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Long run relationship between biological well being, and economic development in Colombia

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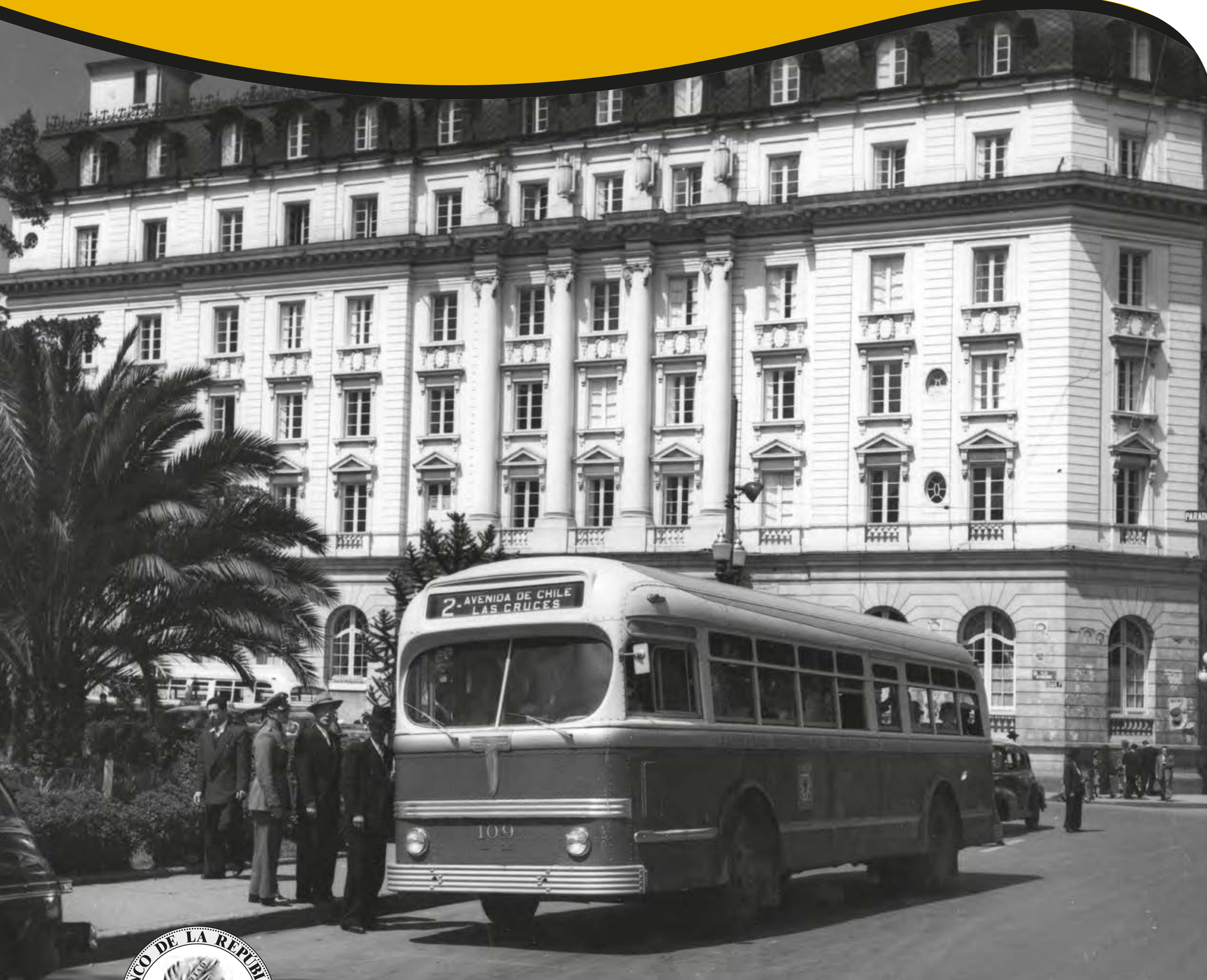

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BANCO DE LA REPÚBLICA COLOMBIA

LONG RUN RELATIONSHIP BETWEEN BIOLOGICAL WELL BEING, AND ECONOMIC DEVELOPMENT IN COLOMBIA[1]

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ABSTRACT

This paper explores the long run relationship between the physical stature of Colombians born during the twentieth century and several socio-economic development indicators using time series techniques. The econometric analysis is carried out considering three height measures: female's height, male's height, and the gender height dimorphism. The database comprises height information from the national identification cards for nearly 13 million persons born between 1910 and 1989: 6.283.452 men and 6.383.023 women. Results suggest the existence of a long-run relationship between all height measures and the economic variables included in the analysis. In general, the results indicate that improvements in the availability of better-quality food, and the reduction in food prices, measured by the degree of openness and by infrastructure developments, as well as improvements in the economic conditions lead to increases in average height. Regarding gender height inequality, the results show that height dimorphism in absolute terms decreased during the twentieth century. However, the downward trend observed until the end of 1950s reversed at the beginning of the 1960s, despite the advances in the living conditions of women during this period. This result suggests that earlier improvements in the economic conditions benefited women more than men, given the considerable gender gap in education, health, and income at the beginning of the twentieth century. On the contrary, GDP growth during the second half of the twentieth had higher returns for men relative to women.

Keywords: Anthropometrics, dimorphism, income, economic development, cointegration.

JEL Classification: I10, I15, N36, C22.

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RELACIÓN DE LARGO PLAZO ENTRE EL BIENESTAR BIOLÓGICO Y EL DESARROLLO ECONÓMICO EN COLOMBIA[2]

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RESUMEN

Este artículo estudia la relación de largo plazo entre la estatura de los colombianos, como un indicador de bienestar de la población, y varios indicadores socioeconómicos durante el siglo XX. El análisis de series de tiempo se lleva a cabo considerando tres medidas de estatura: la estatura promedio de hombres, la estura promedio de mujeres y la brecha de género en estatura (dimorfismo). La base de datos incluye información sobre la estatura de casi 13 millones de personas nacidas entre 1910 y 1989: 6.283.452 hombres y 6.383.023 mujeres, proveniente de las cédulas de ciudadanía. Los resultados sugieren la existencia de una relación de largo plazo entre todas las medidas de estatura y las variables económicas incluidas en el análisis. El aumento de la oferta de alimentos de mejor calidad y la reducción en sus precios, así como el progreso en las condiciones económicas, medidas por el crecimiento del PIB per cápita, la educación y el Índice de Desarrollo Humano llevaron a aumentos en la estatura de la población en Colombia. En cuanto a la desigualdad de género, los resultados muestran que en términos absolutos el dimorfismo disminuyó durante el siglo XX. Sin embargo, la tendencia decreciente observada en la brecha hasta finales de la década de 1950 se invirtió a principios de la década de 1960, a pesar de los avances en las condiciones de vida de las mujeres durante este período. Este resultado sugiere que los avances en las condiciones económicas que tuvieron lugar en la primera mitad del siglo XX beneficiaron más a las mujeres, dada la considerable brecha de género con respecto a educación, salud e ingresos, que ellas presentaban a comienzos del siglo XX. Por el contrario, los incrementos en el PIB observados durante la segunda mitad del siglo XX parecen haber beneficiado más la estatura de los hombres que la de las mujeres.

Palabras clave: Antropometría, dimorfismo, desarrollo económico, cointegración.

Clasificación JEL: I10, I15, N36, C22.

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1. INTRODUCTION

There has been a recent emphasis on the importance of human stature as a reliable indicator of the well-being in economic history literature because stature not only reflects genetic factors but also living conditions during childhood and adolescence. Levels of nutrition, health and the socio-economic environment where an individual grew up are reflected in her/his final adult height.[3]

Research on the socio-economic determinants of height has increased rapidly. This type of analysis is important in order to understand the achievements made in terms of quality of life. Most of the research involves cross-sectional analysis that have been carried out for several countries. These studies mainly use information on male recruits or prisoners' height for a specific region of a country.[4] This literature suggests that there are significant effects of socio-economic variables on adult final stature.[5]

Research on the determinants of height using a time series approach is less common. The long run relationship between income and height has been studied since the late 1970s (Steckel, 1979, 1983). Income affects height since it determines the consumption of food and health services, child labor and the disease environment in which an individual grew up (María-Dolores and Martínez-Carrión, 2011). In addition, nutritional and environmental conditions that determine adult height are also related to different economic variables such

[3] There is a large number or papers that recognize and use physical stature as an indicator of human welfare, see for example Galofré-Vilà (2018), Beltran (2015), Floud *et al.* (2014), Heyberger (2014), Floud *et al.* (2011), María-Dolores and Martinez-Carrión (2011), Komlos (2003, 2009), Bassino (2006), Komlos and Baten (2004), Floud (1994, 2004), Fogel (1994), and Steckel (1995a,b, 2008a, 2008b and 2009), among others.

[4] For the case of Great Britain see the paper of Floud *et al*. (1990); for the Dutch case see Huang e*t al.* (2015); for Switzerland see Schoch *et al.* (2012); see Gyenis, and Joubert (2004) for Hungary; Ayuda and Puche-Gil (2014), Martínez-Carrión and Camara (2015), Martínez-Carrión and María-Dolores (2017) for Spain; Cuff (2005) and Komlos and Baur (2004) for the United States; Bassino (2006) for Japan, Bassino *et al*. (2018) for Philippines; Guntupalli and Baten (2006) for India; Cameron (2003) for South Africa. For America Latina see the comprehensive papers of Salvatore *et al*. (2010), Martínez-Carrión (2009) and Baten (2010); for individual countries see López-Alonso and Condey (2003), López-Alonso (2007), López-Alonso and Velez-Grajales (2015) and Carson (2005) for México; Salvatore (2004a,b) for Argentina; Nuñez and Perez (2015) for Chile; Baten *et al*. (2009) for Argentina, Brazil and Peru; and Meisel and Vega (2007a, 2007b), Acosta and Meisel (2013) and Meisel-Roca *et al.* (2019) for Colombia.

[5] For a detailed historiographical review on the socio-economic determinants of height for several countries see for example Meisel-Roca *et al.* (2019).

as the price of food, the degree of openness of the economy to external trade, health expenses, education, and mortality rates.

Within this line of research, Steckel (1983) explored the relationship between average height and per capita income along with other independent variables, at the aggregate level, including data for 20 developed or developing countries. His results show that a higher GINI and living in rural and poor environments have negative effects on height, while higher levels of wealth have a positive effect. On the other hand, ethnic variables have no statistically significant effect on adult height, but among children, they are negative and statistically significant. These results are important since they suggest some potential determinants of height. However, those estimations do not consider the possible endogeneity of the variables.

More recently, Baten and Murray (2000) used time series analysis to estimate the determinants of height of adult men and women who were imprisoned in 19th century Bavaria. The authors considered time series of infant mortality rates as a measure of the disease environment, real wages as a proxy of economic conditions, and the price of milk as a proxy for the quality of nutrition. Standard OLS regressions were carried out because unit roots tests indicated that the series are stationary. The results show that economic factors in early childhood have more effects on girls' than boys' heights and were more relevant than disease indicators for both sexes. Also, the conditions in the 1st year of life are more important to determine adult height than those in later years.

Jacobs and Tassenaar (2004), explore the link between height and two determinants: income and nutrition in the Netherlands, during the second half of the 19th century. The authors argue that attained adult stature is a function of its determinants during the years of growth, and therefore it is necessary to include lags in the empirical models. However, the traditional literature on this topic, which includes a fixed pattern of lags, assumes that the velocity curve of growth does not vary over time. To solve this issue, the authors derive a dynamic model of stature that measures heights as the sum of the height increases of the years from birth onwards. They assume environmental conditions, such as income or nutrition, affect changes in height in a given year. The derived econometric model allows for a lag pattern that may change over time. Then, the authors use correlation analysis to point out the dynamic relation between height and its determinants over different windows. The authors used the Hodrick-Prescott filter to remove trends and consequently to avoid spurious trend correlations. They find that there is an indication of a change in the lag patterns in the relationship between height and the income and nutrition variables.

Peracchi (2008) reviews the evidence on the long-term relationship between men's height and economic development in Italy. Using the annual series of Italian GDP at constant 1991 prices and a series of height composed, for the most part, of information gathered from military records, the author estimated OLS regressions and correlation coefficients to examine the relation of height and real income in the long run. His results indicate that there is a strong positive correlation between height, GDP and other indicators of well-being, such as caloric intake, life expectancy at birth and gross enrollment rate in primary school.

Baten *et al.* (2010) examine the long-run relationship between economic growth and the average heights, as an indicator of the improvements in the standard of living in Indonesia for the period 1770-2000. The authors construct time series of average stature for the period under analysis. The results indicate that average height is related in the long run to improvements in food supply, hygiene and medical care. However, the correlation between economic growth and average height is imperfect. The authors argued that this result may be explained because advances in nutrition and in health conditions may happen independently of the level of economic development, and because GDP per capita may be an imperfect indicator of average income.

Lastly, María-Dolores and Martínez Carrión (2011) examine the long-run relationship between height and economic development in Spain between 1850 and 1958, using data on military-conscripts. The authors estimate Vector Autoregressive Equilibrium Corrections Models (*VECqM*) to quantify the response of height to changes in some economic indicators. The results indicate the existence of a long-run relationship among height, per capita income, 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. The accumulated generalized impulse response functions indicate that height is related positively to increases in per capita GDP, share of consumption of health services, and the degree of openness. On the contrary, height responds negatively to increases in mortality rates and in the ratio between the consumer-price and GDP deflators.

The purpose of the present paper is to estimate econometrically the long run relationship between physical stature and some economic-development indicators in Colombia during the 20th Century. The main problem for this empirical analysis is the intrinsically endogenous character of the variables. To solve this issue, we use a time series approach, in particular cointegration and vector error correction (VEC) models, which help us to identify long-run relationships, in a multivariate system with non-stationary variables. These techniques allow us to examine the dynamic properties of the multivariate system by estimating impulse response functions (IRF). In this case, IRF allows us to measure the response of height to an unexpected shock in the socio-economic indicators. Following the literature, we include per capita income, the degree of openness of the economy, infrastructure developments, schooling, mortality rates, and the index of human development as key development indicators that could influence height. Our econometric analysis considers three specifications: in the first we include average female height, the second average male height, and in the last one the gender gap in stature. We contribute to the anthropometric literature since previous research in Colombia does not include a comprehensive time series econometric analysis on the determinants of the different measures of height.

The results suggest the existence of a long-run relationship between all height measures and the socio-economic variables included in the analysis. All the measures of average height are positively related to the degree of economic openness, infrastructure development, per capita GDP, and education. Therefore, improvements in the availability of better-quality food, and the reduction in food prices, measured by the degree of openness and by the infrastructure developments, and improvements in economic conditions have a positive effect on average height.

