The relationship between height and economic development in Spain, 1850–1958

Ramón María-Dolores a,*,José Miguel Martínez-Carrión b

a Departamento de Fundamentos del Análisis Económico, Facultad de Economía y Empresa, Universidad de Murcia, Campus de Espinardo 30100 Espinardo, Murcia, Spain
b Departamento de Economía Aplicada, Facultad de Economía y Empresa, Universidad de Murcia, 30100 Murcia, Spain

Article history:
Received 15 December 2009
Received in revised form 20 July 2010
Accepted 20 July 2010

JEL classification:
I1
I3
N3
N9

Keywords:
Height
Health
Income
Education
Economic development
Cointegration

ABSTRACT

We investigate the relationship between height and some economic-development indicators in modern Spain by means of a recently constructed times series of data on conscripts. We estimate a Vector Autoregressive Equilibrium Correction Model (VECqM) to quantify the height and GDP per capita response to various living-standard indicators. We observe that conditions that perpetuate an elevated level of sickness and mortality and that raise the relative price of consumption goods tend to impede human growth, as reflected in a decline in average adult height, whereas factors that promote the purchase of health services and that help to open up the economy to international trade and ideas have tended to have an opposite effect from the 1850s onward. Our results also indicate that neither the level of per capita GDP nor its growth rate has a unidirectional relation to various measures of living standards, chiefly adult stature. Instead, our findings suggest that there may be behavioral factors (e.g., emphasis on health services), political factors (e.g., degree of openness), and economic factors (e.g., relative consumer costs to GDP deflator) whose affects may have been influenced the level of GDP, over the sample period.

1. Introduction

In the last few decades anthropometric history has enhanced our knowledge of the quality of life of numerous populations. The use of physical stature and other anthropometric indicators is widely accepted by economic historians, and recently by economists as well, for the measurement of various aspects of human well-being and in the examination of the impact of socio-economic processes on biological welfare and health outcomes (Fogel, 1994; Komlos, 1985, 1994, 1995a, 1998; Steckel, 1995, 2008; Steckel and Floud, 1997). Some of the main topics debated are the determinants of height and the relationship between stature and indicators of economic development. A high degree of correlation between height and economic development was observed in developing countries in the second half of the 20th century (Steckel, 1979, 1983). Later contributions have clarified the existing relations among height, income per capita, and income inequality over the long term (Brinkman et al., 1988; Drukker and Van Meerten, 1995; Coll, 1998; Craig and Weiss, 1998; Haines, 1998; Jacobs and Tassenaar, 2004; Moradi, 2010; Peracchi, 2008). In recent years a battery of living-standard indicators has been used to measure their...
relationships to height, revealing important connections among health, mortality, and economic development (Easterlin, 2000; Arora, 2001; Deaton, 2003, 2007; Deaton and Arora, 2009; Fogel, 2004; López-Casasnovas et al., 2005; Persico et al., 2004; Steckel, 2008).

In cross-sectional analyses, the correlations between height and levels of economic development are positive (Komlos, 1995b, 2003). However, in longitudinal analyses, the correlations are less clear cut. A quarter of a century ago it was established that time series of income per capita could explain variations in height changes, and that stature could be used as a proxy for income in the absence of information on material well-being (Brinkman et al., 1988), although it is well known that the two indicators do not necessarily evolve in parallel. Many scholars have studied this relationship. Several have found that in developing countries in Europe, North America, and Japan in the late-19th and early-20th centuries average height tended to increase, regardless of the level of industrialization (Sandberg and Steckel, 1997; Weir, 1997; Shay, 1994; Honda, 1997; Baten, 2000; Federico, 2003; Vecchi and Coppola, 2006; Arcaleni, 2006). Height declined, however, in the United States, England, and the Netherlands during the Industrial Revolution, at the end of the 18th and the first half of the 19th centuries (Margo and Steckel, 1983; Floud et al., 1990; Komlos, 1998; Haines, 2004). Nevertheless, nearly everyone agrees that there was an international convergence in biological welfare and other non-income indicators of the standard of living during the 20th century (Kenny, 2005; Deaton, 2007, 2008) which was primarily due to the fact that stature is influenced by (among other factors) health conditions during childhood and adolescence, maternal education, social-welfare policies, child labour, location, and cultural values (Komlos and Baten, 1998; Shutkowski, 2008; Steckel, 2009).

More recently, other researchers (Baten et al., 2010) have pointed out that human stature in adulthood captures an accumulation of factors that contribute to changes in the standard of living of a generation. This implies that GDP per head could also explain height averages.

Evidence of the relationship between height and economic development has also been found in Spain. The first studies of anthropometric history there were done by economic historians who used military data. Thus, Gómez-Mendoza and Pérez-Moreda examined the relationships among height, educational attainment, and infant mortality in the early 20th century. They compared the average height of recruits by province, along with data on the region’s economic performance and infant-mortality rate (Gómez-Mendoza and Pérez-Moreda, 1995). Furthermore, Martínez-Carrón explored height and income trends between 1850 and 1990 on the basis of local military-recruitment data (Martínez-Carrón, 1994, 2002; Martínez-Carrón and Pérez-Castejón, 2000); and Quiroga Valle and Coll (2000) discussed height differences as a proxy for income inequality, and found that changes in height differences among social groups could indicate shifts in income inequality. By expanding beyond the conventional indicators of welfare, the anthropometric approach to socio-economic history opens up a wide variety of research possibilities.

Recently, using both Spanish height data from the Encuesta Nacional de Salud (Spanish National Health Survey) and the dataset of the European Community Household Panel (Eurostat), economists and demographers presented new evidence concerning the evolution of adult height and weight (García and Quintana-Domeque, 2007, 2009). The influence of generational and environmental factors on adult height has been evaluated, and the mechanisms by which socio-economic position may influence individual height have been discussed (Costa-Font and Gil, 2008; Spijker et al., 2008). Moreover, the issue of the determinants of height during a period of significant socio-economic transformation (1960–2000) has been explored. Results suggest that the epidemiological transition before Spain’s entry into the European Union led to increases in adult height (Bosch et al., 2009).

