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Descriptive Finding

Variations in male height during the epidemiological transition in Italy: A cointegration approach

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Contents

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Abstract

BACKGROUND
The historical demography literature has a longstanding interest in establishing a connection between human body development and the living conditions experienced during infancy and childhood. Empirical research on such matters increasingly relies on survival indicators rather than classical economic measures of living standards, as the former are more directly linked to nutritional quality, material well-being levels, and technological development.

OBJECTIVE
We explore the relationship between epidemiological conditions and male adult height variation in Italy to understand if and to what extent progress in survival impacted human body evolution during the epidemiological transition.

METHODS
By exploiting the national military archive data from the Italian National Institute of Statistics and the Human Mortality Database, we focus on conscript cohorts born between 1872 and 1980 to connect average male height at the recruitment age with the prevailing infant and general survival conditions in the calendar year of conscripts' birth. We adopt an econometric approach based on cointegration analysis to study both the long- and the short-run relationships between the time series of interest.

RESULTS
Error correction model estimates find a positive link between epidemiological condition development and the secular increase in male height in Italy.

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CONTRIBUTION
In the long run, as the probability of survival at the first birthday and life expectancy at 5 years increase, so does average male height. In the short term, however, we find an estimated inverse relationship between survival and stature, which we interpret as a counterintuitive mechanism of negative selection in the survival of the most fragile individuals both among infants and the general population.

1. Introduction

Non-monetary measures of living standards are increasingly used to explain variation in human development, animating scholarly debates, especially in the historical and economic literature. On the one hand, the quality and overall potential of economic indicators (e.g., output and consumption per capita) to represent historical development trends are increasingly debated (Peracchi 2008). On the other hand, bio-anthropometric measures – e.g., life expectancy and body size – are considered good proxies for living standards as they are more directly linked to nutritional quality, material well-being levels, and the degree of technological development (Steckel 1995, 2013).

Theoretically, the relationship between living conditions and anthropometric features has been explained in different ways. Techno-physio theorists, who interpret the human body evolution during the demographic and health transitions after the industrial revolution and the onset of urbanization (Floud et al. 2011), explain the secular increase in height as the physiological capital accumulation resulting from innovation in food production, progress in medical knowledge, and increased availability of house heating and clothes (Fogel 2003). Others focus instead on the impact of fetal and neonatal diseases on adult health. According to the theory of early-life conditions, the effects of physiological damage caused by diseases at fetal, neonatal, and infant ages are not limited to childhood but affect the individual throughout the life course. Exposure to pollutants, infectious diseases, malnutrition, and precarious maternal conditions slow down infant development and predict worse health statuses for more fragile individuals, as well as a faster ageing process and higher mortality (e.g., Bengtsson and Broström 2009; Quaranta 2013). Other theories postulate that frailties due to disease burdens affect adult individuals' height (Alter 2004). Generally, scholars agree that systematic differences in stature mirror differences in net nutrition (gross nutrition minus losses due to the disease environment) during the development years, especially early childhood (Silventoinen 2003).

A rich body of study that provides new information on historical variations in human height and weight now makes it possible to empirically investigate such relationships

(Floud et al. 2011). By collecting evidence from different countries and periods, the literature shows that in the contemporary world a strong, positive correlation exists between adult body size and income per capita (Steckel 1995), while poorly nourished children usually fail to achieve their potential height as adults (Eveleth and Tanner 1990). Such studies often draw on the military archives as a source of data on height (Peracchi 2008). Although it has some limitations (the information is limited to the male population), such data constitutes an important historical source of information on height for different contexts. It has been ascertained that before the unification of Italy in 1861, Italian soldiers' height was related to the disease environment and the prevailing nutritional and income levels (A'Hearn 2003; Vecchi and A'Hearn 2017). Early anthropometric studies on the post-unification period also show that height and chest circumference variability is linked to the interregional differences in socioeconomic conditions across the country, suggesting that biometric features reflect unequal distributions of material resources and widespread poverty (Arcaleni 2006; Livi 1896, 1905; Rettaroli 2021). Studies on the 20th century cohorts show that height growth has a strong and positive correlation with different aggregate welfare indicators, such as food consumption, caloric intake, life expectancy at birth, and gross enrollment rate in primary school (Peracchi 2008). Finally, combining data on the mean height of female cohorts born between 1950 and 1980 in the USA and 11 European countries, Bozzoli, Deaton, and Quintana-Domeque (2009) find that post-neonatal mortality is strongly and negatively associated with height, even after controlling for GDP per capita and country and year effects.