Regarding the gender gap, the results are somewhat puzzling. Although, the results indicate that relative dimorphism is negatively related, as expected, to the degree of openness and infrastructure developments, it is positively related to per capita GDP and to the Historical Index of Human Development (HIHD). These results suggest that higher degree of openness and infrastructure developments that allows for a larger supply of food and its price reductions in the markets, have contributed to reduce the stature gender gap. On the contrary, per capita GDP and the HIHD may have contributed to widening this gap, which could be a somewhat paradoxical result.

The rest of the paper is organized as follows: in the next section we describe the data and discuss the determinants of height. Section 3 presents the methodology and analyses the time series econometric results. Finally, our conclusions are presented in the last section.

2. **DATA DESCRIPTION**

i) Data Source and stylized facts

The anthropometric data used in this paper was previous gathered by Meisel and Vega (2007 and 2007a) for individuals born during the period 1910-1985 and updated by us for individuals born between 1986 and 1989. The source of this data came from the national identification cards[6], which provide information on gender, date, and place of birth, and height of the individual. Our database comprises height information for nearly 13 million persons born between 1910 and 1989.[7] Of these observations 6.283.452 correspond to men and 6.383.023 to women. Our database has a number of advantages compared to most of the anthropometric literature. The stature reported by the National Civil Registry is not truncated and not self-reported. Also, since everyone has access to identity card in Colombia, our data has no socio-economic or gender bias.

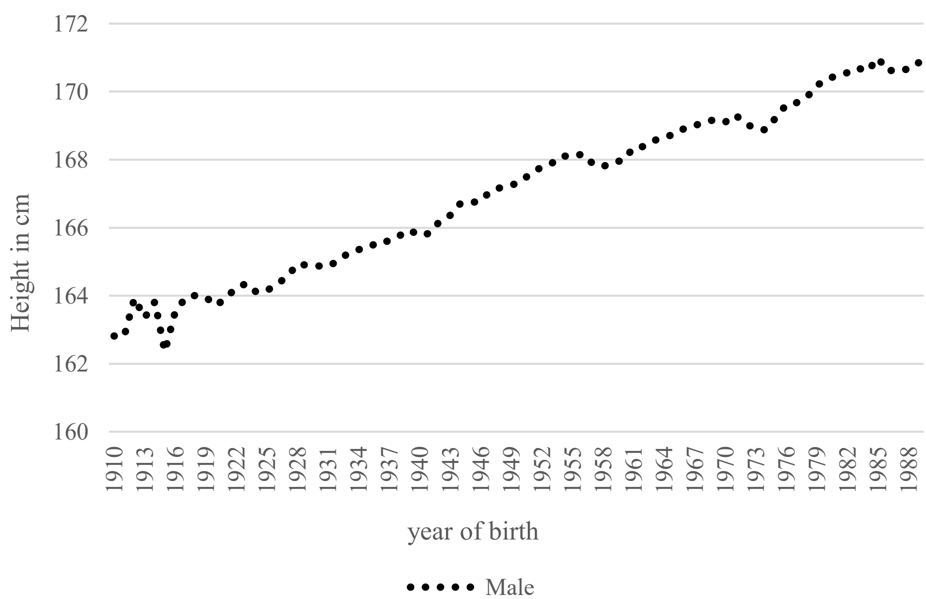
[6] The national identification card (*cédula de ciudadanía*) is issued at age 18 by the *Registraduría Nacional del Estado Civil*.
[7] For a detailed description of the data set and the statistical properties of the height series see Meisel and Vega (2007).

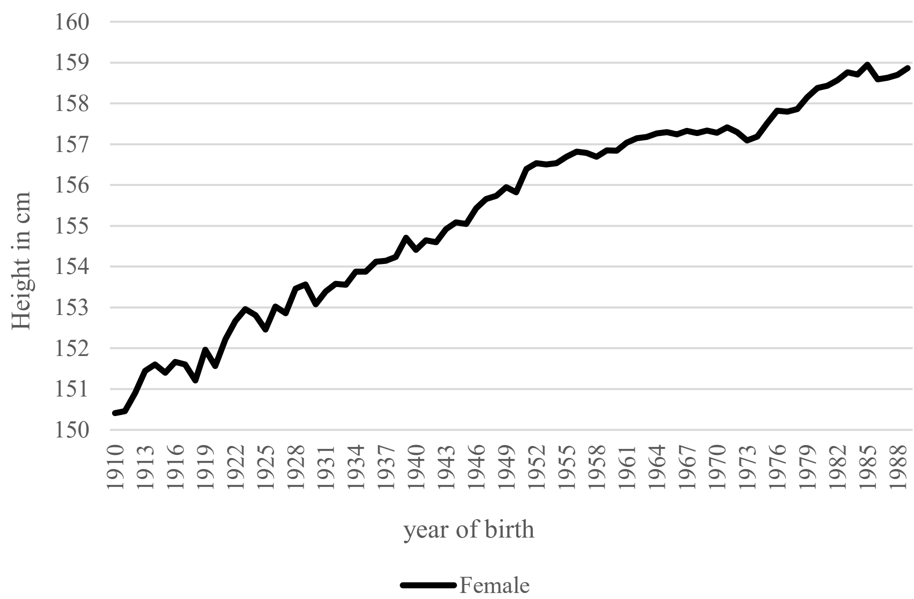
We aggregated the individual height by birth year. Graph 1 presents the evolution in average heights by year of birth and sex. As observed, average height for men and women constantly increased during the twentieth century, with only small fluctuations. The increase in height of men born in 1989 compared to those born in 1910 was 8,04 centimeters and for women it was 8,45 centimeters, which represents an increase of 5% and 5,6%, respectively. To compare height trends between women and men, we calculated both the absolute and the relative dimorphisms. The first one corresponds to the absolute difference between the stature of men and women, and the second one is the absolute dimorphisms related to women stature as define in Koepke *et al.* (2018):

$$DI = \frac{(Height_{male} - Height_{female})}{Height_{female}} * 100 \qquad (1)$$

where DI stands for Dimorphism Index

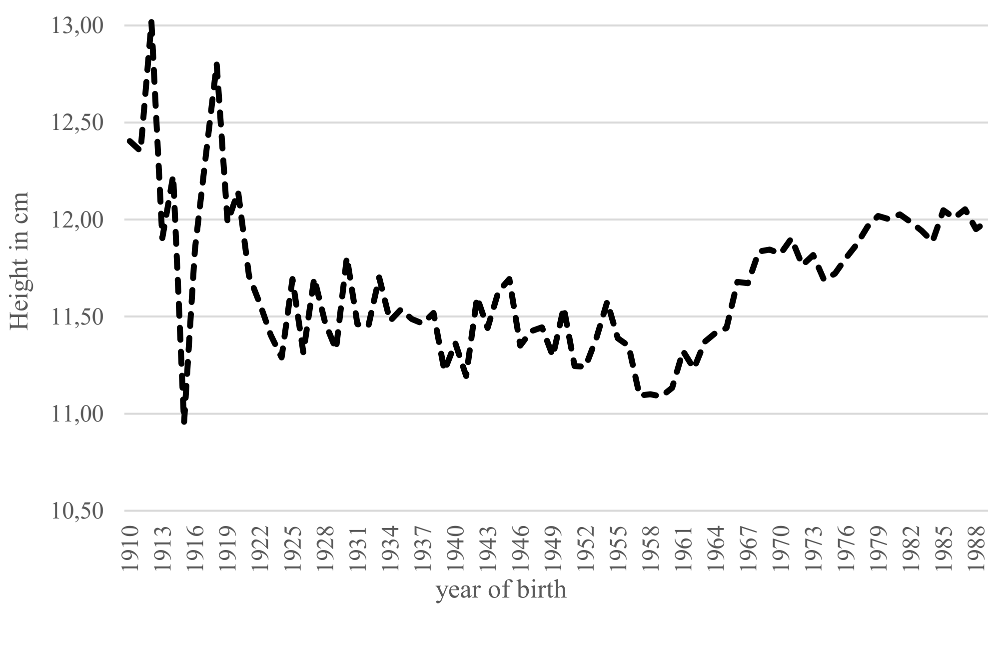
Graph 1
Evolution of average height in Colombia by sex and year of birth: 1910-1989

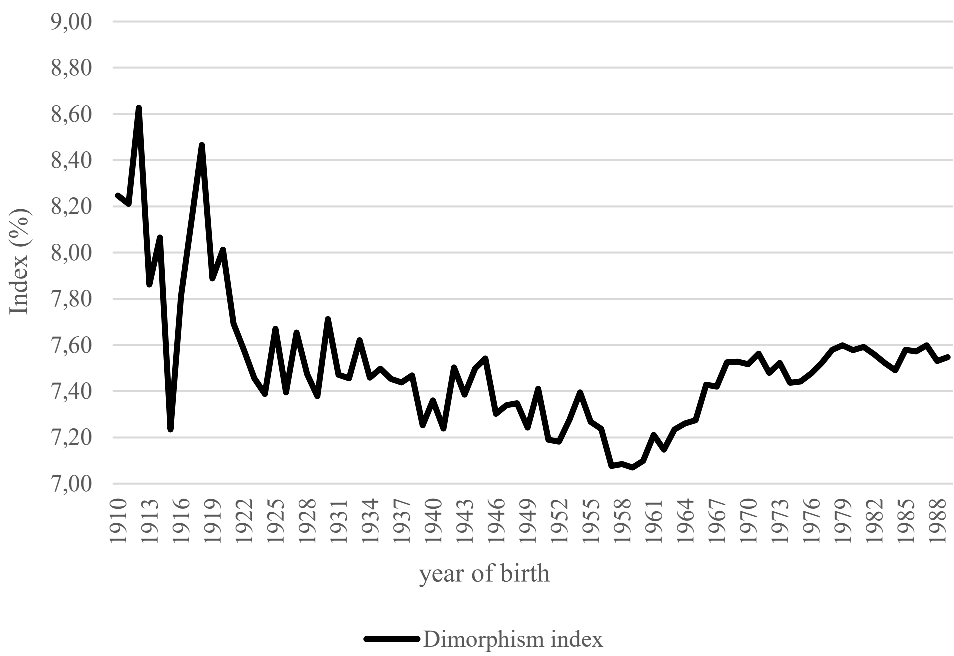




Source: Meisel and Vega (2007) for 1910-1985, and own calculation based on national identification cards issued by *Registraduría Nacional del Estado Civil* for 1986-1989.

Graph 2
Evolution of the absolute and relative dimorphism in Colombia by year of birth





Source: Own calculation based on Meisel and Vega (2007) for 1910-1985, and national identification cards issued by *Registraduría Nacional del Estado Civil* for 1986-1989.

Graph 2 shows that the absolute dimorphism falls from 12,4 centimeters in 1910 to 11,98 centimeters in 1989, which represents a reduction of 3,3% in the absolute dimorphism during the period under study. In relative terms, the dimorphism index (DI) decreased from 8,2% in 1910 to 7,5% in 1989, indicating that female and male mean height converged. However, although, the height dimorphism decreased during the twentieth century, the downward trend observed until the end of 1950s reversed at the beginning of the 1960s. In Graph 1, we also observe that during the 1960s the upward trend of women's average height becomes almost flat. This situation was less pronounced in the case of men's height. According to Meisel and Vega (2007) this result is an apparent paradox given that in these years progress in the relative condition of women begins to improve considerably, as reflected in the advances in education, labor participation, lower fertility, and better health indicators.[8] For these authors this paradox could perhaps be explained by the substantial improvement in the living conditions of men, which due to the urbanization process, and the consequent change in the economic structure which passed from agricultural to industrial and services activities, where

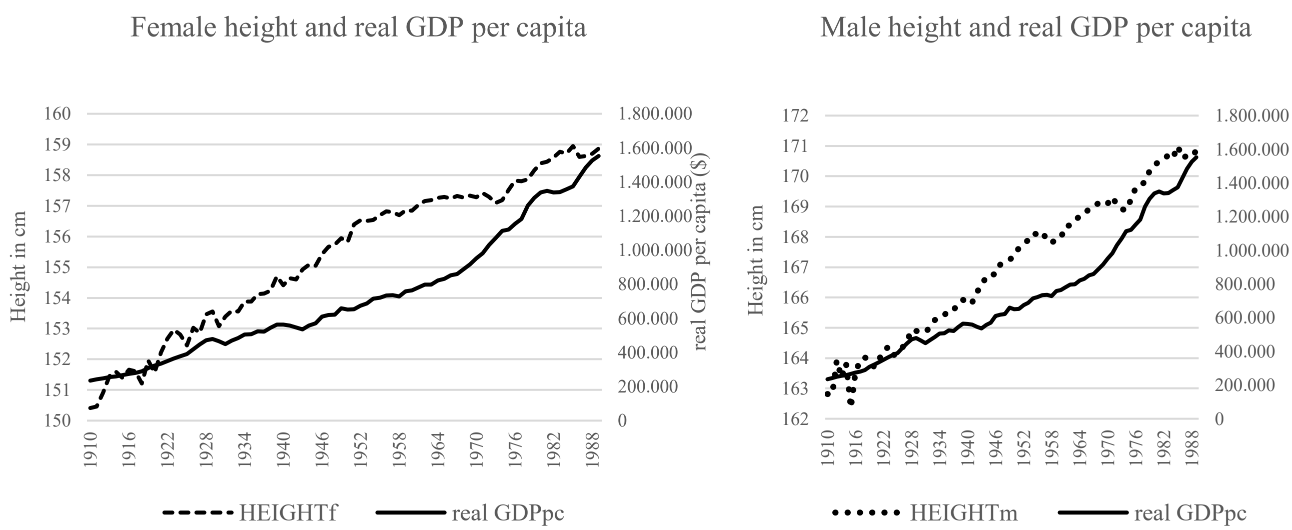
[8] See Jaramillo-Echeverri, Meisel-Roca and Ramírez-Giraldo (2018) for an analysis of the of improvements in the living standard of women in Colombia.

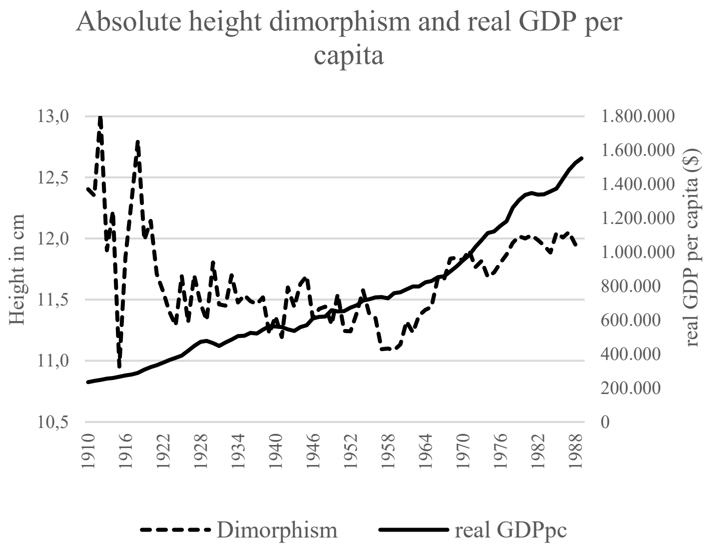
men had to do less physical effort, in comparison with what prevailed previously when the country was more rural (p.93).

