage 6, whereas the adult woman worked 250 days/year in stages 1 and 5, 50 days/year in stages 2, 3 and 6 and 100 days/year in stage 4. For the first stage, I determined the food baskets for men and women of 15–24 years of age, using the average nutritional requirements for each of them. The welfare ratio in this stage is the average of the man's welfare ratio and the woman's welfare ratio. For the other stages, the total nutritional requirements of the family were calculated as the sum of the average requirements of each member of the family.

Table 4 shows the evolution of welfare ratios for alternative life stages. In Toledo and Barcelona, the welfare ratios reached their highest levels in the first stage, when men and women did not have children. As they formed families and started having children, the welfare ratios declined. The welfare ratios reached their lowest levels in the third stage, when the family had five members (two adults and three children). As children left home, the welfare ratios increased. The ratios reached a relatively high level in the fifth stage, when the two parents lived alone and did not have to support their children. In the sixth stage, however, as the two parents, now older, could not work as much as before, the welfare ratios were lower.

In the first stage, young adults from Toledo did not face difficulties to cover their basic needs, even in the late 18th century, when welfare ratios were lower. As families had children, the welfare ratio declined. In the second stage, the welfare ratio was between 1.2 and 1.5 between 1600 and 1750. In the period 1750-1800, however, the ratio was less than 1.0. In the third stage, the ratio was below 1.2 in the entire period, and it was below 1.0 in the 1750-1800 period. In the fourth stage, the welfare ratio in Toledo was usually above 1.0. In the fifth stage, the welfare ratio was always above 1.0, even in the late 18th century. In the sixth stage, families faced more difficulties to afford their living expenses, especially in the second half of the 18th century.[44]

Families in Barcelona usually faced more difficulties than those in Toledo, especially until the mid-18th century. In the first stage, at the time of independence and with no children, the welfare ratio was above 1.0. In the second stage, the welfare ratio was below 1.0 in 1600–50, 1701–25 and 1751–75. In the third stage, the welfare ratio was always below 1.0. As families had to support children and the wife could not work as before, families could not cover their basic needs during most of the period. In the fourth stage, the welfare ratio was above 1.0 and was higher than in the previous two stages. In the fifth stage, as all children had already left home, the welfare ratio was higher than 1.7. In the sixth stage, the two parents did not have to support their children. However, the welfare ratio was usually less than 1.0 or barely above 1.0. Since the parents could not work full time, their income was not high enough to cover their basic needs.

Therefore, in general, families in Toledo and Barcelona faced larger difficulties to cover their basic needs in the periods 1600-1650 and 17501800. However, the welfare ratio depended on the life stage. Families faced more difficulties in the second, third and sixth stages, when families had to raise children or when the parents could not work full time.

7. International comparison

Some studies have compared the welfare ratios of Spain and other countries. According to Allen (2001) and Allen *et al.* (2012), the welfare ratios in Northern Europe in the period 1600-1800 were above those in Toledo, Valencia and other European cities, so the divergence between Northern Europe and the rest of Europe started long before the Industrial Revolution. In contrast, López and Piquero (2021) found that the divergence in welfare ratios between Northern Europe and Spain only started in the 18th century.

[44] Child labour could also contribute to the family income (Sarasúa, 2019). I analyse the case in which children worked, assuming that salaries of children were 75% of women's salaries. This assumption is based on the evidence for England and Wales; children earned less than women during this period (Horrell and Humphries, 2019). Compared to the basic stage three scenario in which only the two parents worked, the welfare ratios in Toledo were around 53% higher if the two adolescents worked 250 days per year (thus increasing the energy requirements to 2.2 BMR).

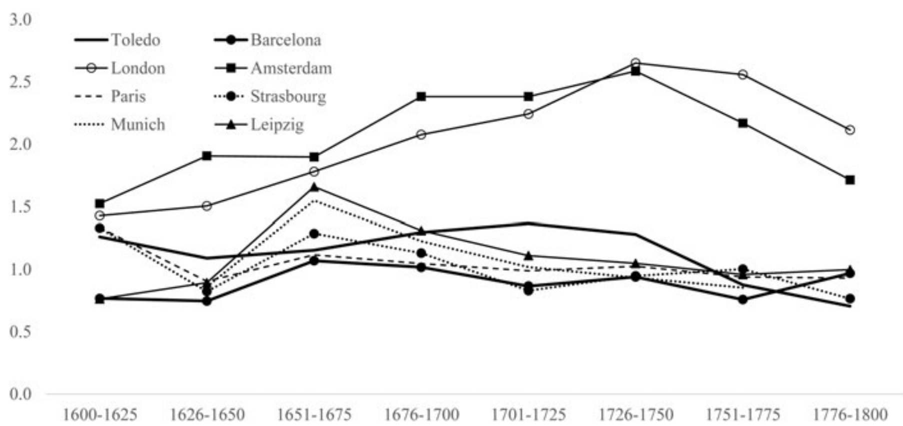

Figure 4. BN welfare ratios.

Notes: The figure depicts the evolution of BN welfare ratios in Europe. For Toledo and Barcelona, the figure depicts my estimates of the BN welfare ratios. For London, Amsterdam, Paris, Strasbourg, Munich and Leipzig, I adjusted the BN welfare ratios from Zegarra (2022) to make them comparable with my estimates. I multiplied the cost of food in those cities by a factor of 0.942, equal to the ratio between the calories of a family in my study and the calories of a family in Zegarra (2022). For all studies, it is assumed that only one male adult of the family worked, and he did so for 250 days/year. For all countries, the BN food basket was obtained using linear programming.