Our study joins this debate to explore early-life disease load and male adult height evolution in Italy. Exploiting the national military archive data, we focus on conscript cohorts born between 1872 and 1980 to connect average height at recruitment age and the prevailing infant survival conditions in the calendar year of the conscripts' birth. We adopt an econometric approach based on cointegration analysis to study both the long- and the short-run relationships between the time series of interest. Since we endeavour to verify if male height growth trends are connected to both infant and the general population's epidemiological conditions, we also consider life expectancy at 5 years at the conscripts' calendar year of birth as an additional survival measure. Covering the post-unification decades, the World Wars, and the subsequent economic recovery, our data encompasses the progressive improvement in living standards and the variation in survival levels that the observed generations experienced over the last century. We expect that the historical progress in epidemiological conditions in Italy positively contributed to the long-term increase in adult male height, although abrupt improvements in living conditions might reverse such a process in the short term.

2. Methodology

2.1 Data

Our data combines information on yearly average male height for cohorts born between 1872 and 1980 at the national level, made available by the Italian National Institute of Statistics (Istat), with selected survival measures from the Human Mortality Database (HMD) (Barbieri et al. 2015).[3] The height variable (*height*) was originally collected during the compulsory medical examination aimed at verifying fitness for military service that every Italian man of conscription age had to undergo according to the legislation in force at the time or as dictated by war events (Fornasin and Freni 2022). Because conscription was universal, the collected data does not suffer the truncation problems typical of historical samples of enlisted soldiers (A'Hearn, Peracchi, and Vecchi 2009).

The main quality issues in this data source concern the variation in conscription age and draft evasion. To overcome the former issue, we use the average height normalized to age 20 by Costanzo (1948). Concerning draft evasion, A'Hearn and colleagues (2009) report that, on average, for the 1855–1910 birth cohorts roughly 12% of the individuals on the conscription rolls failed to appear before the provincial draft council and were not examined. Absenteeism was greatest in times and areas with known high emigration rates and was no longer a major issue after the decline of mass emigration in the 1920s.[4]

Two survival measures are instead computed from the HMD: we consider each cohort's survival probability at the first birthday (*p0*) and life expectancy at 5 years (*e5*), a period indicator derived from the life table of each conscript cohort's year of birth that summarizes both the disease burden and the prevailing general population health status. Setting the limit at age 5 excludes the typical causes of under-5 mortality from the final indicator, indicating the survival level of the Italian population aged 5 and above in the calendar year in question.

2.2 Methods

We apply time series econometric techniques based on Vector Autoregression (VAR) modelling according to the following stepwise procedure. First, we study the series

[3] The average height time series is available starting 1854, whereas HMD data is only available from 1872 onwards.
[4] Draft evasion peaked among the birth cohorts of the 1870s and declined among those born in the 1900s, which corresponds well to the rise of emigration in the 1890s and its decline in the 1920s (Hatton and Williamson 1998).

individually to check their stationarity using the Kwiatkowski, Phillips, Schmidt, and Shin (KPSS) test (Kwiatkowski et al. 1992). Second, if the studied series are not stationary, we test for the existence of a cointegrating equation between average height and survival time series using Johansen's cointegration test (Johansen 1995) to verify if the series are interlinked by a long-run relationship. If that is the case, an error correction model (ECM) needs to be specified as in Equation (1):

$$\Delta y_t = \beta_0 + \sum_{i=1}^{n} \beta_{1i} \Delta y_{t-i} + \sum_{i=1}^{n} \beta_{2i} \Delta x_{t-i} + \beta_3 (y_{t-1} - a - \beta_4 x_{t-1}) + \varepsilon_t, \qquad (1)$$