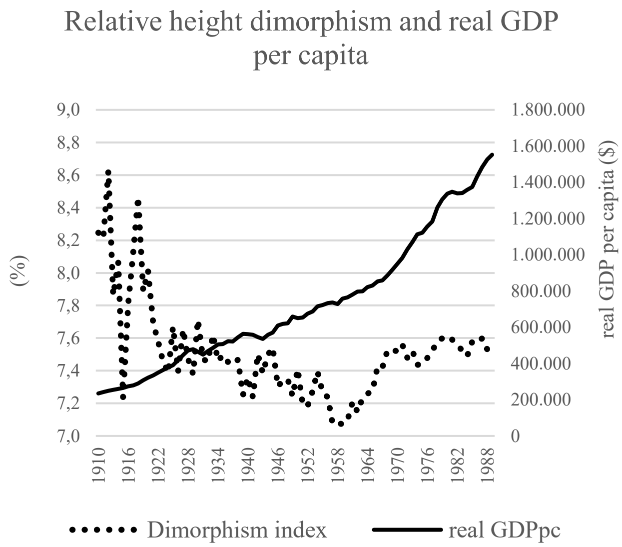
In Graph 3 we also observe that the negative relationship between real per capita GDP and height dimorphism stopped at the beginning of the sixties. This means that the gap between male and female stature increased despite improvements in GDP. This result suggests that earlier improvements in the economic conditions benefited women more, given the considerable gender gap regarding education, health, income, among other dimensions at the beginning of the twentieth century. However, the increments in GDP observed during the second half of the twentieth century seem to benefit men's height more than women's, as has been mentioned.

Graph 3

Relationship between height (birth year) and real GDP: 1910-1989







Source: Own calculation based on Greco (2002) and Meisel and Vega (2007)

This evolution of dimorphism is not only observed in the case of Colombia but also in other countries. For example, Cámara (2018) examines the evolution of absolute and relative dimorphism for several developed countries during the nineteenth and twentieth century. He finds a steady increase in dimorphism during the second half of the 20th century in most of the countries. The results indicate a greater increase in the stature of men compared to that of women.[9] According to the author, previous populations that were subjected to prolonged or structural environmental stress (e.g, chronic malnutrition and / or high prevalence of infectious diseases) are prone to lower values of dimorphism. The evidence suggests that men in generations subjected to a high environmental stress were very short, even in relative terms. Cámara states that male average height is more responsive to environmental factors than female average height. When difficulties in environmental and economic terms are present, the penalty in biological terms is higher for men, and improvements in the economic and environmental circumstances also cause a stronger positive biological response in men compared to women.[10]

[9] For the case of Spain, Cámara (2018) concluded that sexual dimorphisms in height increases between generations whose growth cycle occurs in better nutritional conditions. This result is essentially explained by a greater intergenerational growth of the male population. (p. 127).

[10] See also, Costa-Font and Gil (2008), Blum (2014), Cámara (2015), and Guntupalli and Baten (2009).

Similarly, Bogin *et al*. (2017) analyze average heights for men and women in 169 countries to test if income inequality has a larger relationship with average adult height than absolute income, and if either income or income inequality has an influence on dimorphism in height. The authors find that a larger income equality is more predictive of average height for men and women. However national GDP is not directly related to average height. In addition, they find that with greater average adult height there is greater dimorphism. In the same line as Cámara (2017), Bogin *et al*. (2017) argue that when environmental conditions are adverse the average height of men could be more negatively affected than the average height of women, leading to reductions in sexual dimorphism. On the contrary, if environmental conditions are good, men may grow to a greater height, and dimorphism may increase.

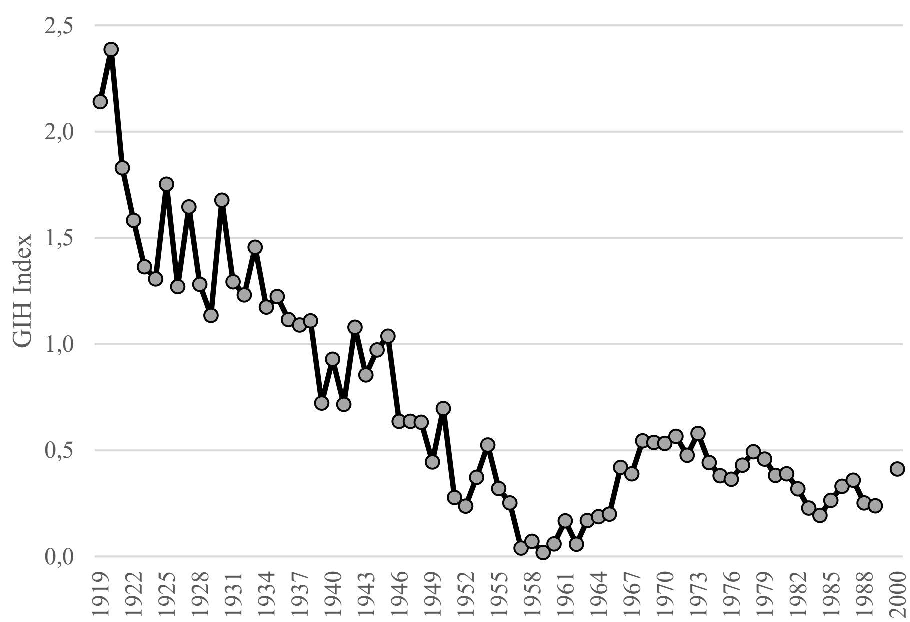
In this line of research, Sohn (2016) examines sexual height dimorphism in South Korea during the second half of the twentieth century, a period of rapid economic growth. The author finds that both men and women's height increased, although for men it increased faster than for women. However, sexual dimorphism remained almost flat.

Recently, Schwekendiek and Baten (2019) analyze height trends in China, South Korea, and Taiwan during the rapid economic growth period of the 1960s to the 1980s. These authors propose a new formula to measure gender inequalities of height. According to the authors: "this formula accounts for the empirical fact that the height gap between males and females increases with average height but not exactly proportionally" (p. 178).[11] The authors find significant increases in height as income grows. However, gender inequality of height rises in China in the 1980s, during the transition period to a market economic system. Similarly, in South Korea and Taiwan gender inequality also followed an increasing trend during these years.

[11] The formula for gender inequality of height proposed by Schwekendiek and Baten (2019) is based on their regression result of regressing height gap between genders on average heights, considering nine countries that are in the middle group of the Gender Development Index. Their formula is:
"$GI_h = H_m - H_f - (-33.75 + 0.276 * H_{mf})$, where H_m and H_f are the height values for males and females, respectively, H_{mf} is the average height of both genders, and GI_h represents gender inequality of height" (p.173).

Following the formula proposed by Schwekendiek and Baten (2019) we calculate the gender inequality of height for Colombia. As observed in Graph 4, this index follows very closely the behavior of the absolute and relative dimorphism. That is, the GIH decreased during the twentieth century, but the downward trend observed until the end of 1950s reversed at the beginning of the 1960s, despite the advances in the living conditions of women during this period.[12]

Graph 4
Evolution of the Gender Inequality of Height (GIH) in Colombia



Source: Own calculation based on a formula proposed by Schwekendiek and Baten (2019), see footnote 10.

Part of the explanation for the decline in the progress made in the first half of the twentieth century in closing the gender gap in height, may be related to biological factors, particularly the relationship between the age of menarche and economic development. Yousefi *et al.* (2013) highlighted that changes during puberty may influence final adult height.[13] The relationship between economic development and height may be due to changes in the age at

[12] In appendix 1 we present both the Gender Development and the Gender Inequality indices for Colombia, for the period 1995-2017. These indices confirmed that Colombia has made important progress in reducing gender inequalities.
[13] Yousefi *et al.* (2013) find that the earlier age of menarche in girls is related to shorter height, while in boys, earlier age of the growth spurt and slower progression through puberty were related to taller height at age 18.

menarche, since economic conditions have an effect on puberty.[14] Nutritional improvements, due to economic progress, could reduce the age of menarche and anticipate the closing of the growth cycle for girls.[15] As Jansen, Herrán and Villamor (2015) point out, the age at menarche offers useful information on the effect of changing environmental and economic conditions on girls' health. These authors study trends and sociodemographic correlates of age at menarche of Colombian girls born between 1992 and 2000. Their estimations indicate that the median age at menarche was 12.6 years; and that there was a reduction of 0.54 years/decade over the birth year.[16] Interestingly, the authors find that this decline was only observed among girls who reside in urban areas, and was more noticeable among girls from wealthier families. Jansen, Herrán and Villamor find that a child's height and the body mass index (BMI), and education, and family wealth were each inversely associated with the age of menarche. They conclude that "a negative trend in age at menarche is still ongoing in Colombia, especially in groups most likely to benefit from socioeconomic development" (p.143).

ii) Determinants of height

Adult height is determined by not only the levels of nutrition and health in childhood and adolescence, but also by the socio-economic conditions in which individuals grow. In this section we analyze econometrically the long-run relationship between indicators of socio-economic development and adult stature for males, females and the dimorphism index in Colombia during the twentieth century.

In our time series estimation, we include first the real per capita income[17], since higher income could lead to improvements in the standard of living in the form of better nutrition, health, and education. Nevertheless, the relationship between income and stature through

[14] As Bogin *et al* (2017) pointed out, on average, men grow larger and mature more slowly than women. Thus, men have greater exposure to environmental conditions that influence their final height. See also, Guntupalli and Baten (2009).
[15] See for example Cámara (2018) and Yosefi *et al* (2013).
[16] Similar results were found by Villamor *et al* (2009), who estimated that the decline in age at menarche of Colombian women born 1941-1989 was 0.55 years/decade.
[17] We use the annual series of real per capita GDP in Colombian 1994 pesos provided by GRECO (2002).

time is not clear for the Colombian case. In fact, for the period 1910-1985 Meisel and Vega (2007) did not find a cointegration relationship between these two variables. These authors mentioned that this relationship is complex since other factors such as changes in relative prices, advances in medicine, and developments in infrastructure, affect changes in height through time. The relative importance of these factors changed during the century and they did not necessarily have an exact relationship with the evolution of GDP per capita (p.97). For this reason, in the present paper we include additional variables in the cointegrating vector.

Graph 3 shows the relationship between the evolution of the annual series of real GDP per capita and the male and female stature. During, most of the century the country presented long periods of stable growth. Between 1910 and 2000, the economy in per capita terms, grew on average 2,3%, but growth was faster during the first half of the century. However, there have been five main phases of slowdowns, most of them caused by external factors. The Great Depression and its effects on the international capital market, jointly with the decline in international coffee prices, and the reduction in the world prices of basic goods, affected the Colombian economy mainly during 1929-1931. During the World War II the contraction of the international trade flows affected the Colombian exports, imports, the terms of trade, and consequently the country's economic growth. After that, a new economic contraction took place in 1950-1951, this time produced by an internal shock. As a response to an increasing inflation, the monetary authorities in conjunction with the commercial banks reached an agreement in which the credit was limited, and the bank portfolio was frozen. As a result, the real money supply suffered a drastic reduction, which lead to an economic recession. With the Latin-American debt crisis of the beginning of the 80s, the Colombian economy decreased between 1981 and 1984, with a pronounced current account deficit and high external indebtedness. Lastly, the largest economic slowdown took place between 1998 and 1999 as a result of the international financial crisis of 1998 and its negative effects on the country's terms of trade and capital market. The international crisis had deep consequences on the economy due to the considerable macroeconomic imbalances that were present in the Colombian economy at the time.

The main expansion occurred during the twenties, with the insertion of the country in the international financial markets along with the increase in international coffee prices. After the Second World War the Colombian economy expanded due to the restoration of international trade and the rise in coffee prices. The boom of commodities prices, mainly coffee and oil, led to high growth between 1966 and 1973, and during the years 1978 and 1986.[18]

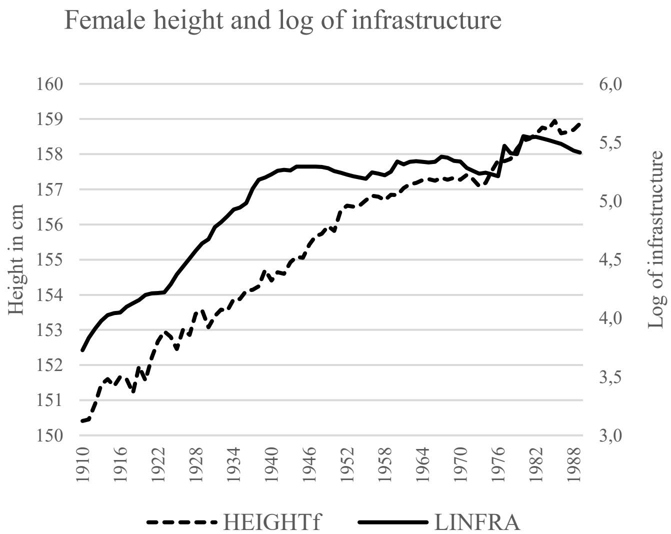
Graph 3 shows a relatively close positive relationship between per capita GDP and adult height through the twentieth century. In the case of the dimorphism index we would expect a negative relationship with real per capita GDP. However, the strong negative correlation presented until 1959 (a correlation of -0.95) is reversed and from 1960 to 1989. In this later period the correlation was positive (0.8).

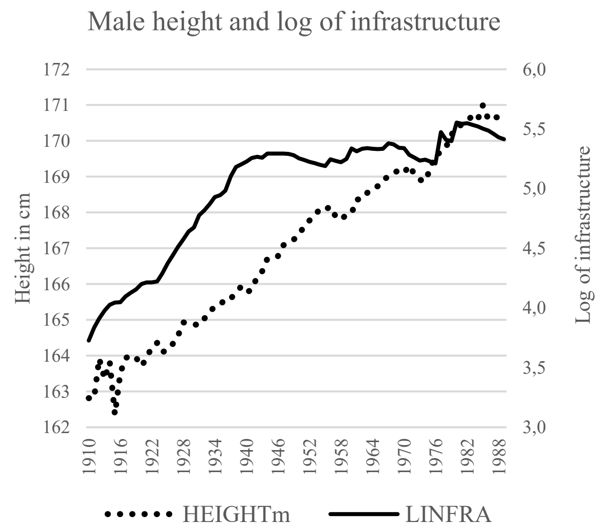
As has been shown in the recent anthropometric literature, nutrition is one of the main determinants of height.[19] Since the time series of nutritional conditions for Colombia are difficult to obtain for the entirety of the period under analysis, we use as a proxy the length of transport infrastructure (kilometers of railways and roads per inhabitants). As shown by Ramírez (2007) infrastructure developments in the country reduced the cost of transportation of food products and, therefore prices fell, and supply expanded. These developments contributed to the integration of a national market since the dispersion in food prices among Colombian cities was reduced considerably, especially during the first half of the twentieth century. Graph 5 shows the relationship between male and female stature and the evolution of transportation infrastructure in the country. A close and positive relationship is observed especially during the first half of the century, when the major expansion in the transport network took place, which allowed reductions in food prices. For example, Graph 6 depicts the reduction of the price of milk and potatoes, important components of the consumption basket in Colombia.