Spanish economic growth in the last few years has traced a parallel path. According to the estimates of Prados de la Escosura, Spain’s long-term underperformance was mostly due to its sluggish growth between 1850 and 1950. In contrast, it was the destruction of human capital during the Spanish Civil War (1936–1939) and its aftermath that explains its poor performance during the 1940s and 1950s. The 1940s constituted a phase of delay in the Spanish economy – an economy that has been catching up with those of advanced countries over the last fifty years, in which 1959–1974 stands out as a period of outstanding performance (Prados de la Escosura, 2003, 2007).

Comparison between the performance of the Spanish economy and that of the most advanced nations of Western Europe reveals that Spain’s GDP was approximately 75% of Europe’s and 50% of North America’s in the early 1930s. The civil conflict of 1936–1939 caused the GDP to decline, and although it improved in the 1950s, the gap between it and the GDPs of developed nations remained unchanged. According to recent estimates, Spain’s per capita GDP stood in 1933 and decreased to 35% in the 1950s. The development of a pro-market attitude, marked by deregulation and a gradual entry into the international economy, resulted in sustained growth and thus a closing of the GDP gap between it and the rest of Western Europe during the second half of the twentieth century. A dramatic slowdown in growth followed by a sustained – recovery – the pivotal year being 1986, when Spain joined the European Union – characterized the last quarter of the twentieth century (Prados de la Escosura, 2007).

We analyse the relationship between physical stature and economic development in Spain between 1850 and 1958 on the basis of previously with a new height database, drawn from military-conscription records. We take into account several key development indicators: per capita income, the share of consumption of health series in total consumption, the ratio of the price of consumer goods to the GDP deflator, schooling and mortality rates, and the degree of openness, which could potentially influence physical stature during the period under consideration. We study the relationship between various indicators of the standard of living without presuming that there exists any interrelationship among them.
Drawing on these anthropometric data, we address the following three questions: What are the long-run trends among height and various indicators of economic development in Spain? How are height and per capita GDP influenced by certain economic-development indicators? Is per capita GDP a function of height or vice versa, or is each a function of the other?

The rest of the paper is organized as follows. In Section 2 we describe our database; in Section 3 we apply a Vector Auto-Regressive (VAR) framework with a Vector Equilibri- um Correction Model in order to identify the determinants of height changes and other standard of living indicators in Spain between 1850 and 1978; and in Section 4 we offer our conclusions.

2. Data description

2.1. Height

In order to analyze secular height changes, a standard-ized time-cohort series can be constructed for Spain from the 1850s onwards,¹ thanks to Local Military Recruitment Acts, or LMRA.² These data sources are preserved in the Sección de Quintas of the municipal archives. Earlier data are both scarce and fragmentary; in fact, scarcely any were recorded until the end of the eighteenth century. The first military draft dates to 1770. Until the end of that century, the conscripts were between 16 and 40 years of age. In the first decades of the 19th century the age range was reduced to 16–25 (Cámara-Hueso, 2006). Not until the 1850s, however, is recruitment limited to a one-year cohort, which is modified over the course of the next 120 years: 20 years (1850–1885), 19 years (1885–1900), 20 years (1901–1906), and 21 years (1907–1970).

Our height database include records of all the conscripts in 19 municipalities spanning three geographical regions (Andalusia, the Region of Murcia, and the Valencian Community) across from five provinces of Spanish Levant.³ The municipalities are representative of different socio-economic environments: cities, towns, and villages.

There are reasons to believe that the relationship found for these provinces of Spanish Levant are representative of the whole country. According to several studies, when considered according to total productivity, labour produc-tivity, income per capita, well-being, and inequality the Levant ranked in the middle (Domínguez-Martín, 2002; German et al., 2001; Núñez, 2005). However, when it comes to height, in several anthropometric studies of Spanish Levant prove to be nearer to the national average. The average height of the 1915–1929 and 1965–1980 recruits (year of measurement) are in line with average heights nationwide at the time (Gómez-Mendoza and Pérez-Moreda, 1995, p. 85; Martínez-Belmonte, 1983; Martínez-Carrión, 1994, p. 697; Rebato, 1998).⁴ We determine each cohort’s average height by year of birth. The height series that we use comprises data on 328,248 conscripts between the ages of 19 and 21 who were measured between 1857 and 1969 or who were born between 1837 and 1948. The backgrounds of these series have been analyzed by Martínez-Carrión and Pérez- Castejón (1998, 2000) and incorporate the recent dataset of Puche-Gil (2009).⁵ Our height series is linked with the national series collected by the Statistics of Recruitment and Replacement of the Armies from 1955 and estimated by Quiroga (2003a). In that paper, the height series starts in 1850 as do the economic-developement indicators.

The chief problems posed by height data from any military source are changes in the recruitment age and in the minimum-height requirement. In Spain, however, all recruits were measured before being declared fit or unfit for military service, so there is no selective bias on account of a truncated distribution. The potential problem posed by changes in the recruitment age and by the rounding of the height data, has been resolved by our using standardized heights at age 21 that take into account estimations of growth.⁶ We constructed a new height series by birth cohorts using five-year moving averages standardized at the age of 21.⁷

We present distributions of height data for several periods in Fig. 1.⁸ We verified that there is an accumulation of observations around height finished at five and zero centimeters that are attributable largely to rounding. Heaping is mainly observed at 150, 155, 160, 165 and 170 cm, but is very mild. The degree of heaping is more pronounced in the first periods. Our data are normally distributed or Gaussian and do not suffer from typical truncation problems.