To determine the differences in welfare ratios between Spain and other countries, it is necessary to compare welfare ratios obtained using similar methodologies. However, most estimations of welfare ratios for other European cities have been obtained using historical diets, not linear programming. Only recently, I used linear programming to estimate BN welfare ratios in London, Amsterdam, Paris, Strasbourg, Munich and Leipzig (Zegarra, 2022). In the following paragraphs, I compare the BN ratios in Spain with the BN estimates for those six cities (Figure 4).[45]

In the early 17th century, the BN ratios in Spain were below the ratios in London and Amsterdam: in the period 1600-25, the welfare ratio was around 1.3 in Toledo, 0.8 in Barcelona, 1.4 in London and 1.5 in Amsterdam. From then and until the mid-18th century, the BN ratios in London and Amsterdam followed an upward trend, whereas the ratios in Toledo and Barcelona remained below 1.4. The BN ratios in Toledo and Barcelona were usually similar to those in Paris, Strasbourg, Munich and Leipzig.

The evidence suggests that in the 17th century the welfare ratios in Spain were already lower than those in Northern Europe. Over time, the welfare ratios differed even more. According to my estimates, the BN welfare ratio of Toledo represented around 88 per cent of the ratio in London in the period 1600-25. This percentage declined over time, reaching 33 per cent between 1776 and 1800. As a percentage of the welfare ratio in London, the ratio in Barcelona also declined over time from more than 50 per cent in the early 17th century to 46 per cent in the late 18th century.

My estimates support some of the findings in Allen (2001) and Allen *et al.* (2012), in particular that Spain had lower welfare ratios than Northern Europe long before the Industrial Revolution. However, my estimations also show that in the early 17th century the differences between Northern Europe and Spain were lower than those found by

[45] To estimate welfare ratios in London, Amsterdam, Paris, Strasbourg, Munich and Leipzig, I assumed that a family needed to obtain 9,768 kcal calories per day (Zegarra, 2022). In contrast, for the present study, I assume that a Spanish family required 9,207 kcal calories per day. In order to compare the estimates, I adjusted the estimates of the other six European cities. I multiplied the cost of food in those cities by a factor of 0.94 and then recalculated the welfare ratios in London, Amsterdam, Paris, Strasbourg, Leipzig and Munich.

Allen and Allen *et al*. On the other hand, my estimates contradict the argument of López and Piquero that the divergence in welfare ratios started in the 18th century. An important similarity between my estimates and those from previous studies is that the differences in welfare ratios between Northern Europe and Spain increased over time.

8. Conclusions

Welfare ratios constitute a useful indicator for the study of living standards. Two methodologies can be used to estimate welfare ratios. It is possible to use historical diets to calculate the food cost at subsistence levels. In addition, it is possible to use linear programming to find the lowest-cost food basket. When using historical diets, welfare ratios measure the capacity of families to cover their consumption habits. When using linear programming, welfare ratios measure the capacity of families to cover their basic needs.

In their studies, Allen (2001), Allen *et al*. (2012) and López and Piquero (2021) estimated welfare ratios for pre-1800 Spain using historical diets. Allen (2001) and Allen *et al*. (2012) found that between 1600 and 1800 the welfare ratio in Spain was always below that of Northern Europe. In contrast, López and Piquero found that the divergence in welfare ratios between Northern Europe and Spain only started in the 18th century.

In this study, I estimated welfare ratios in Spain using a linear programming model. By doing so, I obtained the optimal food basket that allowed people to cover the requirements of several nutrients. The BN baskets include a large quantity of cereals, in particular wheat bread and barley bread. The basket of Barcelona also includes beans. In several decades, the baskets of Toledo and Barcelona include mutton; at times, the basket of Barcelona includes codfish and eggs. One similarity between this study and previous studies refers to the inclusion of large quantities of cereals, although the quantities vary. In addition, unlike previous studies, the food baskets are not assumed constant over time (in fact, they change over time). There are also differences in the inclusion of legumes, codfish and eggs, among other items.

The results of this study show that the welfare ratio of a family of four members in Toledo was above 1.0 in the period from 1600 to 1750 and below 1.0 between 1751 and 1800, whereas the welfare ratio in Barcelona was usually below the ratio in Toledo. My estimates differ from previous studies. The welfare ratios of this study are higher than those of Allen (2001), far lower than those of Allen *et al*. (2012) and slightly lower than those of López and Piquero (2021). On the other hand, my estimates show that welfare ratios depended on the life stage. Welfare ratios were lower when families had to raise children and when the parents could not work full time.

According to my calculations, Spain did not compare favourably with Northern Europe. In most of the period 1600-1800, the BN welfare ratios in Toledo and Barcelona were below those in London and Amsterdam. However, the ratios in Spain were similar to those in France and Germany. My results show that Spain had lower welfare ratios than Northern Europe before the Industrial Revolution.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S0212610924000107.

Acknowledgements. I am very grateful to the Editors of *Revista de Historia Económica/Journal of Iberian and Latin American Economic History* and the three anonymous referees for their comments and suggestions. Those comments were very helpful for improving the article. I am also grateful to the personal of the National Library of Spain at Madrid and the Library of the University of Barcelona in the process of data collection. In 2022, I presented the methodology used in this article (linear programming) in VII CLADHE and seminars organised by the University of Barcelona, University of Valencia and the University of Sevilla. The comments of the participants in those seminars were very helpful for improving the methodology used in this article. In 2022, I spent time as Visiting Professor in the University of Barcelona. I worked on this article during my stay in Spain. Funding for this travel was provided by the Pontificia Universidad Católica del Perú (PUCP) and the Research Group of Economic History (Grupo de Investigación de Historia Económica) of PUCP.

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Cite this article: Zegarra L.F. (2024) Prices, wages and living standards in Spain in the modern era. *Revista de Historia Económica / Journal of Iberian and Latin American Economic History* 42(2), 243–268. https://doi.org/10.1017/S0212610924000107