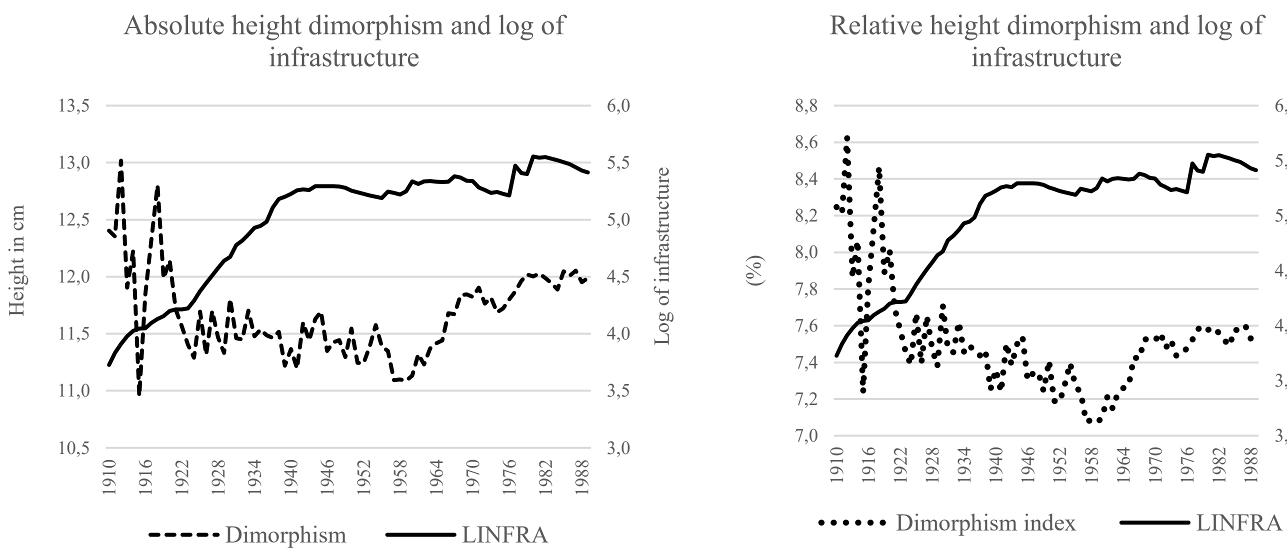
[18] For details on the evolution of GDP growth in Colombia during the twentieth century, see for example Greco (2002) and Misas and Ramírez (2007).
[19] See for example Komlos and Lauderale (2007).

The relationship between infrastructure developments and dimorphism is interesting (Graph 5). During the first half of the century, when major expansions in infrastructure were observed, dimorphism fell, suggesting that infrastructure developments have an important role in closing the stature gender gap. However, at the end of the 1950s, when major developments in infrastructure stagnated, dimorphism reverted its tendency and the index started to increase until the beginning of the eighties, when the index stabilized and remained at a constant level.

Graph 5
Relationship between height (birth year) and infrastructure (kilometers of railways and roads per inhabitants): 1910-1989

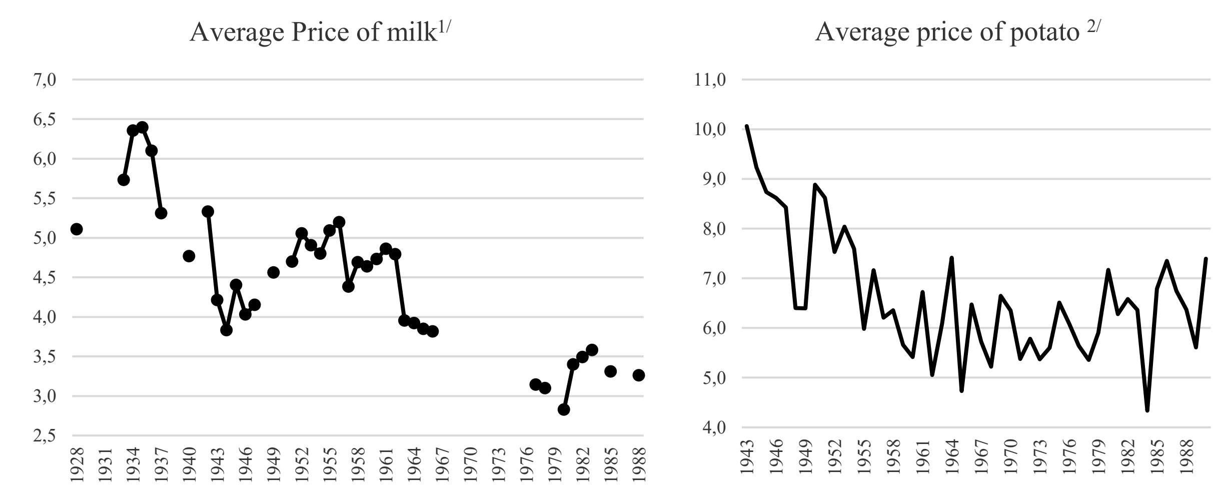






Source: Own calculation based on Meisel and Vega (2007) and Ramírez (2007).

Graph 6
Average price of some products* (constant $ of 1998)



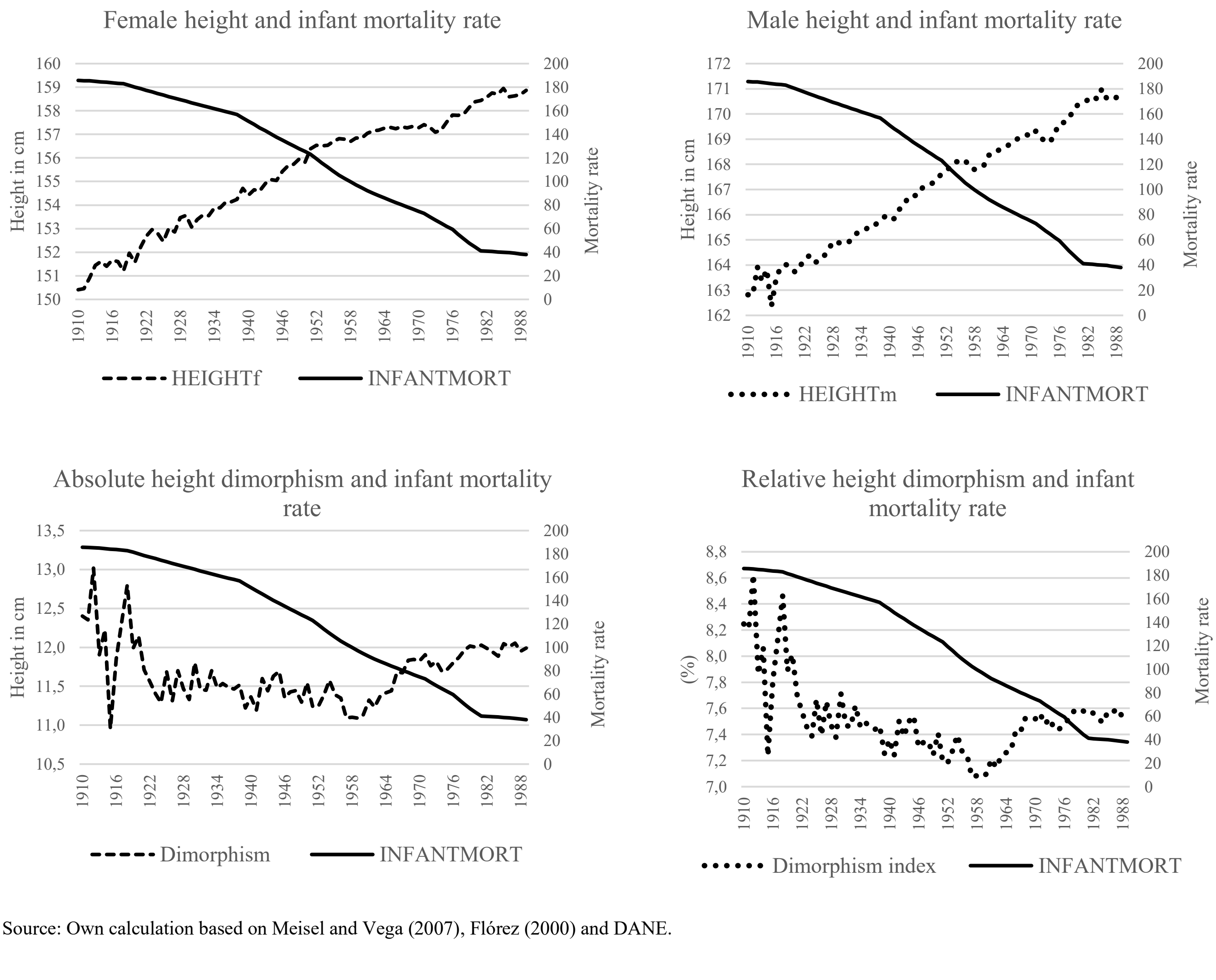
1/ Corresponds to the price, in January of each year of a 500g unpasteurized milk bottle. 2/ Corresponds to the price of the average price per arroba. Source: Contraloría General de la República de Colombia and DANE.

The anthropometric literature has shown that height is closely related with health conditions. In fact, both nutrition and diseases in childhood are two of the main non-genetic factors that affect stature (Silventoinen, 2003). Therefore, as an indicator of health conditions, we use the infant mortality rate (per 1,000 inhabitants). In Graph 6 we observe a negative correlation between mortality rates and male and female stature. The decline in mortality rate was mostly explained by improvements in the provision of aqueducts and sewerage, which reduced mortality rates, especially those related to waterborne diseases. Reductions in mortality rates, led to an exceptional increase in life expectancy during the twentieth century, and to an improvement in the welfare of the population. (Jaramillo-Echeverri *et al*., 2018).

Regarding dimorphism and mortality rates, we observe that as the mortality rate declined, the gap between male and female stature fell until the end of 1950s, when the gap started increasing again (Graph 7).

Graph 7

Relationship between height (birth year) and Infant mortality rate (per 1.000 live births): 1910-1989

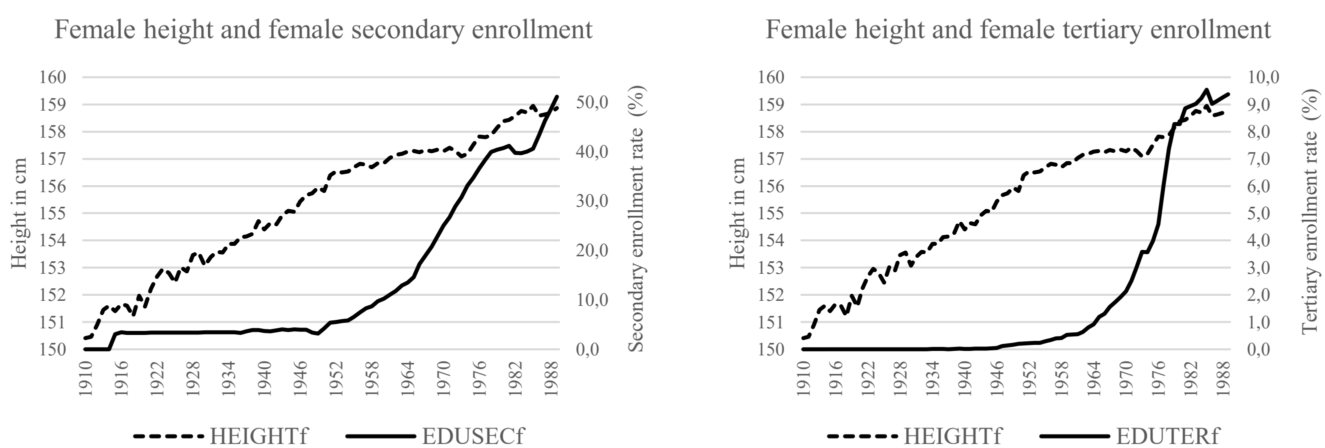


Source: Own calculation based on Meisel and Vega (2007), Flórez (2000) and DANE.

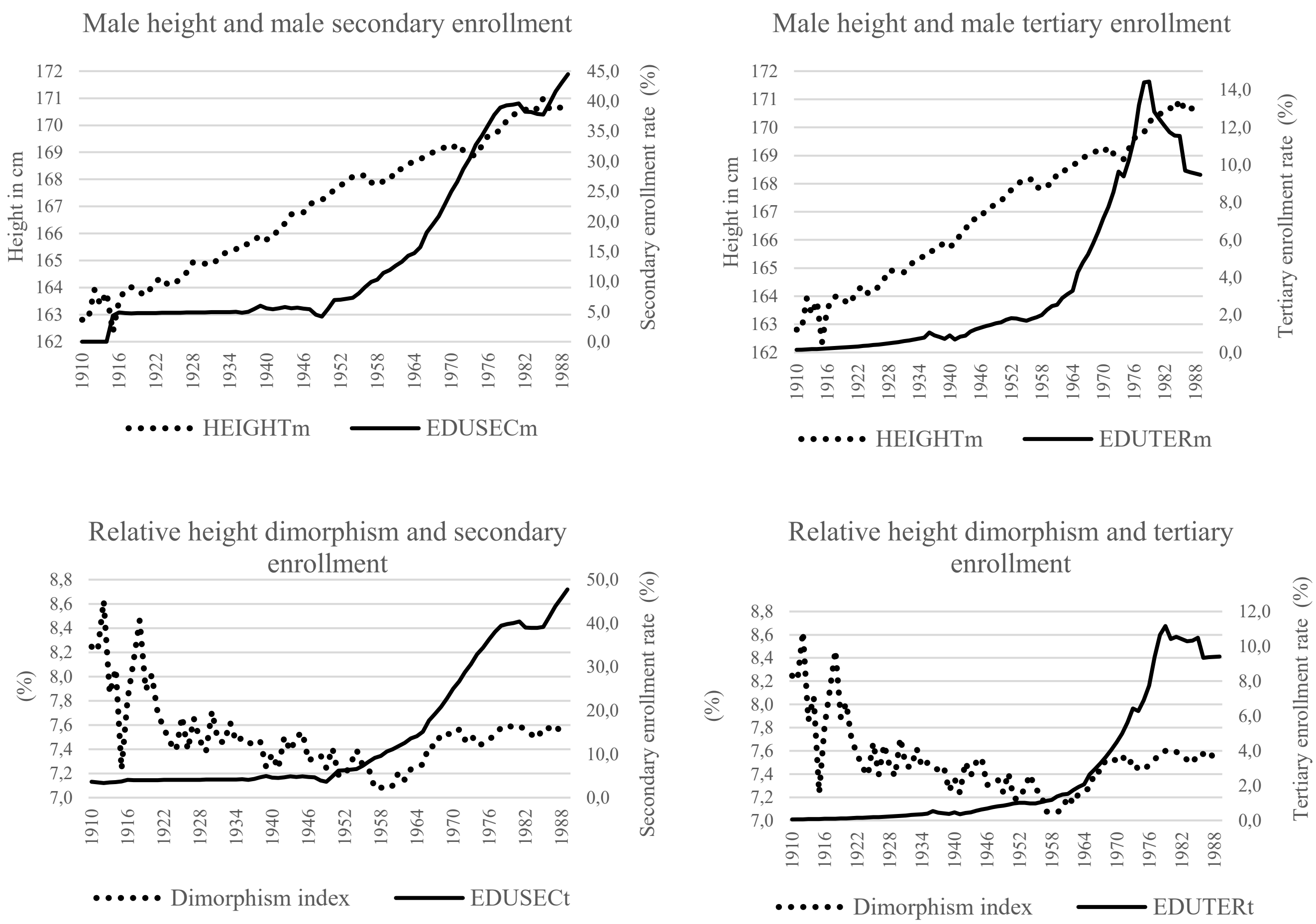
The relationship between education and height has been well recognized in the literature (see for example Ayuda and Puche-Gil, 2014; Chanda, 2008). Higher levels of education have, for example, important effects on nutrition, hygiene habits, and population health, which may lead to a greater stature. Graph 8 depicts the long run relationship between height and education. There are no similarities in the evolution of these variables until 1950, when substantial improvements in education took place, for both men and women.[20] However, the relationship is contrary to what we expected when comparing the evolution of education with the dimorphism index. When education began to expand, the gender gap also began to increase, which is a counter-intuitive fact, as explained before.