2.2. Income and other measures of welfare

To calculate real income, we use the annual series of Spanish per capita GDP at constant 1995 prices in pesetas

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¹ A state-of-the-art database for stature and other elements of Spanish anthropometric history; see the Historia Agraria monograph coordinated by Martínez-Carrión (2009).
² The original records are Actas de clasificación de los mozos y declaración de soldados, Actas de Reclutamiento y Reemplazo.
³ The municipalities are the next: Vera (province of Almería); Region of Murcia: Cartagena, Cieza, Murcia, Mazarrón, Totana, Torre-Pacheco Yeca (province of Murcia); Alcoi, Elche, Orihuela, Pego, Villena (province of Alicante); Alzira, Gandía, Requena, Sueca (province of Valencia); and Castellón y Villareal (province of Castellón).
⁴ Note that Spain is a cultural composite but that all towns in our sample are in the Southeast where the Mediterranean culture was predominant.
⁵ The dataset is composed of 141,861 records on the height of men. See the doctoral thesis of Puche-Gil (2009), and Martínez-Carrión and Puche-Gil (2010).
⁶ See in Martínez-Carrión and Moreno-Lázaro (2007) the way height series is standardized at the age of 21. After standardizing the series we construct our final series as a five moving-average.
⁷ Our height series is constructed as a five moving-average. This is frequently done in order to obtain trends rather than short-term fluctuations. Many authors have provided height series by doing 3-moving, 5-moving or even 10-moving year average. Some references where it is done, just to name a few, are: Komlos (1994, 1995a, 1995b), Komlos and Baten (1998), and Steckel and Floud (1997). Note also that in our paper we are estimating a VECqM model and this analysis is considering long-run relationships among variables. So, it is better to use a series of this type.
⁸ Martínez-Carrión and Pérez-Castejón (1998) use a sample of the height of 127,310 conscripts out of a total of 141,911 men (89.7%) called up for service.
Fig. 1. Distribution of heights (1837–1948) several periods by birth year. (a) Distribution of heights by year of birth, 1837–1865. (b) Distribution of heights by year of birth, 1866–1885. (c) Distribution of heights by year of birth, 1886–1915. (d) Distribution of heights by year of birth, 1916–1994.
provided by Prados de la Escosura (2003). His recent economic growth estimates show that there have been three main phases in Spain’s economic development: 1850–1950, 1951–1974, and 1975–2000, a decline occurring during the first phase as a consequence of the Civil War of 1936–1939. Within this 150-year span, growth rates fluctuated in reaction to economic policies, access to international markets, and technological change can be distinguished century’s average.

During the first phase, the most intense growth of the period was achieved in the 1920s, coinciding with the dictatorship of Primo de Rivera (1923–1929). This was a period of institutional stability that provided a favourable environment for investment and business. While the Great Depression (1929–1933) had a moderate impact the Civil War (1936–1939) had a negative impact on economic growth, reducing the per capita GDP near 15% of the secular growth rate (Comín, 2002; Prados de la Escosura, 2003). During the early years of General Franco’s dictatorship – the so called autarchy period-, the economic growth was weak and its average growth rate was only 0.6% per annum, whereas the average for the rest of Europe was 1.4% per annum. The Spanish economy did not regain its pre-war GDP levels (in absolute terms), until 1955 (in per capita terms). As in other countries in the European Periphery, the main spur of economic growth in Spain was delayed until the 1960s. This recovery ushered in an exceptional phase of rapid growth, lasting until 1974, a period known as the Golden Age. The years 1959–1974 emerge as a period of rapid growth, reducing the per capita GDP near 15% of the secular social average.

When we compare the evolution of height and per capita GDP for the period 1850–1978, we find no similarities until the end of the 19th century (Fig. 2). Nevertheless, they seem to be closely correlated during the period 1900–1920. We obtain a correlation of 0.91 among the series for the whole sample period. Examination of the average height and per capita GDP by decade, reveals a lack of correlation between income and height during the initial stages of modern economic growth (Table 1), which is possibly related to Kuznets’ inverted-U hypothesis, namely, that income inequality rises and then falls with the level of economic development. Researchers have recently observed a long-term rise in the inequality index during the early phase of globalization that peaked with World War I (Prados de la Escosura, 2008). Using Spanish-recruit data, Quiroga Valle and Coll (2000) conclude that there was a long-term increase in height inequality among socio-professional groups between the turn of the century and World War I. Moreover, Martínez-Carrón and Moreno-Lázaro (2007) demonstrate that inequality trends between rural and urban areas increased during the late-nineteenth century.

Anthropometric measures reveal the interrelations among various components of human health and the standard of living. Recent studies have shown that improvements in housing and nutrition, comprehensive health care, and health education have a positive effect on height (Komlos and Lauderdale, 2007). We use two health-related measures of consumer activity: the share of consumption of health services in total consumption and the ratio between the price level of consumer goods and the GDP deflator. These series, which end at the end of 1958, are provided by Prados de la Escosura (2003) at constant 1995 prices. Building on previous research into the relationship between mortality and height (Fogel, 2004), we include the mortality rate from 1858 to 1980 as an additional independent variable (Nicolaou, 2005, pp. 124–126; Carreras and Tafunell, 2005).

We plot the relationships among stature, mortality rate, the share of consumption of health services in total consumption, and the ratio between the private consumption and the GDP deflators, respectively (Figs. 3–5). The mortality variable is interpreted broadly as an indicator of the population’s rate of fatal illness. We infer that a low rate is associated with an increase in average adult stature and observe that the relationship becomes especially pronounced after the Civil War (Table 2). The effects of the 1918 flu epidemic and the Civil War, were immediately reflected in the mortality series, and influenced the height of the next generation of conscripts, measured during the period 1933–1959. As for the share of health services in total consumption, we observe a high value of the correlation coefficient for this variable (0.87).

