Fertility and Economic Development: Quantile Regression Evidence on the Inverse J-shaped Pattern

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Abstract This paper analyses empirically the relationship between economic development and fertility. Through a new sample selection and quantile regression, it investigates whether there is an inverse J-shaped pattern between these two variables, and, if so, whether it depends on development and fertility levels. Our results confirm that the inverse J-shaped pattern exists, but only when a certain level of economic development is attained. Results also suggest an innovative finding: the J-shape depends not only on the development but also on the fertility level. The higher the fertility rate, the higher the GDP per capita needed to reverse fertility decline, and the faster the negative and positive segments of the J-shape fall and grow.

Keywords J-shaped pattern · Fertility rate · Economic development · Quantile regression

JEL Classification C21 · J11 · J13

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1 Introduction

During the twentieth century, the world experienced both unprecedented rates of economic development and significant declines in fertility (Bryant 2007; Maddison 2007). This negative association between economic development and fertility has been one of the most solidly established and accepted empirical relationships in the economic and social sciences (Myrskylä et al. 2009; Doepke 2004; D’Addio and d’Ercole 2005). At the beginning of the twenty-first century, however, Myrskylä et al. (2009)—through cross-country analysis—and Luci-Greulich and Thévenon (2013, 2014)—using panel data and focusing on within-country variations—found that the relationship between development and fertility reversed, from negative to positive, when a country attained an advanced economic position.¹ Beyond this point, fertility and economic development increased simultaneously,² opening new debate on whether the former negative development–fertility association had taken the form of an inverse J-shaped pattern.³

Using traditional panel regressions, the above-cited papers found this new aggregate inverse J-shaped relationship in only some highly developed countries, creating another debate on the type of country where reversal occurs, that is, whether the reversal depends on development level. Luci-Greulich and Thévenon (2014: 205) found that there is an inverse J-shaped pattern between GDP per capita and fertility in those developed countries where economic development comes in hand with increases in female employment, while fertility stagnates on low levels in other countries. However, it stays unclear why the inverse J-shaped pattern as a whole occurs on quite different fertility levels.

The present paper attempts to fill these gaps and clarify this unresolved issue by using a new method of panel-data quantile regression (QR) and new sample division to provide a deeper and more detailed quantitative analysis of the relationship between economic development (measured by GDP per capita) and fertility (measured by fertility rates). The specific goals are two: first, to test whether the empirical relationship between economic development and fertility takes the form of an inverse J-shaped pattern, and, if so, whether it depends on development level; second, to test whether the inverse J-shaped pattern also depends on fertility level. Whereas previous literature has investigated this pattern in a group of countries, the present study does not focus on countries—as the observation unit—but on development levels. Thus, it hypothesizes that the J-shape depends on each GDP pc and fertility level at different periods of time.

To address these research goals, the analysis requires two stages. The first runs a panel regression for the overall sample of 151 countries and for five different

¹ Myrskylä et al. (2009) define this advanced economic position as a Human Development Index (HDI) of 0.86 or higher, whereas Luci-Greulich and Thévenon (2014) use GDP per capita (GDP pc) to measure development and a GDP pc of 22,000 US dollars or higher to define the advanced economic position.

² Some recent papers that attempt to explain this fertility rebound through institutional variables such as female employment, family, and social policies or gender equality include Luci-Greulich and Thévenon (2013, 2014), Myrskylä et al. (2011), and Esping-Andersen and Billari (2015).

³ This debate is open since studies such as Furuoka (2009, 2013) and Harttgen and Vollmer (2014) find no empirical evidence for the J-shape.

subsamples to determine whether the J-shape depends on development level. The sample is divided into OECD and non-OECD countries following the analysis carried out by Luci-Greulich and Thévenon (2014), and into first, second and third tertiles of GDP pc as an alternative division. The second stage runs a quantile panel-data regression using different panel-data sets for 1970–2010 and the observations classified by income level to determine whether the J-shape also depends on fertility level. Therefore, the present paper contributes to the literature by exploring two ideas: (1) whether the inverse J-shaped pattern depends on development level, through a new selection and division of the sample, i.e. tertiles, and (2) whether the J-shape depends on fertility level, through a QR to test for differences in the effect of GDP pc on fertility across low, middle, and high fertility rates. This is the first paper using QR to analyse empirically whether the inverse J-shaped pattern changes across fertility levels, an analysis not possible with other estimation techniques.