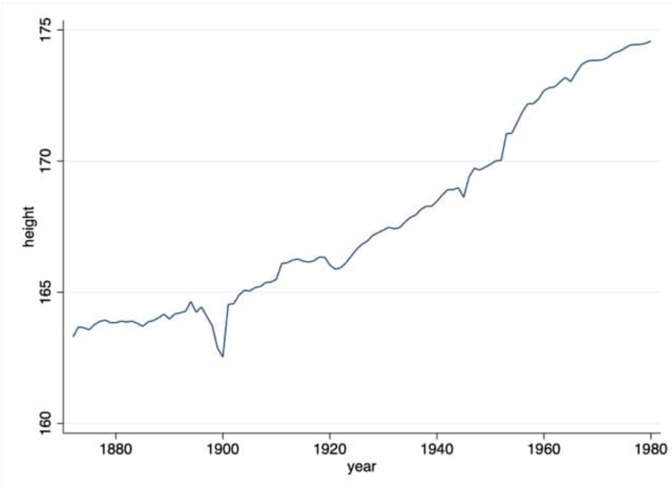
where y_t and y_{t-i} are the dependent variable at time t and $t-i$, x_t and x_{t-i} are the explanatory variables at time t and $t-i$, and the short-run component is expressed by the part of the equation $\beta_0 + \sum_{i=1}^{n} \beta_{1i} \Delta y_{t-i} + \sum_{i=1}^{n} \beta_{2i} \Delta x_{t-i}$. In the latter, the coefficient β_0 represents the intercept in the short period, the coefficient β_{1i} measures the magnitude of the short-run relationship between the lagged dependent variable y_{t-i} and y_t, and the coefficient β_{2i} measures the magnitude of the short-run relationship between the lagged independent variable x_{t-i} and y_t. The long-run component is instead expressed by the cointegration vector $\beta_3(y_{t-1} - a - \beta_4 x_{t-1})$ where a and β_4 represent the long-run intercept and the magnitude of the long-run coefficient, and the coefficient β_3 is the speed of adjustment, or the speed at which the two series tend to converge in the long run. The optimal lag n is estimated using the most common information criteria for lag order selection. Dummy variables are also included in the model to control for possible structural breaks in the series, whose statistical relevance is investigated with appropriate tests (Bai and Perron 1998, 2003). Finally, econometric tests and models are run on the dependent variable transformed into logarithmic scale (*log_height*) to interpret the estimated coefficients in terms of semi-elasticity.

3. Results

Figure 1 plots the evolution of Italian conscripts' average height in the 1872–1980 period, highlighting the persistent increase in height over the century, even during the transwar period, and the acceleration of such increase after World War II. During the time considered the average stature in Italy increased from 163.19 cm to 174.58 cm – by nearly 1 cm every ten years, although to a different extent depending on the sub-period: 0.58 cm in 1871–1910, 0.95 cm in 1911–1950, and 1.52 cm in 1951–1980. A similar trend is observed in other Mediterranean countries such as Greece, Spain, and Portugal, where stature is lower on average compared with continental and northern Europe and height growth rates are delayed (Hatton and Bray 2010). Concerning infant survival probability trends in Italy, *p0* attains 0.79 for the 1870s cohorts and then rises considerably – to 0.94

during the 1950s and 0.98 during the 1970s. Analogously, improvements are observed in terms of life expectancy at 5 years, which rises from 47.5 years in 1872 to 70.3 in 1980. A summary of the studied variables is provided in Table 1.