The relationships between stature and schooling variables (as a proxy for human capital) such as literacy rates and educational levels have also received the attention of specialists (Meyer and Selmer, 1999; Schultz, 2003). Recently, Case and Paxson (2008) stressed that

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9 If we split our sample period we observe how the correlation starts increasing at the end of the 19th century. We also found a positive value for the relationship between the height series and the detrended per capita GDP.

10 We are grateful to one of the reviewers for suggesting that we use these two variables.

11 Our consumption of health services series is taken from Prados de la Escosura (2003, p. 457), Table A.7.1, column five.

12 Many authors used to employ schooling variables as a proxy for human capital. However, these variables are inadequate as indicators of human capital over long sample periods, their roles shifting, for instance, from regime to regime.
height is positively associated with physical and mental health and with cognitive ability; we have therefore included some education variables in our study, such as the schooling rate (Núñez, 2005). Historians have indicated that in Spain advances in education and the standard of living have lagged behind those of other European countries and that at least until 1960, there was a wide gap between the gains achieved by men and of women. Although studies demonstrate that literacy spread and that average height increased in the course of the first half of the twentieth century, a height gap separated literate from illiterate conscripts after the Civil War, the divergence being due to differences in the degree of their access to education, and reflected in the varying quality of their signatures (Martínez-Carrirón and Puche-Gil, 2009; Quiróga, 2001, 2003b, pp. 616–617).

This reevaluation indicates that most of the human capital of the Spanish population in the second half of the twentieth century was due to expanded primary schooling rather than to secondary or university studies. Likewise, it identifies the Civil War as one of the most serious setbacks during two centuries of slow and

### Table 1
Average height and GDP per head (1850–1978).

<table>
<thead>
<tr>
<th>Year</th>
<th>Average height (birth year in centimeters)</th>
<th>Average GDPpc (pesetas 1995)</th>
<th>Height variation (centimeters)</th>
<th>Annual GDP pc growth rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1850–59</td>
<td>161.87</td>
<td>142.25</td>
<td>−0.86</td>
<td>1.07</td>
</tr>
<tr>
<td>1860–69</td>
<td>162.08</td>
<td>157.75</td>
<td>0.47</td>
<td>−0.45</td>
</tr>
<tr>
<td>1870–79</td>
<td>162.25</td>
<td>188.69</td>
<td>0.40</td>
<td>2.33</td>
</tr>
<tr>
<td>1880–89</td>
<td>163.06</td>
<td>210.67</td>
<td>0.47</td>
<td>−0.09</td>
</tr>
<tr>
<td>1890–99</td>
<td>163.38</td>
<td>213.45</td>
<td>0.29</td>
<td>0.78</td>
</tr>
<tr>
<td>1900–09</td>
<td>164.19</td>
<td>236.46</td>
<td>1.07</td>
<td>1.02</td>
</tr>
<tr>
<td>1910–19</td>
<td>165.05</td>
<td>257.55</td>
<td>−0.20</td>
<td>0.76</td>
</tr>
<tr>
<td>1920–29</td>
<td>164.38</td>
<td>305.88</td>
<td>−0.02</td>
<td>2.32</td>
</tr>
<tr>
<td>1930–39</td>
<td>165.51</td>
<td>290.02</td>
<td>1.37</td>
<td>−3.08</td>
</tr>
<tr>
<td>1940–49</td>
<td>166.68</td>
<td>273.23</td>
<td>0.73</td>
<td>0.35</td>
</tr>
<tr>
<td>1950–59</td>
<td>168.82</td>
<td>350.60</td>
<td>3.37</td>
<td>3.37</td>
</tr>
<tr>
<td>1960–69</td>
<td>171.92</td>
<td>582.59</td>
<td>2.64</td>
<td>6.98</td>
</tr>
<tr>
<td>1970–78</td>
<td>174.30</td>
<td>994.50</td>
<td>0.94</td>
<td>4.11</td>
</tr>
</tbody>
</table>


![Fig. 3. The relationship between height (birth year) in centimeters (left vertical axis) and CDR crude mortality rate (right vertical axis).](image1)

![Fig. 4. The relationship between height (birth year) in centimeters (left vertical axis) and the share of consumption of health services in total consumption (right vertical axis).](image2)

![Fig. 5. The relationship between height (birth year) in centimeters (left vertical axis) and the ratio of private consumption deflator.](image3)
irregular human-capital accumulation. The early years of the Franco regime further depleted the stock of human capital (Núñez, 2005). While we find that there is a negative correlation between height and level of schooling at $-0.77$ it is insignificant.\footnote{Our correlation results are different from Arora (2001), but this variable was also statistically insignificant in this paper.}

From our results, it can be observed that the underlying institutional reasons for schooling in Spain may have been completely different from the causes underlying increases in average stature. This observation is based on the fact that there is no reason to assume that the two variables would develop in tandem. Thus, it is important to study adult stature in Spain as distinct from schooling and other conventional forms of human capital.

Finally, we have also included other important development indicators such as the degree of openness to international trade, measured as the ratio of export plus imports over GDP, Prados de la Escosura (2003, p. 188). Some papers have described a negative association between the barriers to trade and economic growth (Ben-David, 1993; Sacks and Warner, 1995; Edwards, 1998; Frankel and Romer, 1999). The interrelationships among health, the welfare state, and openness have yet to be sufficiently treated from an anthropometric perspective. This subject is particularly pertinent to Spain because of the pro-autarky policies, including economic liberalization (1939–1975). Autarky as practiced in Nazi Germany and formerly Communist European countries has been shown to have negative effects on well-being, as a result of market restrictions and controls such as fixed prices, production contingents, import restrictions, food rationing, and limitations on certain types of foods (Baten and Wagner, 2003; Laska-Mierzejewska and Olszewska, 2007). Analysis of the relationship between human height and openness to international trade must also include the rise of the welfare state (Rodrik, 1997, 1999). Norway is an example of a growing welfare state that was accompanied by a height increase (Sunder, 2003). The annual series of the degree of openness we used come from recent estimations made by Tena (2005, pp. 628–630).