2 Theoretical Framework

Fertility is a complex phenomenon, and its determinants are difficult to define. Finding a single complete theory of fertility is almost impossible. After all, fertility is influenced by both social and biological behaviours, socially linked to numerous socioeconomic and sociocultural factors, and biologically dependent on evolutionary antecedents and physiological constraints (McNicoll 1980: 441).

Throughout history, economic development has been accompanied by a decrease in fertility (Doepke 2004; McNicoll 1980; Bongaarts 2008; Anderson and Kohler 2015). The twentieth century, for example, experienced significant rates of economic growth and a substantial decline in fertility (Bryant 2007). Since 1960, the Total Fertility Rate (TFR)⁴ has dropped from 3.3 births per woman in 1960 to 2.5 in 2012 (WDI 2015). Projections by the United Nations have found that the TFR of countries in economic transition will decrease to slightly below replacement level (Bongaarts 2008).

Over the past 60 years, the negative association between economic development and fertility has been one of the most solidly accepted empirical regularities in the economic and social sciences. Many studies during this time have attempted to explain this negative association—known as *demographic transition*—from a variety of theoretical, ideological and disciplinary perspectives, including biology, sociology and economics (Anderson and Kohler 2015; Galor and Weil 2000; Lesthaeghe 1995; Kirk 1996; Caldwell 1976, among others).

In the economic literature, two basic types of theories have been developed to explain fertility decline: cultural and structural theories. The former include *Diffusionist* and *Innovation* theories, which focus on the emergence and spread of new ideas, values and techniques for limiting fertility. The latter include *Socioeconomic* and *Demand* theories, which focus on changing social and economic

⁴ Total Fertility Rate (TFR) indicates number of children that would be born to a woman if she were to live to the end of her childbearing years and bear children in accordance with current age-specific fertility rates (World Bank 2015).

conditions that motivate couples to limit their fertility, such as increased income, higher education level and women's increasing participation in the labour market (De Lange et al. 2014; Bryant 2007). The best-known structural theory is the *Microeconomic Household Model*, which argues that increased income reduces fertility in modern societies because it produces a substitution effect against the number of children in favour of the quality per child—essentially, more investment in individual human capital. Households choose to have fewer children in order to give each child more education (Becker 1960, 1981; Becker et al. 1990). Another reason given for the negative association between economic development and fertility is the indirect cost for the woman of having children. As economic development increases, gender inequality decreases, opening more educational and professional opportunities to women (Boserup 1970; Galor and Weil 1996) and enabling them to replace having children with a professional career (Hotz et al. 1997).

Nevertheless, the impact of economic development on fertility remains theoretically and empirically ambiguous (Luci-Greulich and Thévenon 2013, 2014). Theories differ on the importance of economic development in explaining fertility decline. Empirically, although the long-term data show a negative relationship between economic development and fertility, what seemed to be a clear negative association has been questioned and even viewed as positive,⁵ opening debate on the inverse J-shaped relationship between these two variables.

In recent years, some authors, such as Myrskylä et al. (2009) and Luci-Greulich and Thévenon (2013, 2014), argue that the well-established negative relation between development and fertility has reversed and is now positive in some highly developed countries. Further, since the early 2000s, many developing countries have experienced a stall in their demographic transition (Schoumaker 2009; Bongaarts 2008). Some explanations of this new positive association between development and fertility are risen in female employment availability (Luci-Greulich and Thévenon 2013, 2014), changing attitudes towards female employment and childbearing behaviours (Lesthaeghe 2010; Goldstein et al. 2009), investments in social and family policies that increase the availability of childcare services and therefore opportunities for woman to combine work and family life (Luci-Greulich and Thévenon 2013; Thévenon 2011; McDonald 2000), gender equality institutional context and changing norms of contraceptive use and childbearing behaviour (Myrskylä et al. 2011; Esping-Andersen and Billari 2015; Anderson and Kohler 2015), decreasing relative cost of childcare (due to increase in wages and opportunities for women) (Martínez and Iza 2004; Day 2004), increasing fertility at older reproductive ages (Myrskylä et al. 2011) and the end of the birth postponement process (Goldstein et al. 2009). Another recent explanation provided by Anderson and Kohler (2015) posits that egalitarian institutional and household gender norms, which reduce work–family conflicts, are the variable enabling