We also analyze the relationship between height and other indicators of the standard of living such as the Historical Index of Human Development (HIHD), a comprehensive indicator which includes three dimensions of well-being: income, schooling, and a long and healthy life. Graph 9 suggests a positive relationship between stature and human development. As in the case of the other variables, the stature gender gap falls as HIHD increases until the end of 1950s, when the relationship reverts.

Graph 8
Relationship between height (birth year) and Education: 1910-1989

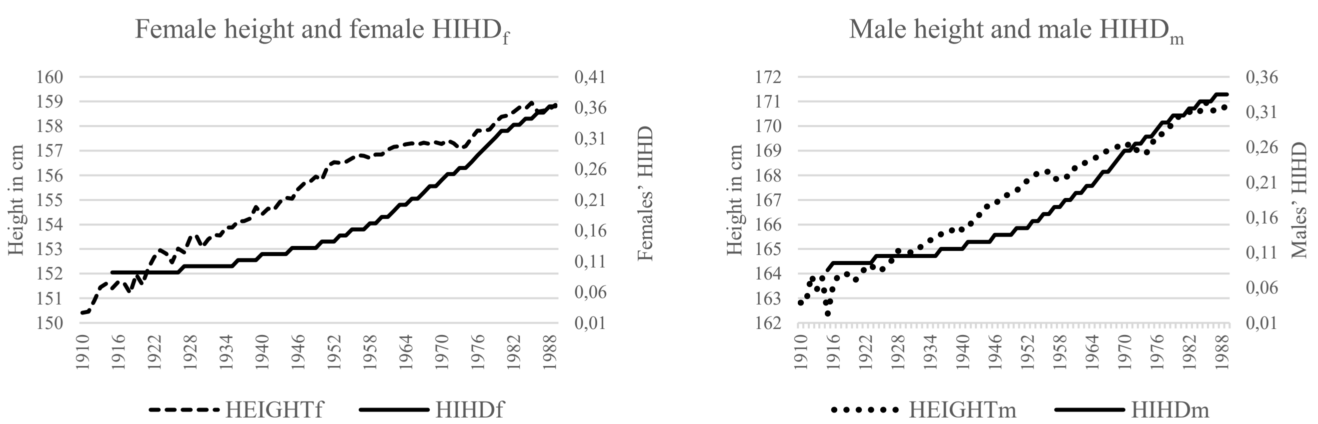


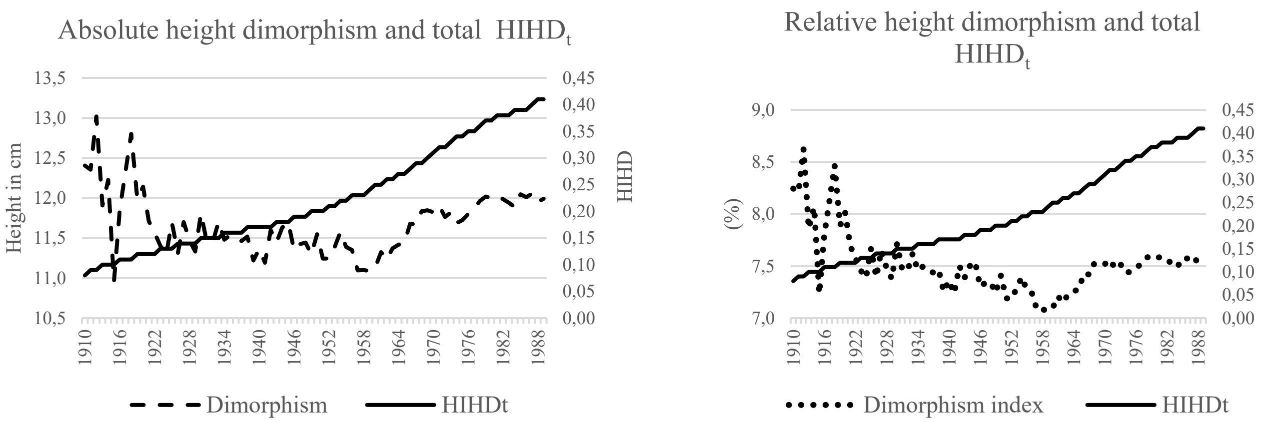
[20] For a detailed analysis on the evolution of education in Colombia during the twentieth century, see Ramírez and Téllez (2007).



Source: Own calculation based on Meisel and Vega (2007) and Jaramillo-Echeverri *et al*., 2018.

Graph 9
Relationship between height (birth year) and the Historical Index of Human Development (HIHD): 1910-1989

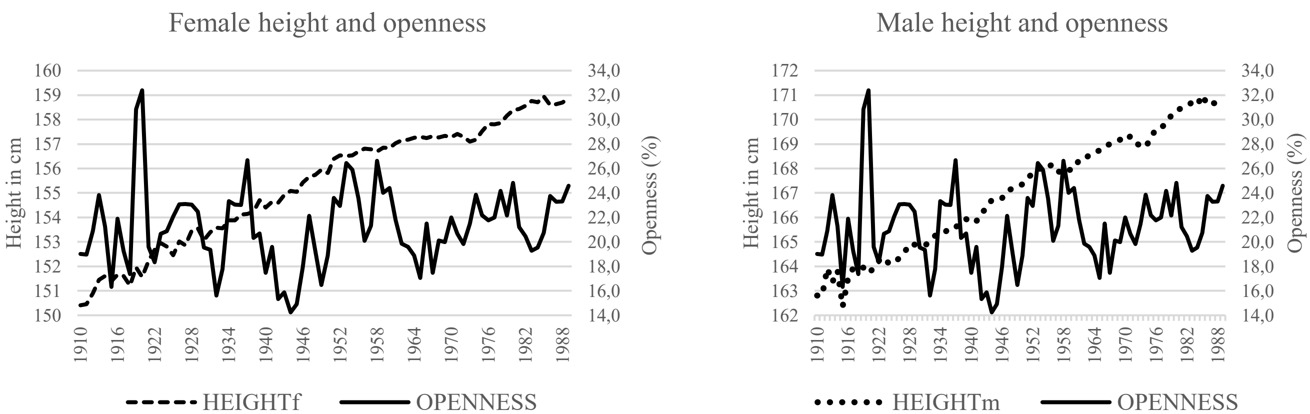


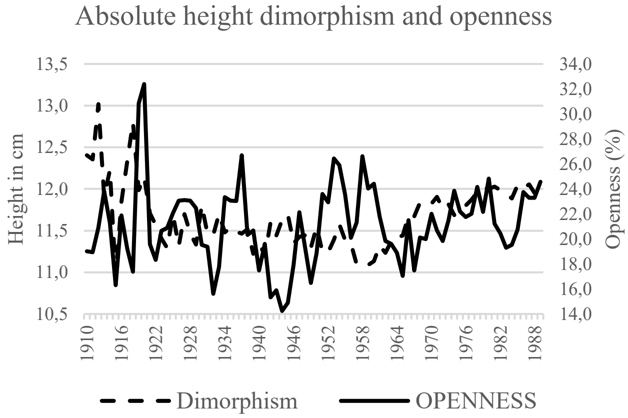


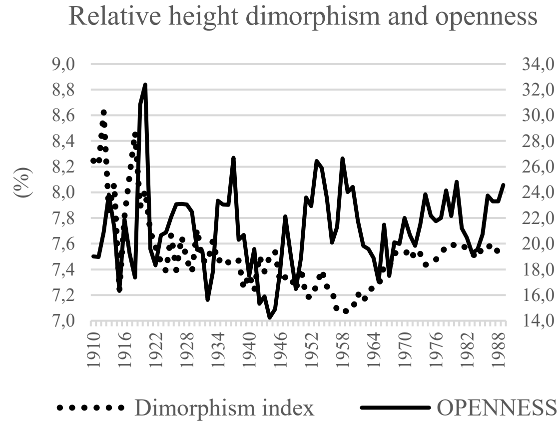
Source: Own calculation based on Meisel and Vega (2007) and Jaramillo-Echeverri *et al*., 2018.

Finally, following María-Dolores and Martínez-Carrión (2011) we included the degree of openness to international trade (ratio of exports plus imports over GDP) as another development indicator. A positive relationship between the degree of openness and height is expected since a higher degree of openness could lead to a larger supply of goods and to price reductions for food, affecting nutrition positively. Graph 10 presents the paths of male and female stature and the degree of openness. Graphically, the relationship between these variables is not very clear.

Graph 10
Relationship between height (birth year) and the degree of openness: 1910-1989







Source: Own calculation based on Meisel and Vega (2007) and Greco (2002).

3. DETERMINANTS OF HEIGHT: METHODOLOGY AND RESULTS

In this section, we estimate the long run relationship between male and female physical stature and some socio-economic development indicators in Colombia during the 20th century. The main problem in this analysis is the intrinsically endogenous character of the variables. To solve this difficulty, we use time series econometric techniques, specifically cointegration and vector error correction (VEC) models, which help us to identify long-run relationships, in a multivariate system with non-stationary variables. These techniques allow us to examine the dynamic properties of the multivariate system by estimating the impulse response functions (IRF) of each variable to shocks in the other variables. In this case, IRF allows us to assess how height responds to changes in different socio-economic indicators.

As mentioned, we consider per capita income, the degree of openness of the economy, the length of transport infrastructure, schooling, mortality rates, and the index of human development as key development indicators that could influence male and female height, as well as the gender gap in stature, during the twentieth century.

Preliminary examination of the stationary properties of the series during this period suggests that the majority of the series are integrated of order one, I(1), and their first difference are stationary I(0), according to the Augmented Dickey Fuller (ADF) and Philips and Perron (PP) unit root tests (Table 1).

Given that the series are not stationary, and therefore estimating a single equation by OLS is not appropriate, we proceed with cointegration tests among these variables, using the Johansen multivariate methodology for cointegration. Cointegration tests allow us to examine the possibility of a long-run relationship between height and some socioeconomic variables. We estimated the equations considering different definitions of stature as a dependent variable. In the first equation we included the natural logarithm of female height, in the second case the natural logarithm of male height, and in the last equation we considered the relative dimorphism as a dependent variable.[21]

Table 1
Unit root tests

Variables	***Augmented Dickey-Fuller***	***Phillips-Perron***
ln(female-height)	I(1)	I(1)
ln(male-height)	I(1)	I(1)
Relative height dimorphism	I(1)	I(1)
Absolute height dimorphism	I(0)	I(1)
Openness	I(0)	I(0)
ln(infrastructure)	I(1)	I(1)
ln (GDP per capita)	I(1)	I(1)
Female secondary enrollment rate	I(1)	I(1)
Male secondary enrollment rate	I(1)	I(1)
Female tertiary enrollment rate	I(1)	I(1)
Male tertiary enrollment rate	I(1)	I(1)
Female-HIHD	I(2)	I(1)
Male-HIHD	I(2)	I(1)
Infant mortality rate	I(1)	I(1)
Total mortality rate	I(1)	I(1)

Source: own estimations.

Appendix 2 (tables A.2.1 to A.2.3) shows the results of the Johansen cointegration tests. In all cases, except two, the *rank-test (trace-statistic)*, indicates the presence of a unique cointegration vector.[22] Finally, we present the results for the normalized cointegrating coefficient for the cointegration equation and the IRFs for each of the height definitions.

[21] The series of height included in the models are central moving average (5 years) of the height time series, to obtain trend instead of short-term fluctuations.
[22] The lags were chosen according to the AIC and SIC, considering the most parsimonious model which had the best behavior in the residuals.

i) Female Height

Table 2 presents the normalized cointegrating coefficients for the cointegration equation, when the logarithm of female height (*ln(female-height)*) is considered as a dependent variable. We find that female height is positively and significantly related to the degree of openness, and infrastructure. Interestingly, per capita GDP is not significantly related to female height. However, when we consider female-HIHD in the cointegration equation, instead of per capita GDP (Model 2), the results indicate that female stature is positively and significantly related to a more comprehensive indicator of human development. In Model 3, when we include in the cointegration vector female tertiary enrollment and per capita GDP, none of these variables were significant. Lastly, in Model 4, when GDP is excluded from the cointegration equation, we find a long-run and significant relationship among female stature and its determinants: degree of openness, infrastructure, and female tertiary education.