3. Determinants of changes in Spaniards’ stature

The average height of a given cohort is a function of (in addition to genetic factors) nutritional intake during Table 2

<table>
<thead>
<tr>
<th>Average height (birth year in centimeters)</th>
<th>Mortality rate (%)</th>
<th>Share of consumption of health services/total consumption</th>
<th>Ratio of deflator for private consumption/GDP deflator (1995 = 100)</th>
<th>Population no schooling rate (%)</th>
<th>Openness (exports + imports/GDP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1850–1859</td>
<td>161.87</td>
<td>28.4</td>
<td>0.43</td>
<td>1.35</td>
<td>61.12</td>
</tr>
<tr>
<td>1860–1869</td>
<td>162.08</td>
<td>30.3</td>
<td>0.48</td>
<td>1.39</td>
<td>56.38</td>
</tr>
<tr>
<td>1870–1879</td>
<td>162.25</td>
<td>30.9</td>
<td>0.40</td>
<td>1.46</td>
<td>51.14</td>
</tr>
<tr>
<td>1880–1889</td>
<td>163.06</td>
<td>31.6</td>
<td>0.65</td>
<td>1.56</td>
<td>51.50</td>
</tr>
<tr>
<td>1890–1899</td>
<td>163.38</td>
<td>30</td>
<td>0.74</td>
<td>1.50</td>
<td>53.31</td>
</tr>
<tr>
<td>1900–1909</td>
<td>164.19</td>
<td>25.6</td>
<td>1.00</td>
<td>1.44</td>
<td>57.23</td>
</tr>
<tr>
<td>1910–1919</td>
<td>165.05</td>
<td>23.4</td>
<td>0.73</td>
<td>1.40</td>
<td>49.97</td>
</tr>
<tr>
<td>1920–1929</td>
<td>164.38</td>
<td>19.7</td>
<td>1.02</td>
<td>1.47</td>
<td>47.70</td>
</tr>
<tr>
<td>1930–1939</td>
<td>165.51</td>
<td>17.2</td>
<td>1.91</td>
<td>1.33</td>
<td>54.62</td>
</tr>
<tr>
<td>1940–1949</td>
<td>166.68</td>
<td>13.5</td>
<td>3.12</td>
<td>1.77</td>
<td>33.20</td>
</tr>
<tr>
<td>1950–1959</td>
<td>168.82</td>
<td>9.6</td>
<td>2.96</td>
<td>1.70</td>
<td>33.23</td>
</tr>
</tbody>
</table>

Sources: Height, Table 1; mortality, Nicolau (2005); consumption of health services, deflator for private consumption, GDP deflator and consumption per head, Prados de la Escosura (2003); population no schooling rates, Núñez (2005, pp. 232–236); openness (Tena, 2005, pp. 628–630).

Fig. 6. The relationship between height (birth year) in centimeters (left vertical axis) and the grade of openness (right vertical axis).
infancy and childhood. Attained height reflects the trade-off between the amount and quality of nutrients available for growth from childhood to maturity and the demands imposed by body maintenance, disease, and work. Thus, the influence of income on height is indirect. Income affects height because it is one of the determinants of food consumption and health services consumption, and is also related to child labour and the disease environment.

Thus, an increase in the average height of individuals living under a given set of economic conditions could stem from: an increase in per capita GDP, a decrease in food prices relative to the GDP deflator, an increase in the share of consumption of health services, or a decrease in the mortality or infant-mortality rate. Other factors that indirectly influence income could also influence height, such as the degree of openness, and various human-capital variables, such as the schooling rate, previously mentioned.

Following Jacobs and Tassenaar (2004), we model human stature as a Vector Autoregressive Model (VAR). We let $H_t^c$ be the average height of conscripts at age $t$ of the cohort measured in year $t$, which is observed from $t = 1, \ldots, T$. The attained height at each age is by definition equal to the increments in stature from the year of birth:

$$H_t^c = \Delta H_t^{c,-1} + \Delta H_t^{c,-2} + \cdots + \Delta H_t^{c,1} + \Delta H_t^{c,0}$$  \hspace{1cm} (1)

where $\Delta H_t^{c,i} = H_t^{c,i} - H_t^{c,i-1}$ is the increment in height of the cohort of conscripts measured in year $t$ between age $t - i$ and $t - i - 1$, $i = 1, \ldots, \tau$ and $\Delta H_0^c$ (or $H_0^c$) is the length at birth. We assume that the (unobserved) increments in height depend linearly on income and other explanatory variables, such as those described in Section 2.

$$\Delta H_t^{c,i} = a_i t Y_{t-i} + \epsilon_{t-i}$$  \hspace{1cm} (2)

where $\epsilon_{t-i}$ is an error term and $a_i$ is the coefficient associated with the explanatory variables. Substituting in a recursive way gives:

$$H_t^c = \sum_{i=0}^{\tau} a_i t Y_{t-i} + \sum_{i=0}^{\tau} a_i \epsilon_{t-i} = \alpha(L)Y_t + \epsilon_t$$  \hspace{1cm} (3)

where $L$ is the lag operator and $\epsilon_t$ is a moving-average error expression.

Estimating Eq. (3) poses several problems. Since the majority of explanatory variables are endogenous, estimating a single-equation for height by Ordinary Least Squares (OLS) is not appropriate as regressors are endogenous. We would have an endogeneity problem because the error term and the regressors would be correlated.

We therefore estimate a structural VAR model that permits the existence of a cointegration relationship among the variables in (3).