⁵ Myrskylä et al. (2009) open a new debate on when reversal occurs. For them, 2005 is an important year for this reversal, but they also identify different years for different countries—such as 1976 in the USA, 1983 in Norway and 1994 in Italy—as well as some countries (e.g. Japan, Canada, South Korea) where decline in fertility does not reverse at all. The question of when the reversal occurs is beyond the scope of this paper.

re-increase in fertility rate. No consensus exists, however, on the causes of these reversals in fertility decline (Moultrie et al. 2008).

Finally, other authors such as Furuoka (2009, 2013) and Harttgen and Vollmer (2014) find a negative relationship between development and fertility for all of the countries and no evidence of the inverse J-shape, even in the most developed ones. Specifically, Harttgen and Vollmer (2014: 183) find *very little support for simple interpretations that fertility rates will automatically start to increase beyond a certain level of development*. Along the same lines, Schoumaker (2009) affirms that the stalls in fertility decline experienced by many developing countries (especially sub-Saharan African countries) are spurious due to serious data quality problems. Therefore, this debate on the existence and causes of the inverse J-shape is still open.

3 Empirical Analysis

The aim of this research is to shed light on the empirical regularities in the relationship between economic development and fertility, deepening knowledge of the J-shaped relationship originally found by Myrskylä et al. (2009). The paper states two hypotheses. First, the J-shaped pattern between fertility and development exists, but only when a country attains an advanced economic position. Second, the J-shape depends not only on development level but also on fertility level.

3.1 Data

The fertility rate data used here come from the World Development Indicators (hereafter WDI) (World Bank 2015). Development level is measured by GDP pc (PPP at constant prices for 2005) provided by the Penn World Tables (PWT 7.1) (Heston et al. 2012). As in Luci-Greulich and Thévenon (2013, 2014), we use the GDP pc rather than the Human Development Index (HDI) because this variable is more appropriate for the purposes of this paper.⁶

The analysis uses a balanced panel-data set covering a total of 151 countries for the period 1970–2010. Table 6 in “Appendix 1” provides a list of the 151 countries in the sample population.

To perform the empirical analysis, the overall sample is divided into five subsamples. First, the observations are classified according to OECD and non-OECD countries following Luci-Greulich and Thévenon (2014) (see Table 6, Appendix 1). Second, as an important novelty of this paper and in order to clarify the unresolved issues in previous literature and find new empirical evidences, the observations are divided into three tertiles of GDP pc—low, middle and high—

⁶ Since one of our main objectives is to divide the sample by income level to study the relationship between fertility and income, it is preferable to use GDP pc as the main covariate for measuring this relationship. The HDI is a compounded score of 3 indicators: Education Index, Health Index and GDP pc (Malik 2014). According to Luci-Greulich and Thévenon (2014: 192), “as life expectancy and school enrolment are correlated with GDP per capita... it is unclear what elements behind human development drive the fertility rebound in highly developed countries”.

producing a more homogeneous classification of observations by income level than would occur with a single OECD/non-OECD classification (Table 6, Appendix 1). It is important to note that the observations from one country may not all belong to the same income tertile throughout the period analysed. Some observations from a country may be included in one tertile and others for the same country included in another. That is, the division distinguishes not countries but income level (GDP pc). This is because the inverse J-shaped pattern appears when certain level of income is attained. Until one country reaches this certain level, it cannot experience the positive relationship between development and fertility. All observations classified in the high development level, where the relationship between fertility and development could change, must thus be separated from the others in the analysis to accurately identify the J-shaped pattern.

All in all, this new tertile sample division improves our ability to analyse the J-shape because it provides more homogeneous groups, improving the efficiency of the estimators and avoiding the emergence of outliers. Throughout the period analysed (1970–2010), most countries in the sample experienced a development process, with some observations from a country included in one tertile and others for the same country in another. Grouping observations by income irrespective of period is essential to avoid outliers and improve estimation efficiency.⁷ Therefore, it also improves our ability to determine whether it occurs in some highly developed countries, as previous literature suggests, or when a certain level of GDP pc is reached.