Table 2
Normalized long-run relationship between natural logarithm of female height and its socioeconomic determinants from Johansen Cointegration Tests

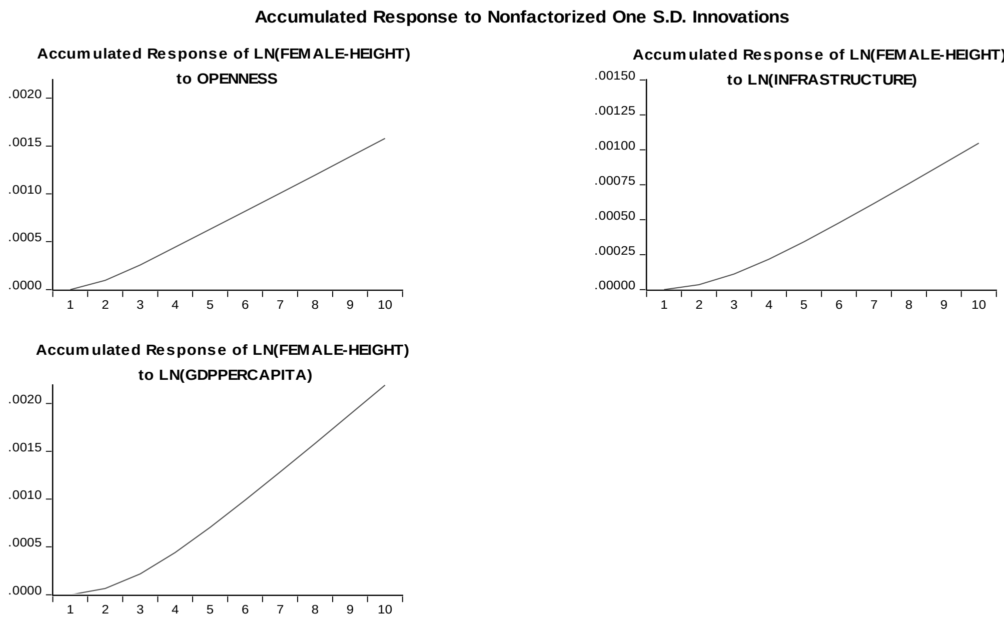
Variable	*Model 1*	*Model 2*	*Model 3*	*Model 4*
Openness	0.00311 (0.0005)	0.00088 (0.0002)	0.00276 (0.0005)	0.00225 (0.0003)
ln(infrastructure)	0.01982 (0.0092)	0.01451 (0.0020)	0.02392 (0.0094)	0.02280 (0.0024)
ln(GDP per capita)	0.00418 (0.0121)		-0.00381 (0.0134)	
Female-HIHD		0.06860 (0.0189)		
Female tertiary enrollment			0.00082 (0.0009)	0.00084 (0.0005)
Dummy-change in fertility	yes	yes	yes	yes
Observations	74	71	74	74
Lags	1	1	1	1
Cointegration Rank	1	1	1	1

Source: Own estimations. Standard error in parentheses.

From the VEC models we estimate the accumulated impulse response functions (IRF) in which average female height responds to a positive shock in real per capita GDP, the degree of openness, infrastructure, education, and female HIHD, from each specification. Graph 11 displays these accumulated responses through time (annually). As observed, an exogenous positive shock in per capita income, openness, and infrastructure is followed by an increase in female height. A one standard deviation increase in the independent variables will lead to a 1cm increase in female height after ten years.

Graph 11

Accumulated Response of *ln(female-height)* to determinants in Model 1



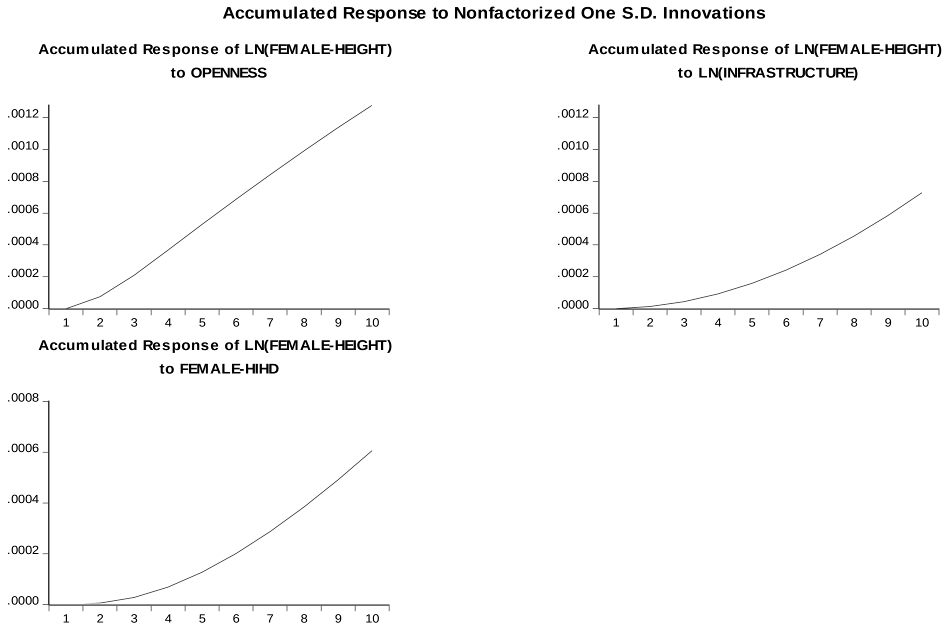
Source: own estimations.

In addition, Graph 12 indicates that female height responds also positively to an exogenous one-standard deviation shock in female-HIHD, which reflects the progress of women well-being through time. A one standard deviation increases in the female' HIHD will lead to a 0.9 cm increase in females' height after ten years.

Lastly, from Graph 13 we observed that female height responds positively to a positive increase in women tertiary education, meaning that higher education leads to progress in women's quality of life, and as a result, to increases in stature.

Graph 12

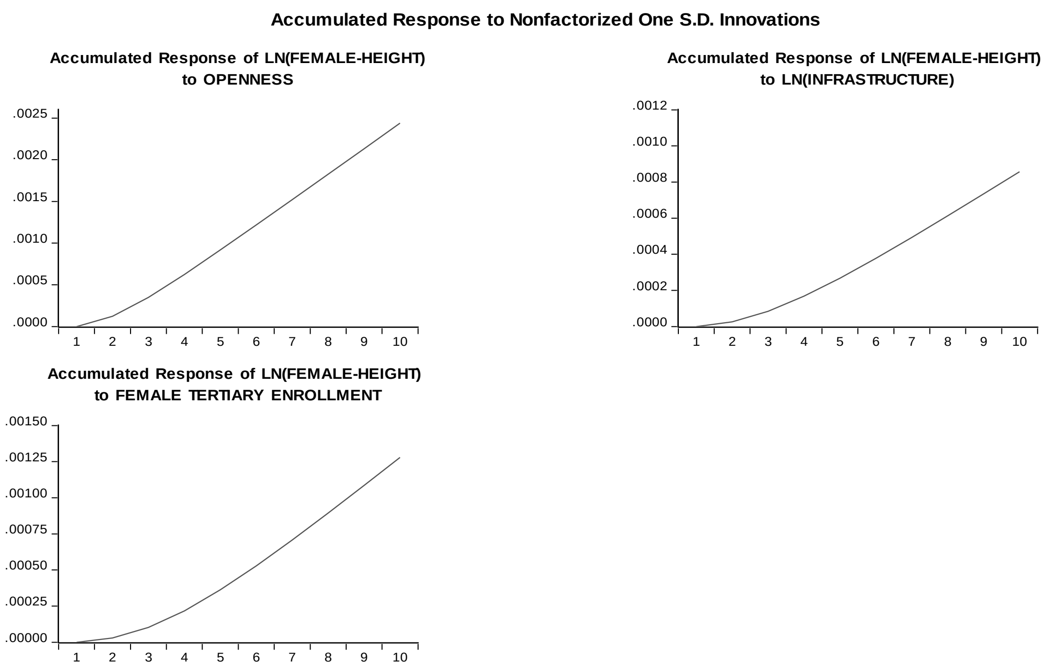
Accumulated Response of *ln(female-height)* to determinants in Model 2



Source: own estimations.

Graph 13

Accumulated Response of *ln(female-height)* to determinants in Model 3



Source: own estimations.

ii) Male height

Table 3 presents the normalized cointegrating coefficients for the cointegration equation, when the logarithm of male height (*ln(male-height)*) is considered as a dependent variable. The results indicate a long-run relationship among male average height and its determinants. Contrary to the female case, per capita GDP is positive and significantly related to male stature (Model 1), suggesting that improvements in national income could have a greater effect on men´s average adult height compared to women's. As expected, men's HIHD coefficient is positive and significant, as well as to the degree of openness, and to improvements in transport infrastructure (Model 2). In Model 3, when we add male tertiary education to the equation, height is positively and significantly related to this variable, but per capita GDP is no longer significant. In Model 4 we excluded per capita GDP from the cointegrating vector. The results are positive and significant in a long run relationship between male stature and male tertiary education, the degree of openness, and infrastructure developments.

Table 3
Normalized long-run relationship between natural logarithm of male height and its socioeconomic determinants from Johansen Cointegration Tests

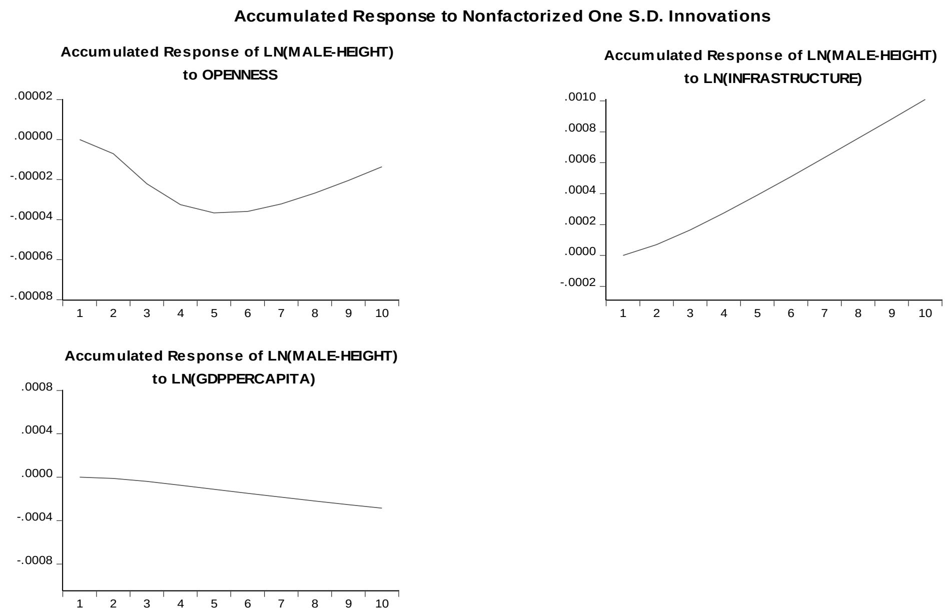
Variable	*Model 1*	*Model 2*	*Model 3*	*Model 4*
Openness	0.00193 (0.0003)	0.00116 (0.0002)	0.00218 (0.0003)	0.00209 (0.0003)
ln(infrastructure)	0.00137 (0.0046)	0.01284 (0.0018)	0.01490 (0.0078)	0.01695 (0.0024)
ln(GDP per capita)	0.02231 (0.0045)		0.00004 (0.0117)	
Male-HIHD		0.08355 (0.0103)		
Male tertiary enrollment			0.00130 (0.0006)	0.00119 (0.0003)
Observations	74	71	74	74
Lags	1	1	1	1
Cointegration Rank	1	1	1	1

Source: Own estimations. Standard error in parentheses.

Graph 14 displays the accumulated IRF from the VEC models for the Model 1 of Table 3. As observed male height responds positively to a shock in infrastructure. However, in the short run male height did not respond positively to changes in the degree of openness. That only happens after five periods. On the other hand, the response of height to shocks in per capita GDP, is very small although negative, even though these variables present a positive long-run relationship.

Graph 14

Accumulated Response of *ln(male-height)* to determinants in Model 1



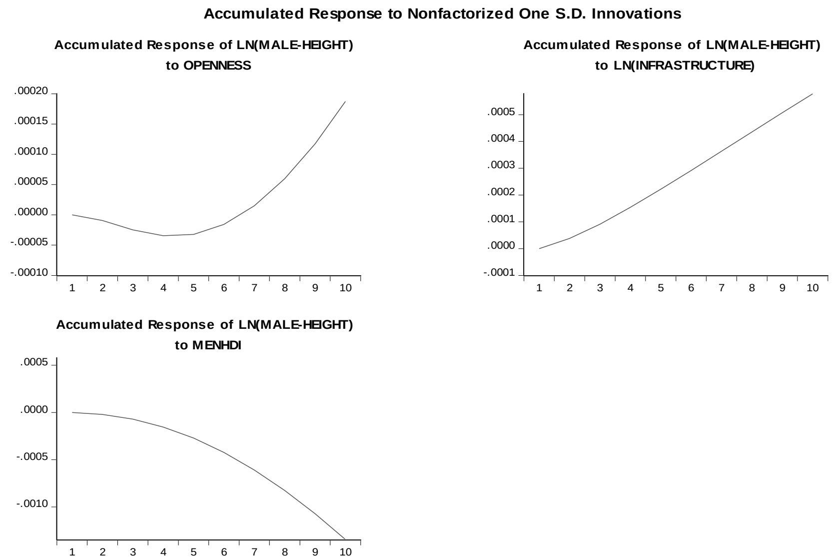
Source: own estimations.

Graph 15 shows the response of male height to an unexpected positive change in openness, infrastructure, and male-HIHD in Model 2. In this specification, male height responds positively to shocks in infrastructure and openness. However, contrary to what we expected, male height responds negatively in the shorth run to a shock in male-HIHD. However, as the cointegration test shows, these variables are positively related in the long run.

Graph 16 displays the response of height to a positive increase in openness, infrastructure and male tertiary education in Model 3. IRF shows that male height responds positively to shocks in these three variables. As in the case of female height, male height responds positively to an unexpected shock in male tertiary education, suggesting that higher education leads to progress in men's well-being, and as a result, to increases in stature.

Graph 15

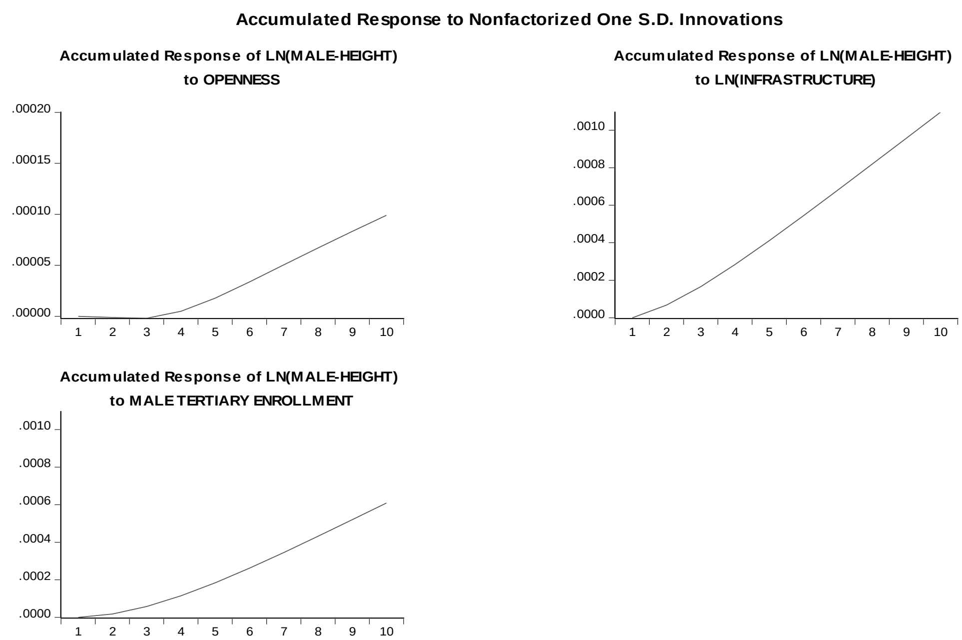
Accumulated Response of *ln(male-height)* to determinants in Model 2



Source: own estimations.