Figure 1: Plots of time series of variables *height*, *p0*, and *e5*



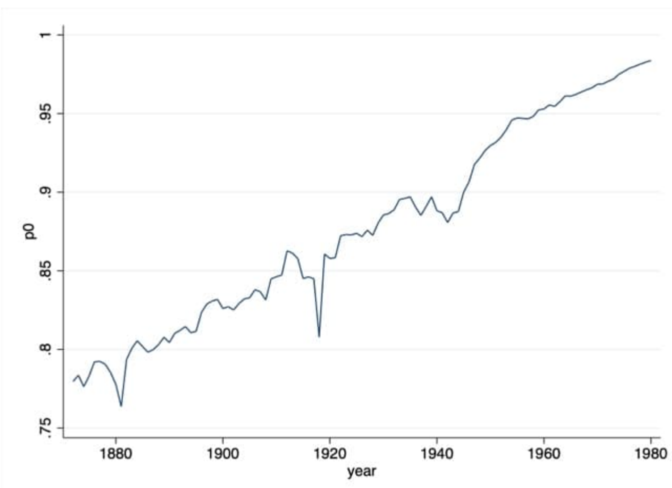
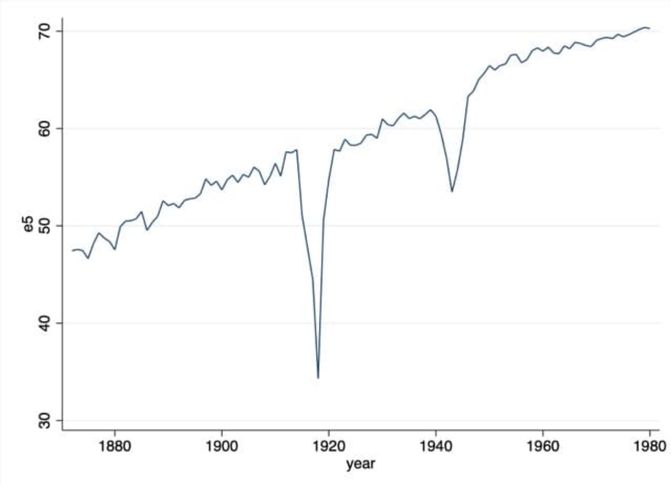


Figure 1: (Continued)



Source: Own elaboration of Istat and Human Mortality Database data.

Table 1: Descriptive statistics

Variable	N	Mean	SD	p5	p10	p25	p50	p75	p90	p95
height	109	167.83	3.69	163.68	163.84	164.44	166.83	171.05	173.84	174.29
p0	109	0.88	0.06	0.78	0.79	0.83	0.87	0.94	0.97	0.98
e5	109	58.7	7.7	47.6	48.8	52.8	58.3	66.6	69.1	69.6

Source: Own elaboration of Istat and Human Mortality Database data.

Turning to the cointegration analysis, within the period studied both the upward trends of the series and the KPSS test indicate that *log_height*, *p0*, and *e5* are locally integrated and become stationary at the first differences.[5] Moreover, Johansen's cointegration test (Table 2) verifies the existence of a long-term relationship between the two pairs of variables, suggesting that *log_height* and *e5* and *log_height* and *p0* are both connected by a long-run equilibrium.[6]

[5] Since human height cannot exceed its biological limit, the evolution of the variable is bound to follow a unit root process locally, that is, during the period 1872–1980. We thank an anonymous referee for sharing such an insight that improved the accuracy of our speculation.

[6] The econometric analysis was carried out using EViews 12. The lag order selection test used here – based on Final Prediction Error (FPE), Akaike information criterion (AIC), Schwarz's Bayesian information criterion (SBIC), and Hannah and Quinn information criterion (HQIC) – indicate that the optimal lag is equal to 1.

Table 2: Johansen's cointegration test

Number of cointegrating equations	Eigenvalue	Trace statistic	Critical Value 1%	Prob.**	Max-Eigen statistic	Critical Value 1%	Prob.**
log_height* vs. *p0							
None*	0.16551	32.25	24.60	0.0005	19.54	20.20	0.0029
At most 1	0.11104	12.71	12.97	0.0351	12.71	12.97	0.0351
log_height* vs. *e5							
None*	0.16150	30.12	24.60	0.0004	19.02	20.20	0.0025
At most 1	0.09763	11.09	12.97	0.0383	11.09	12.97	0.0383

Note: (*) denotes rejection of the null hypothesis at 1%; (**) are the MacKinnon-Haug-Michelis p-values (1999).
Source: Own elaboration of Istat and Human Mortality Database data.