For that purpose, we use the Vector Error Correction Equilibrium (VECqM) VAR model (4):

$$\Delta Y_t = c + \sum_{i=1}^{p} \Phi_i \Delta Y_{t-i} - \lambda Y_{t-1} + \epsilon_t$$  \hspace{1cm} (4)

where $Y_t$ is a vector of endogenous variables, $c$ is a vector of constants, $\Phi_i$ is the matrix of autoregressive coefficients, and $\epsilon_t$ is the vector of white-noise processes. Identification of the structural shock is achieved by applying the Pesaran and Shin (1998) technique to the variance-covariance matrix of the reduced form residuals $\tilde{\epsilon}_t$.\(^{14}\)

The orthogonized and the generalized impulse-response functions differ in a number of respects. The generalized impulse responses are invariant to the reordering of the variables in the VAR, but this is not the case with the orthogonized ones. There are many alternative parametrizations that could be employed to compute orthogonized-impulse responses, and there is no indication of which parameterization should be used (especially in the absence of any a priori theory). In contrast, the generalized impulse responses are unique and take into account the historical patterns of correlations observed amongst the different shocks.

Our baseline VAR consists of a six-variable model. It includes height in natural logarithms (ln $h$), mortality rate (mort), the share of consumption of health services in total consumption (consume), the ratio between deflator of private consumption and GDP deflator (relativprice), real per capita GDP in natural logarithms (ln $gdp$), and openness (openness).\(^{15}\)

3.1. Preliminary step: unit root, cointegration, and regime-shift tests

A preliminary step, before estimating Eq. (4), is to conduct an individual cointegration analysis. Three univariate unit-root tests were done. The results of the augmented Dickey–Fuller (ADF) test and the Phillips–Perron (P–P) (1988) test suggest that the majority of the variables are I(1), and the Ng–Perron (2001) test, which corrects by distortions size indicates that height continues to be an I(1) variable, but that the rest of the series are I(2) (Table 3).\(^{16}\)

Next, we carry out a Johansen (1990) cointegration test, in order to examine the possibility of a long-run cointegration relationship among the variables and to estimate the cointegration vectors. According to the $\lambda$-max statistic, the null hypothesis of no cointegration versus one cointegration vector and one cointegration vector versus two was rejected at the 95% confidence level. Two cointegration vectors were suggested by the unrestricted cointegration rank test (Maximum Eigenvalue). We now introduce the two normalized cointegrating coefficients for the two cointegration equations, since all the variables are I(1) processes using the Johansen cointegration test for variables in levels. Table 5 offer the main results of Johansen cointegration test for variables.

We find that height is positively related to the share of consumption of health services in total consumption and

\(^{14}\) One of the main advantages of this technique is that it does not require the orthogonalization of shocks and is therefore invariant to the ordering of the variables in the VAR, permitting us to obtain generalized impulse response functions exempt from criticism about the election of the ordering of the variables in the VAR.

\(^{15}\) The percentage of the population without schooling was also included as an explanatory variable, but it was insignificant during our sample period.

\(^{16}\) We present the results of the test in Table 3. The values of the test statistics are available upon request.
the degree of openness and negatively related to the ratio between the consumer prices and GDP deflators and the mortality rate. The second equation reveals that the per capita GDP depends positively on the share of consumption of health services in total consumption and openness, and negatively on the mortality rate, and the consumer prices deflator relative to the GDP deflator. All the explanatory variables were significant in both equations.

The results of the Ng–Perron (2001) test permit us to apply the Johansen cointegration test for the height series in levels and the rest of the variables in differences. We again obtain two cointegration relationships.

In this case height is responding positively to changes in the share of consumption of health services in total consumption and the degree of openness, and negatively to the changes in the ratio between consumer prices of and the GDP deflator and mortality rates. We also observe that the per capita GDP is responding positively to changes in prices and openness and negatively to the mortality rate. The changes in the share of consumption of health services in total consumption are insignificant.

Finally, we use the Gregory and Hansen (1996) test to determine whether a regime shift in the cointegration relationship is possible. This is designed to test the null of no cointegration against the alternative of cointegration in the presence of the regime shift and thus to determine the place of the shift in the time series. We have run the GAUSS programs for this test using series at levels for all the variables and for all the variables in differences, except for height. We reject the null hypothesis of no cointegration, and we find a regime shift around 1936 (Table 4).17

3.2. Vector autoregressive error correction model main results

We estimate the VECqM specification, and we impose the two long-run cointegration relationships derived there by means of the Johansen (1990) test. Our baseline VAR consists of a six-variable model with four lags. It includes height in natural logarithms (ln height), mortality rate (mortality), the share of consumption of health services in total consumption (consume), the ratio between the personal consumption and the GDP deflators (relativprice), real per capita GDP in natural logarithms (ln gdp), and openness (openness). We also include one dummy variable for the Civil War period following the regime-shift test results. By considering four lags in our estimation, we are in effect including the influence of GDP on height during eight lags, since our height variable is a five-year moving-average variable. This implies that we are limiting our analysis to height changes from adolescence through the age of 21, and therefore are not capturing the childhood, stage of growth. It should also be taken into account that there are statistical difficulties in introducing a very large number of lags in a VAR. We determine the two normalized derived cointegration relationships by estimating the VECqM (Table 6). The results are similar to those obtained by means of the Johansen (1990) test.