Graph 16

Accumulated Response of *ln(male-height)* to determinants in Model 3



Source: own estimations.

iii) Relative dimorphism

Table 4 presents the normalized cointegrating coefficients for the cointegration equation, with relative dimorphism as the dependent variable. The results show that relative dimorphism is negatively related, as expected, to the degree of openness and infrastructure development, but positively related to per capita GDP. These results suggest that higher degree of openness and infrastructure developments that allows for a larger supply of food and its price reductions in the market, have contributed to a reduction in the stature gender gap. On the contrary, per capita GDP may have contributed to widening this gap, which is apparently a paradoxical result. However, this result is in line with what we find in the cointegration equations for women and men' height. The results show that per capita GDP is not significantly related to female height while it is significantly related to male stature, suggesting that improvements in per capita income could have larger effects on men's average stature compared to women's. This result is similar when we considered the HIHD instead of per capita GDP (Model 2). In Models 3 and 4, we include female and male's HIHD. We include the indices separately. Interestingly but paradoxically, female's HIDH contributed to expand the gender gap while male's HIDH decreased it. Since major expansion in all levels of education took place at the end of 1950s, precisely at the same moment that dimorphism reverted its negative tendency and starts to increase. The effect of education on relative gender dimorphism is positive as shown in the tables Models 5 and 6.[23] In Models 7 and 8, when we include in the cointegration equation both per capita GDP and education, education ceases to be significant.[24]

Lastly, from Model 9, we find that relative dimorphism is positively related to mortality rates, meaning that the reduction in mortality rates helps to close the gap between men's and women's stature.

[23] We considered different definitions of education: literacy rate, primary and secondary enrollment rates, total enrollment rate. To save space we only present the results when we included tertiary education rate. The results are very similar regarding the definition of education we used.

[24] In a paper in progress, Meisel-Roca, Ramírez-Giraldo and Santos-Cárdenas, using a quantile regression approach, study gender inequalities of height in Colombia by level of education, occupation, health conditions, and place and date of birth. The authors use a dataset of more than 225,000 individuals born between 1920 and 1990.

Table 4
Normalized long-run relationship between relative dimorphism and their socioeconomic determinants from Johansen Cointegration Tests

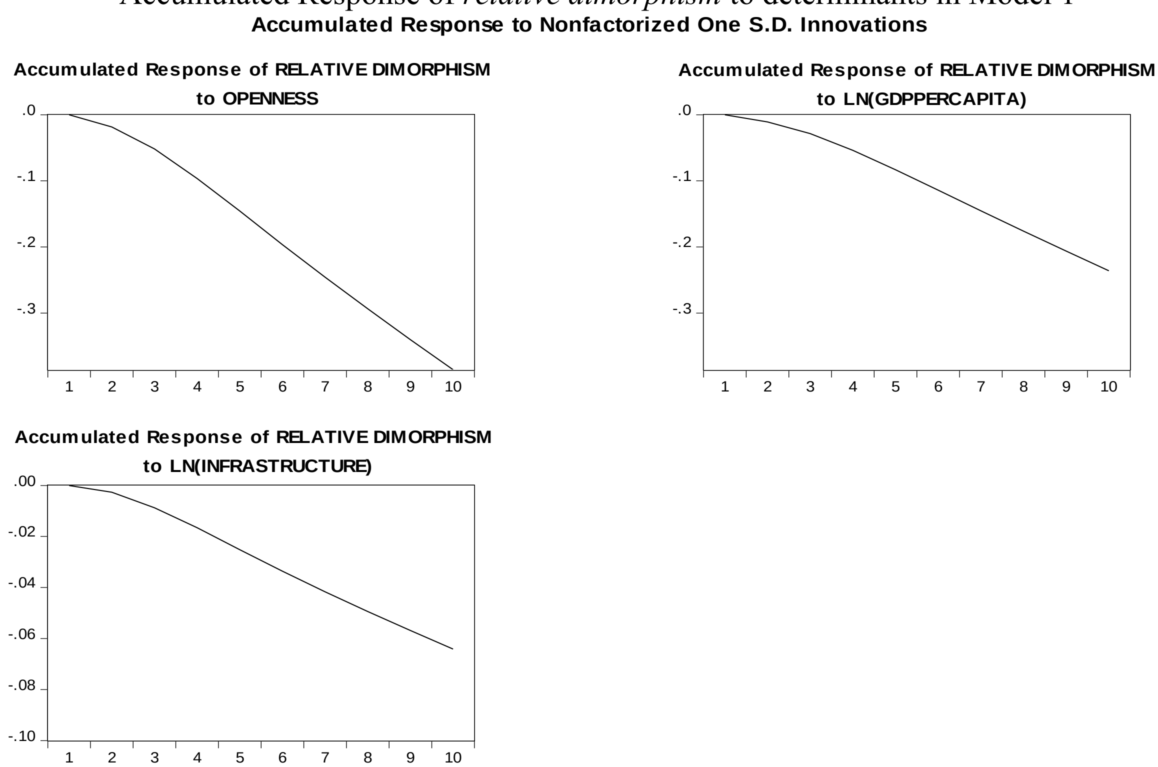
Variable	***Model 1***	***Model 2***	***Model 3***	***Model 4***	***Model 5***	***Model 6***	***Model 7***	***Model 8***	***Model 9***
Openness	-0.07934	-0.06419	-0.05638	-0.04882	-0.03988	-0.04248	-0.25604	-0.25763	-0.07236
	(0.0155)	(0.0119)	(0.0118)	(0.0104)	(0.0075)	(0.0076)	(0.0406)	(0.0394)	(0.0188)
ln(infrastructure)	-1.21032	-0.74239	- 0.58568	-0.54065	- 0.59135	-0.61916	-2.23185	-2.22719	-3.33306
	(0.1781)	(0.0916)	(0.0946)	(0.07761)	(0.0473)	(0.0500)	(0.7938)	(0.79568)	(0.5667)
ln(GDP per capita)	0.84033						2.63651	2.83403	4.85239
	(0.1716)						(1.12274)	(1.2176)	(0.9184)
Total-HIHD		2.85042							
		(0.5435)							
Female-HIHD			2.054941						
			(0.8299)						
Male-HIHD				-2.53778					
				(0.4519)					
Female tertiary enrollment					0.04143		-0.05990		
					(0.0105)		(0.0701)		
Male tertiary enrollment						0.03947		-0.08817	
						(0.0050)		(0.0689)	
Total Mortality rate									0.02705
									(0.0058)
Dummy-change in fertility			yes		yes		yes		
Observations	73	73	70	70	73	73	73	73	70
Lags	2	1	2	2	1	1	1	1	2
Cointegration Rank	1	1	1	1	1	1	1	1	1

Source: Own estimations. Standard error in parentheses.

Graph 17 shows the response of relative dimorphism to a positive shock in openness, infrastructure developments, and per capita GDP from Model 1. The graph indicates that dimorphism responds negatively to a positive shock in the independent variables. As expected, a positive shock in these variables contributes to close in the short run the gender gap in average stature. A one standard deviation positive shock to openness (3.46%) will result in a decrease of the dimorphism index of 38% after 10 years. Similarly, a one standard deviation positive shock to per capita GDP (1.8%) and infrastructure (1.9%) will result in a decrease of the dimorphism index of 23% and 6% after 10 years, respectively.

Graph 17

Accumulated Response of *relative dimorphism* to determinants in Model 1

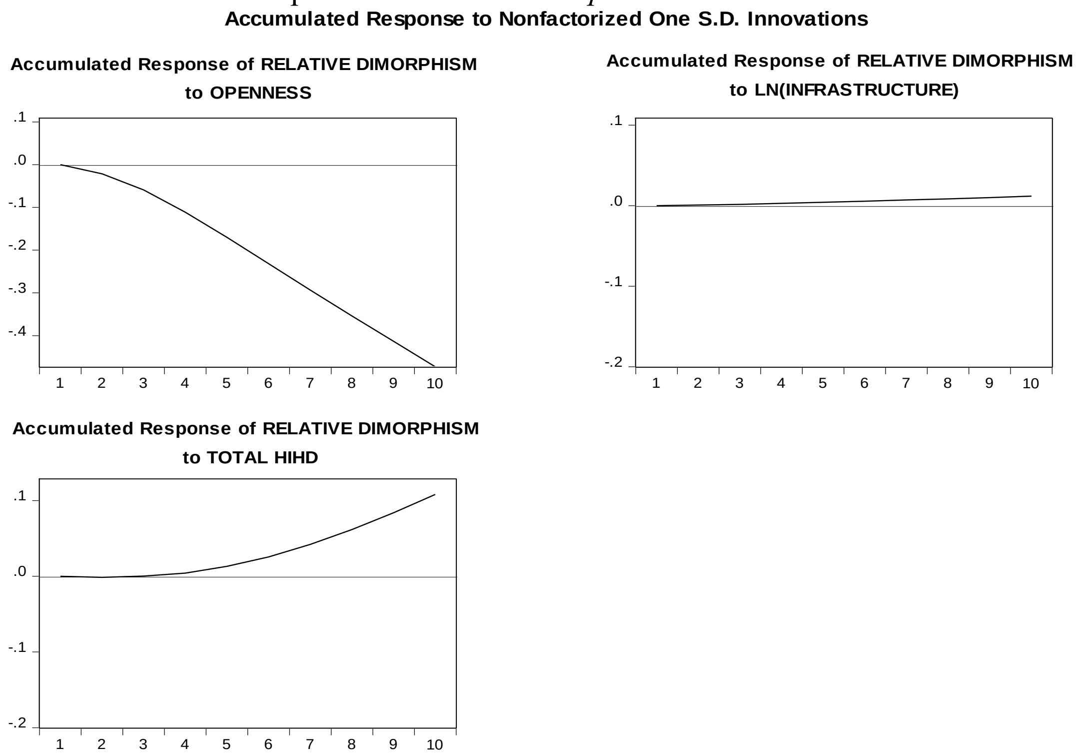


Source: own estimations.

Graph 18 indicates that an exogenous positive shock in the total *HIHD* is followed by an increase in the stature gender gap in the short run. Similar results are obtained from Model 3 (Graph 19) and Model 4 (Graph 20), when female-HIHD, and male-HIHD are included in the cointegration vector, respectively.

Graph 18

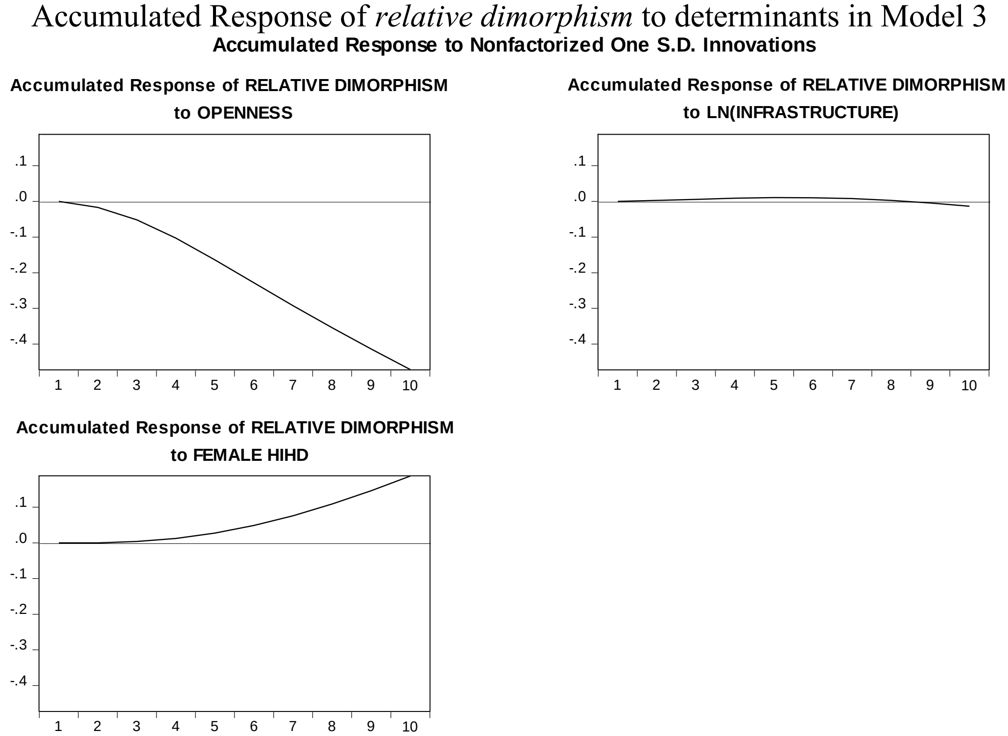
Accumulated Response of *relative dimorphism* to determinants in Model 2



Source: own estimations.

Graph 19

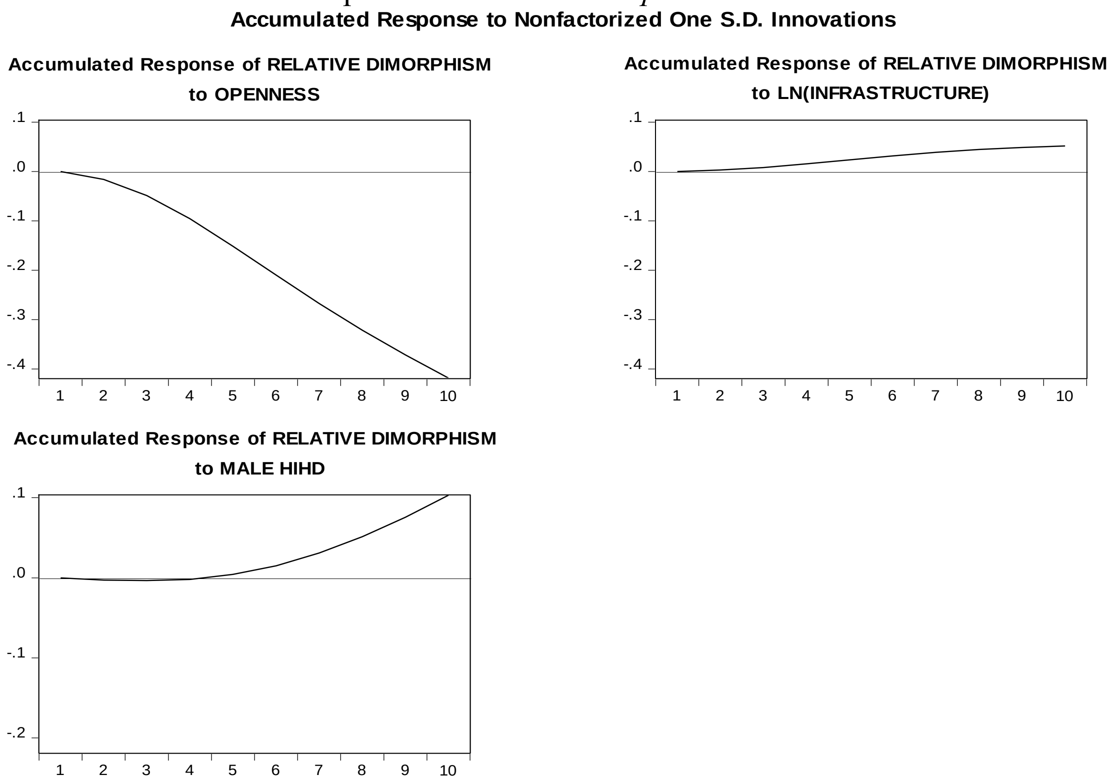
Accumulated Response of *relative dimorphism* to determinants in Model 3



Source: own estimations.