The time series analysis also identifies two structural breakpoints. The first falls around 1900 as confirmed by the Bai-Perron test, indicating that the break is likely associated with a temporary change in the relationship between survival and height between 1897 and 1900. Height values for that period correspond to the cohorts that turned 20 across the years 1916–1920, during World War I (Figure 1). During this major conflict the Italian military broadened its recruitment base to allow men who were either of less than average height, younger than 20, or previously excused from the service (Fornasin and Freni 2022) to join the military, producing a negative height selection (Lamioni 2002). In the immediate post-war period this negative selection might have lasted for another few years, given the significant number of human lives lost in the conflict. Such a hypothesis resulted in constructing a dummy variable ($D1$) that takes the value 1 during the period 1897–1900 and 0 otherwise.

The second breakpoint falls around 1953, starting when a permanent change in the slope of all the considered series is observed. Because the average height of the 1953 cohort was registered in 1973 when the children of the Italian economic miracle first entered the military, the hypothesis is that the average height of conscripts began to increase more rapidly following the constant and significant rise in living standards which began in the early 1950s. This enhancement of general living conditions was irreversible and lasted throughout the subsequent years included in the time series. We therefore code a second dummy variable ($D2$) that takes a null value until 1952 and a value of 1 from 1953 onwards.

A further consideration concerns whether or not to estimate short- and long-run intercepts and a long-run trend component (Kennedy 2008). We specify a long-run constant as we assume that there exists a minimum average height in the population of conscription age, independent of survival levels, while a long-run trend is excluded, as it

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Results from this and any other statistical test not shown in the paper are available from the authors upon request.

seems less plausible to assume that height can vary net of any other factor linked to the epidemiological or socioeconomic context – i.e., solely due to time. Finally, the specified short-term relationship has neither its own intercept nor a trend component.

We now proceed to estimate two bivariate ECMs, where the outcome variable y_t is the logarithm of average height (*log_height*) and the explanatory variables are the survival probability at first birthday (*p0*) (model A) and life expectancy at 5 years (*e5*) (model B). Both models include the dummy variables $D1$ and $D2$, and are specified as in Equation 2:

$$\Delta y_t = \beta_1 \Delta y_{t-1} + \beta_2 \Delta x_{t-1} + \beta_3 (y_{t-1} - a - \beta_4 x_{t-1}) + \beta_5 D1 + \beta_6 D2 + \varepsilon_t. \qquad (2)$$

Table 3 summarizes our results. For both models, the long-term constant represents the estimated historical minimum level of Italian conscripts' average height.[7] Regarding model A, the cointegrating equation confirms that a long-term relationship exists between stature and the probability of survival at first birthday. The positive *p0* coefficient indicates that as *p0* increases by one percentage point, average height tends to increase by 0.28%. Moreover, the negative speed of adjustment coefficient suggests that the two series tend to converge towards long-run equilibrium. However, as far as the short-run relationship is concerned, the coefficient associated with infant survival probability seems to indicate that there is a weak, inverse relationship between *p0* and *log_height*. A possible interpretation of this is that general improvements in perinatal and infant survival engendered an immediate, negative selection effect involving the most fragile new-borns; i.e., future adults characterized by weaker biometric characteristics who would have been less likely to survive had they been born in worse epidemiological conditions. Finally, the signs of the two dummy variables are consistent with the hypotheses of temporary negative selection in terms of height and survival between 1897 and 1900 ($D1$) and permanent positive selection from 1953 onwards ($D2$).