As for the main results of the VAR estimated coefficients, we center on the error correction results. The error correction results are not amenable to generalization and indicate more nuanced interaction between the variables. In particular, we find more instances in which per capita GDP adjusts to the deviations from its cointegration relationship with the rest of the economic-development indicators and the cointegration relationship among height and the same set of indicators. The adjustment coefficient of height with respect to the long-run cointegration relationships is negative and significant for the first cointegration relationship (−0.013) and positive and significant (0.0062) for the second. Changes in stature depend on changes in the share of consumption of health services, and changes in the ratio of consumer prices to the GDP deflator, income, the mortality rate, and the degree of openness. Using these variables, we can explain almost 69% (using the value of the R-square) of the changes in stature during the period 1850−1958.18

With reference to the per capita GDP equation, we can explain only about 56% of the changes in per capita GDP during the sample period. Changes in per capita GDP depend positively on the height variable, the degree of openness, and the share of consumption of health services, and negatively on the mortality rate and the ratio between the consumer-price and the GDP deflators. The two cointegration relationships are significant, with adjustment coefficients to the deviations from the cointegration relationships of −0.94 and −0.77, respectively. This result indicates that the size of the adjustment associated with the per capita GDP is due to more than the height variable and it lends support to our argument that the relationship between per capita GDP and height is not unidirectional.

Although we concentrate our attention on the height and income variable for the sake of brevity, we will also comment the mortality equation results. We can explain about 54% of the changes in mortality rate during the sample period. Changes in mortality rate depend negatively on the height variable, per capita GDP, the share of consumption of health services in total consumption and

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17 We are grateful to a reviewer for advising us to use this test.

18 We obtain a high value of the t-ratios for the constants in the long-run cointegration regressions. This reflects, as we had expected, the elevated weight of the omitted variables in the model. It is to be noted that we are studying the relationship among height, per capita GDP, and some economic-development indicators by means of VECqM models. It is impossible to explain all the changes because crucial data are unavailable.
openness, and negatively on the ratio between the consumer-price and the GDP deflators.

3.3. Generalized impulse-response functions

A convenient feature of this analysis is the possibility of representing an accumulated impulse response of changes in stature or other standard of living variables to the rest of the variables without having to deal with the issue of the ordering of the variables. This point is rather controversial because Cholesky’s decomposition is traditionally used to calculate the impulse response. To apply this methodology one must first determine the ordering of the variables; this poses a problem for us, because we have no a priori idea of what the ordering should be. An possible solution is to apply the Granger causality test to each of the variables but when we attempted to do so, in a previous version of this paper, the ordering that we obtained was unrealistic.

For this reason we decided to calculate generalized impulse-response functions instead of obtaining them by means of Cholesky’s orthogonalization. This technique, proposed by Pesaran and Shin (1998), does not require the orthogonalization of the shocks and is invariant to the ordering of the variables.

The accumulated generalized impulse response of height to one-standard-deviation shock (unexpected changes) in the independent variables is presented in Fig. 7. These indicate that height responds negatively to a positive increase in the mortality rate and to the ratio of the consumer-price and the GDP deflators and positively to an increase in GDP, the share of consumption of health services in total consumption, and the degree of openness. We conclude from the impulse-response analysis that the height response to a positive shock in per capita GDP is positive, but approximately eight years are required to obtain this positive effect – an indication, perhaps, of the importance of the standard of living during the adolescence period as a determinant of adult height.

For purposes of illustration, we proceed to interpret numerically the results of the impulse-response functions. A one-standard-deviation unexpected increase (a positive shock) in per capita GDP – equal to 4.20% – will lead to a 1-cm height increase (0.0052 in logs) after twenty years. A one-standard-deviation positive shock to mortality (e.g. an epidemic) – equal to 5.40% – will result in a decrease in average stature of 0.019 (in logs) over the same sample period. This implies that the response of height (in logs) to a mortality shock is 3.65 times greater than the response to a per capita GDP shock. A one-standard-deviation positive shock to the share of consumption of health services in total consumption – equal to 0.86% – will mean a 0.0055-cm (in logs) height increase, and a one-standard-deviation positive shock to the relative price of consumption – equal to 5.7% – will lead to a 0.0052-cm (in logs) decrease in average stature after twenty years. The response of height to these two latter variables is similar to the response with respect to per capita GDP.

Table 6
Normalized Long-run cointegration relationships among height and their determinants by applying Johansen cointegration tests.

<table>
<thead>
<tr>
<th>Long-run relationship</th>
<th>Dependent variable height</th>
<th>Dependent variables GDP per head</th>
</tr>
</thead>
<tbody>
<tr>
<td>1850–1958</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consume</td>
<td>0.222* (2.43)</td>
<td>0.380* (4.78)</td>
</tr>
<tr>
<td>Relative price</td>
<td>−0.129* (1.89)</td>
<td>−1.147* (5.01)</td>
</tr>
<tr>
<td>Mort</td>
<td>−0.394* (5.91)</td>
<td>−1.327* (5.93)</td>
</tr>
<tr>
<td>Openness</td>
<td>0.1009* (3.90)</td>
<td>0.158* (1.83)</td>
</tr>
<tr>
<td>Constant</td>
<td>−5.08 (217.24)</td>
<td>−0.036 (26.74)</td>
</tr>
<tr>
<td>Trend</td>
<td>−0.00026* (4.21)</td>
<td>0.00067* (3.25)</td>
</tr>
</tbody>
</table>

*-Ratio between parentheses. 
Significant 5% level. 

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19 The Granger causality test provided information about precedence changes, in which changes in one variable precede changes in the other, but were unable to derive any realistic interpretations.

20 See María-Dolores and Martínez-Carrilón (2009). In that version of the paper we estimated a first version of the VAR, in which prices were before per capita GDP (this implies that prices are flexible in the long run); then we reversed the order, making prices after per capita GDP (this implies that prices are rigid, and is unrealistic in the long run).
The final issue to be considered is that of the accumulated generalized impulse response of per capita GDP to one-standard-deviation in shocks (Fig. 8). We observe how per capita GDP responds positively to positive height shocks, and the share of consumption of health services, and openness, and negatively to an increase in the ratio between the price and GDP deflators and the mortality rate. The response of per capita GDP to height changes is small and positive at the start and then increases after the age of sixteen.