Graph 20

Accumulated Response of *relative dimorphism* to determinants in Model 4



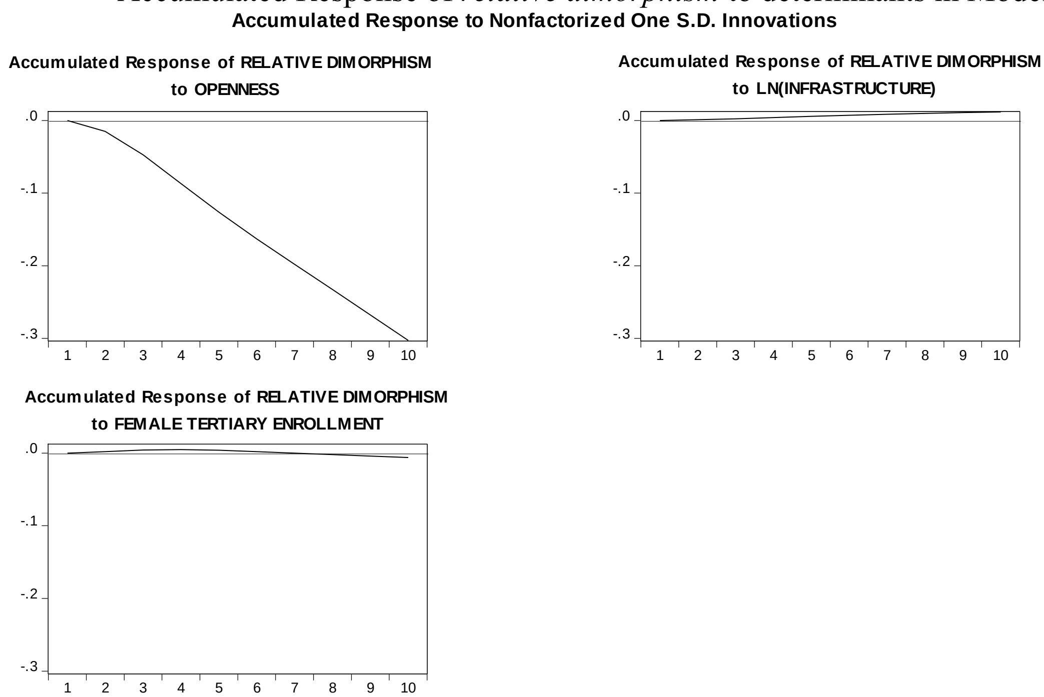
Source: own estimations.

Graphs 21 and 22 show the response of relative dimorphisms to a shock in the independent variables, when female and male tertiary education are included in the cointegration equation (Models 5 and 6, respectively). IRFs indicate that a positive shock in education does not have an important effect on reducing the stature gender gap.

Finally, Graph 23 displays IRF from the VEC model obtained from the specification 9 in table 4, in which relative dimorphism responds negatively to a positive shock in the degree of openness, infrastructure development, and real per capita GDP. As expected, after a shock in these variables, the gap between the stature of males and female decreases. Also, an increase in the mortality rates leads to an increment in relative dimorphism. Therefore, reducing mortality rates, could help to reduce the stature gender gap.

Graph 21

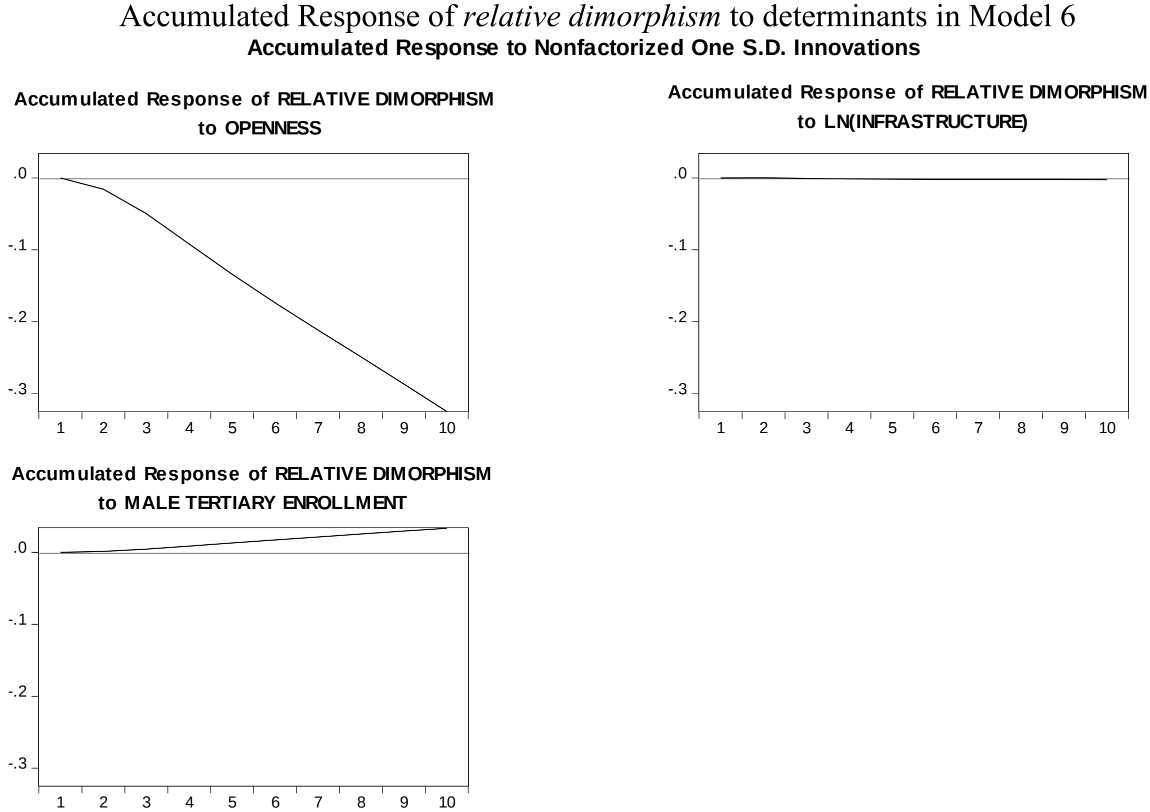
Accumulated Response of *relative dimorphism* to determinants in Model 5



Source: own estimations.

Graph 22

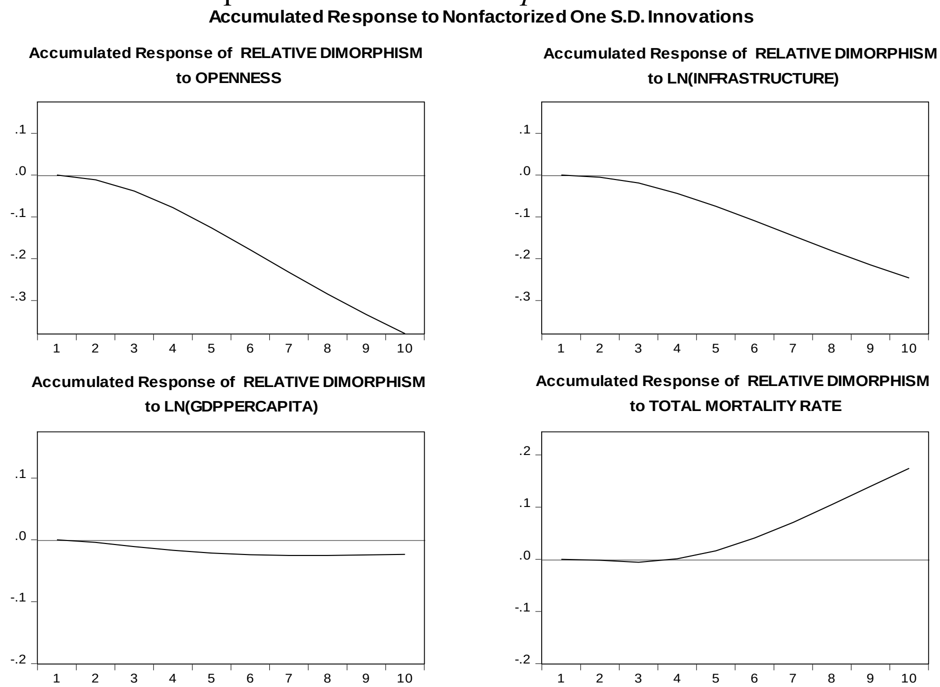
Accumulated Response of *relative dimorphism* to determinants in Model 6



Source: own estimations.

Graph 23

Accumulated Response of *relative dimorphism* to determinants in Model 9



Source: own estimations

4. CONCLUSIONS

The analysis of the relationship between height and some economic development indicators in Colombia during the twentieth century reveals a long-run relationship between female and male average height and the economic variables included in the analysis as shown by the cointegration tests. The results indicate that improvements in the quality and quantity of food, and the reduction in food prices, measured by the degree of openness, and by infrastructure developments, as well as improvements in the economic conditions, proxied by per capita GDP, HIHD, and education, lead to increases in female and male height. Regarding the gender height dimorphism, the results suggest that higher degree of openness and infrastructure developments have contributed to a reduction in the stature gender gap. On the contrary, improvement in per capita GDP and in the HIHD may have contributed to widening this gap during the second half of the 20th century. This result suggests that improvements in per capita income and in the HIHD could have a larger effect on men’s stature than on women’s height in the last decades of the 20th century.

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Appendix 1

Gender Development and Inequality Indices: Colombia, 1975-2017

Year	Gender Development Index	Gender Inequality Index
1995	0.941	0.542
2000	0.960	0.508
2005	0.971	0.490
2010	0.993	0.434
2015	0.996	0.398
2017	0.997	0.383

Source: United Nations, Human Development Reports. http://hdr.undp.org/en/data

Appendix 2

Table A.2.1. Unrestricted cointegration rank test (trace) – relationship between *natural logarithm of female height* and its determinants.

	Model 1	***Model 2***	***Model 3***	***Model 4***	***Model 5***
None					
Eigenvalue	0.362107	0.451645	0.398938	0.388876	0.364560
Trace Statistic	60.69400	123.2153	63.88702	81.96422	54.47140
Critical value (0.05)	47.85613	95.75366	47.85613	69.81889	47.85613
Prob.	0.0020**	0.0002**	0.0008**	0.0039**	0.0105**
At most 1					
Eigenvalue	0.181474	0.407524	0.286287	0.211516	0.190405
Trace Statistic	27.42469	80.55627	27.74396	45.52251	20.91698
Critical value (0.05)	29.79707	69.81889	29.79707	47.85613	29.79707
Prob.	0.0917	0.0054**	0.0847	0.0815	0.3628
At most 2					
Eigenvalue		0.245662			
Trace Statistic		43.39169			
Critical value (0.05)		47.85613			
Prob.		0.1233			
Observations	74	71	71	74	74
Lags	1	1	1	1	1
Rank	1	2	1	1	1

** Significance of 5%

Table A.2.2. Unrestricted cointegration rank test (trace) – relationship between *natural logarithm of male height* and its determinants.

	Model 1	***Model 2***	***Model 3***	***Model 4***	***Model 5***
None					
Eigenvalue	0.397981	0.428915	0.393096	0.423963	0.382576

Trace Statistic	64.98395	86.97388	56.76230	82.37375	56.08747
Critical value (0.05)	47.85613	69.81889	4785613	69.81889	47.85613
Prob.	0.0006**	0.0012**	0.0058**	0.0036**	0.0070**
At most 1					
Eigenvalue	0.230277	0.309954	0.203853	0.260846	0.173860
Trace Statistic	27.43143	47.19849	21.30593	41.55653	20.40478
Critical value (0.05)	29.79707	47.85613	29.79707	47.85613	29.79707
Prob.	0.0915	0.0576	0.3388	0.1715	0.3958
Observations	74	71	71	74	74
Lags	1	1	1	1	1
Rank	1	1	1	1	1

** Significance of 5%

Table A.2.3. Unrestricted cointegration rank test (trace) – relationship between *relative dimorphism* and its determinants.

	Model 1	*Model 2*	*Model 3*	*Model 4*	*Model 5*	*Model 6*	*Model 7*	*Model 8*	*Model 9*
None									
Eigenvalue	0.343121	0.394115	0.411880	0.368598	0.382429	0.378167	0.392754	0.393936	0.451349
Trace Statistic	55.56860	65.26741	64.89137	61.79240	58.13622	57.81698	83.45844	78.24876	96.42741
Critical value (0.05)	47.85613	47.85613	47.85613	47.85613	47.85613	47.85613	69.81889	69.81889	69.81889
Prob.	0.0080**	0.0005**	0.0006**	0.0015**	0.0041**	0.0044**	0.0028**	0.0091**	0.0001**
At most 1									
Eigenvalue	0.198778	0.205360	0.223492	0.246862	0.152141	0.176505	0.285731	0.263108	0.305142
Trace Statistic	24.88999	28.18856	27.20287	29.60553	22.47113	22.66079	46.54564	41.19180	54.40692
Critical value (0.05)	29.79707	29.79707	29.79707	29.79707	29.79707	29.79707	47.85613	47.87613	47.85613
Prob.	0.1654	0.0757	0.0968	0.0526	0.2730	0.2631	0.0660	0.1826	0.0107**
At most 2									
Eigenvalue									0.247833
Trace Statistic									28.92360
Critical value (0.05)									29.79707
Prob.									0.0628
Observations	73	73	70	70	73	73	73	73	70
Lags	2	1	2	2	1	1	1	1	2
Rank	1	1	1	1	1	1	1	1	2

** Significance of 5%


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