Analogously, results from model B show that the long-run relationship between stature and life expectancy at 5 years is positive, indicating that each additional year of life expectancy after the fifth birthday increases average height by 0.24%. Furthermore, the coefficient of the speed of adjustment is negative, confirming the hypothesized tendency of the two series to converge in the long run. Again, the estimated short-term relationship between stature and *e5* is negative, suggesting that a slight, negative selection of the least physically endowed individuals – i.e., those who would have been least likely to survive had they been born in more deprived living conditions – might have occurred in the considered period. Finally, the signs of both the $D1$ and $D2$ coefficients are also consistent with the hypotheses formulated in model B.

[7] Such levels are estimated to be 131.33 cm in model A and 146.28 cm in model B by exponentiating the coefficient associated with the intercept of the long-run component.

Table 3: ECM estimates of model A (*log_height* vs. *p0*) and model B (*log_height* vs. *e5*)

	Model A	Model B
Long-run relationship		
P0(-1)	0.280073	
	(0.01421)	
	[19.7161]	
E5(-1)		0.002408
		(0.00028)
		[8.69835]
C	4.877723	4.985489
	(0.01204)	(0.01531)
	[405.049]	[325.553]
Speed of adjustment	–0.245328	–0.094821
	(0.02977)	(0.01590)
	[–8.23941]	[–5.96224]
Short-run relationship		
D(LOG_HEIGHT(-1))	–0.127316	–0.162724
	(0.07457)	(0.08410)
	[–1.70728]	[–1.93477]
D(P0(-1))	–0.041386	
	(0.01610)	
	[–2.57036]	
D(E5(-1))		–0.000158
		(6.6E-05)
		[–2.40817]
D1	–0.005748	–0.004852
	(0.00076)	(0.00082)
	[–7.52466]	[–5.91837]
D2	0.002812	0.001439
	(0.00034)	(0.00030)
	[8.20388]	[4.80511]
R-squared	0.438900	0.307796
Adj. R-squared	0.416896	0.280650
Sum sq. resids	0.000181	0.000224
S.E. equation	0.001333	0.001480
F-statistic	19.94647	11.33884
Log likelihood	559.1298	547.8957
Akaike AIC	–10.35757	–10.14758
Schwarz SC	–10.23267	–10.02268
Mean dependent	0.000603	0.000603
S.D. dependent	0.001745	0.001745
Determinant resid covariance (dof adj.)	1.23E-10	1.12E-05
Determinant resid covariance	1.12E-10	1.02E-05
Log likelihood	922.1140	311.1758
Akaike information criterion	–16.99278	–5.573379
Schwarz criterion	–16.66805	–5.248643
Number of coefficients	13	13

Note: Standard errors in parentheses ( ) and t-statistic in [ ]. The sample includes $N = 107$ observations (years 1874–1980) after adjustment.

4. Conclusions and discussion

This study estimates the relationship between survival conditions and average male height in Italy by applying time series analysis to 1872–1980 data on body size from Istat, based on military medical records of conscription-age individuals, and the data on survival conditions provided by the Human Mortality Database.

Results from cointegration tests and EC modelling confirm that the hypothesized long-term relationship is positive, indicating that as the probability of survival at first birthday and life expectancy at 5 years increase, so does average male height. However, in the short term there seems to be a slight, inverse relationship between survival and stature. Such evidence may suggest that following a general improvement in living conditions a counterintuitive mechanism of negative selection of the most fragile individuals might occur, both during infancy and in later stages of life.

The used statistical information has a few issues that affect our results and are worth discussing. First, the national-level data even out subnational survival and height figures, which are known to vary considerably in Italy, especially between the north and the south of the country. Second, between the 19th and 20th centuries a substantial share of the male population in the target age – presumably positively selected based on both biometric and health characteristics – emigrated from Italy before undergoing the military medical examination so that their information is missing from the available data. Therefore, it is necessary to further investigate the phenomenon taking into due consideration both subnational variability and height-selective migration. Such perspectives, enriched by international comparisons and additional socioeconomic explanatory factors, will constitute the core of future inquiry.

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