Next, we comment on the numerical results for the per capita GDP impulse-response functions. A one-standard-deviation positive height shock – equal to 0.044% – will increase per capita GDP in 1.19 pesetas after twenty years and one-standard-deviation shock in the share of consumption of health services will increase per capita GDP by 1.46 pesetas (constant prices 1995). In contrast, a one-standard-deviation shock to the relative price of consumption will decrease per capita GDP by 1.49 pesetas in twenty years. The response of per capita GDP to the share of consumption of health services and the relative price of consumption is larger than its response to a per capita GDP shock or a height shock.

Our VECqM results – and particularly those that concern the impulse-response functions also reveal that per capita GDP is not simply a function of height and that height is not simply a function of per capita GDP, but rather that there is a mutual dependency between the two.

3.4. Robustness analysis

By using the Ng–Perron (2001) test, we found that all the standard of living indicators except the height variable could be I(2) processes. To assess the extent to which our results
are sensitive to these results, we re-estimate the VECqM specification, deriving the two long-run cointegration relationships by means of Johansen’s (1990) test (Section 3.1). Our baseline VAR consists of a six-variable model. It includes height in natural logarithms (ln height), changes in mortality rate (Δmort), changes in the share of consumption of health services in total consumption (Δconsume), changes in the ratio between the private consumption and the GDP deflators (Δrelativprice), changes in real per capita GDP in natural logarithms (Δln gdp), and changes in the degree of openness (Δopenness).

The long-term relationships derived from this procedure are of interest (Table 7). Height depends positively on the increase in the share of consumption of health services in total consumption and the degree of openness, and it depends negatively on the changes in the ratio of prices to the mortality rate. The adjustment coefficients of height with respect to the two cointegration relationships are -0.013 and 0.00062, respectively. All of the accumulated generalized impulse-response functions of height to the different variables are presented in Fig. 9. Height responds positively to unexpected changes in per capita GDP, the

<table>
<thead>
<tr>
<th>Long-run relationships</th>
<th>Dependent variable height</th>
<th>Dependent variable Changes in GDP per head</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΔConsume</td>
<td>0.064* (2.49)</td>
<td>0.403* (2.08)</td>
</tr>
<tr>
<td>ΔRelativprice</td>
<td>-0.024* (2.09)</td>
<td>1.112* (2.43)</td>
</tr>
<tr>
<td>ΔMort</td>
<td>-0.092* (4.83)</td>
<td>-2.076* (3.10)</td>
</tr>
<tr>
<td>ΔOpenness</td>
<td>0.025* (3.79)</td>
<td>0.460* (1.95)</td>
</tr>
<tr>
<td>Constant</td>
<td>-5.55* (465.25)</td>
<td>0.030* (2.54)</td>
</tr>
<tr>
<td>Trend</td>
<td>-0.00118* (3.69)</td>
<td>0.000695* (2.07)</td>
</tr>
</tbody>
</table>

* Ratio between parentheses.

* Significant 5% level.
share of consumption of health services, and the degree of openness, and negatively to unexpected changes in the mortality rate and to changes in the ratio between consumer prices and the GDP deflator.

By observing the behavior of changes in the per capita GDP, we appreciate how it responds positively to changes in height, in the share of consumption of health services in total consumption, and in the ratio between prices, and negatively to changes in the mortality rate and the degree of openness.

Finally, we comment on the numerical results for the height impulse-response functions. A one-standard-deviation positive shock in per capita GDP growth – equal to 4.66% – will lead to a 0.0038-cm (in logs) height increase after twenty years. A one-standard-deviation positive shock to the growth rate of share of consumption of health services – equal to 0.99% will produce a 0.008-cm (in logs) height increase. In contrast, a one-standard-deviation positive shock in the growth of the relative price of consumption – equal to 5.96% – will cause a 0.00525-cm (in logs) height decrease. We observe how mortality shocks are again producing greater effects on height.

4. Conclusions

This examination of the relationship between height and economic development in Spain for the period 1850–1958 reveals a long-running relationship among height, income, and other indicators of economic development, such as the mortality rate, the share of consumption of health services in total consumption, the ratio between the consumer-price and the GDP deflators, and the degree of openness.

Having calculated, by means of a VAR-Vector Equilibrium Correction Model (VECqM), the impact on height of changes in the explanatory variables, we could account for
almost 69% of the changes in stature during the period 1850–1958. The accumulated generalized impulse response of the changes in stature to these variables revealed that height responds positively to an increase in per capita GDP, an increase in the share of consumption of health services in total consumption, and the degree of openness, and negatively to the mortality rate and the ratio between the consumer-price and GDP deflators.

To assess to what extent our results are sensitive to the cointegration order of the variables, we re-estimated the model, setting height at levels and the rest of the economic-development indicators in first differences. Our main results remain unchanged. We therefore conclude that conditions that provoke an increase in sickness and mortality rates and that raise the relative price of consumption tend to impede cellular growth and adult height, whereas factors responsible for an increase in the proportion of health services to overall consumption and for an opening up the economy to trade have tended to benefit biological growth, which in turn is reflected in an increase in the average height of Spain's adult population.

Our VECqM-based results indicate that the dependency between per capita GDP and height is mutual: that each can be a function of the other. The impulse-response function and our main VAR confirm that there is a synergetic relationship between per capita GDP and height (at least that of adult males). There is not a unidirectional relationship. However, this mutual causality is difficult to determine, because height and per capita GDP trends are not always synchronized. We can state with confidence that – setting aside the issue of per capita GDP levels – height is an important economic-development indicator.

The next step is to apply other methodologies to the relationship between height and a range of economic-development indicators. For instance, Den Haan (2000) has suggested a procedure for analyzing the co-movement between output and prices, by determining the correlations of the corresponding VAR forecast errors at various forecast horizons; such a procedure might resolve some of the issues that we addressed in this paper but were unable to answer.

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