3.2 The Model

To test whether economic development, measured by GDP pc ($\log \text{GDPpc}_{it}$),⁸ has any impact on fertility rate (TFR_{it}), we estimate the following equation:

$$\text{TFR}_{it} = \beta_0 + \beta_1 \cdot \text{Log_GDPpc}_{it} + \beta_2 \cdot \text{Log_GDPpc}_{it}^2 + \alpha_i + \delta_t + \varepsilon_{it} \quad (1)$$

where α_i captures individual heterogeneity and δ_t represents time effects.⁹ The inclusion of the square of the logarithm of GDP pc (Log_GDPpc_{it}^2) in the model *allows (testing) for a change in the sign of the effect of an increase in GDP per capita on fertility levels, which is compatible with a reversal of fertility trends* (Luci-Greulich and Thévenon 2013, 2014: 197). If the estimates give a positive and significant coefficient for Log_GDPpc_{it}^2 , and a negative and significant effect for Log_GDPpc_{it} , we can confirm the J-shaped relationship between development and fertility.

⁷ An empirical test—comparing regression coefficients between tertile groups (Allison 2009)—has been made to contrast whether a significantly differentiated effect of the J-shape relationship exists among the tertile groups considered in our analysis. The outcomes of this test—available upon request—prove the importance of considering a differentiated regression analysis for each tertile group to provide a better knowledge of the J-shape pattern, as this pattern is significantly different for each group.

⁸ We estimate the log transformation of GDP pc (see Luci-Greulich and Thévenon 2013, 2014) because the logarithmic form reduces absolute increases in the level of this variable and thus captures proportional rather than absolute differences in GDP pc distribution.

⁹ Following Luci-Greulich and Thévenon (2014), we include 10-year-period effects to control for variables not observed in the model that influence variation in fertility rate by decade.

3.3 Estimation Method

We first use linear regression models (LRM) to estimate Eq. (1) and determine whether the J-shape occurs when a country attains an advanced economic position (Hypothesis 1). We run a fixed-effects panel-data model for the whole sample, the groups of OECD and non-OECD countries, and the observations classified into the three GDP pc tertiles. The fixed-effects panel-data model focuses on variations within countries, permitting us to test the extent to which increases in GDP per capita are linked to variations in total fertility rates within a country.

To test our second hypothesis, which contrasts whether the J-shape depends on fertility, we run a QR for panel data with fixed effects.

Since LRM are techniques based on the assumption of a common slope for all countries, all previous papers using this type of model have focused only on modelling the conditional mean of the covariates and the dependent variable, without taking into consideration the latter's full conditional distribution properties. Such models introduce a strong constraint based on the normality assumption of the dependent variable in order to obtain the best linear unbiased estimator (BLUE) through OLS methodology. Focusing on the mean implies that these estimates were not well suited to explain why the inverse J-shape is located at quite different fertility levels as Luci-Greulich and Thévenon (2013, 2014) suggest something that we can analyse using conditional quantile regression (CQR).¹⁰ This location of J-shaped pattern at different fertility levels could be related to the existence of specific cultural norms in each country. Since cultural norms affect individual fertility decisions, national fertility rates will not depend on GDP alone (Miranda 2008; Booth and Joo Kee 2006; Fernández and Fogli 2005; Bisin and Verdier 2000, 2001; Gustavus and Nam 1970; Westoff and Potvin 1967). QR will thus be useful to analyse whether the J-shape behaves differently among the developed countries with different fertility levels (Miranda 2008; Booth and Joo Kee 2006).

The CQR model for the τ th quantile may be formulated as the following optimization problem:

$$\hat{Q}_Y(\tau) = \min_{\theta \in \mathbb{R}^K} \left[\sum_{i \in \{i: y_i \geq X_i \hat{\theta}\}} \tau |y_i - X_i \hat{\theta}| + \sum_{i \in \{i: y_i < X_i \hat{\theta}\}} (1 - \tau) |y_i - X_i \hat{\theta}| \right] \quad (2)$$

$$\hat{Q}_Y(\tau) = \min_{\theta \in \mathbb{R}^K} \sum_i \rho_\tau(y_i - X_i \hat{\theta})$$

¹⁰ The CQR approach, developed by Koenker and Bassett (1978), provides rich characterization for using a regression model to analyse the effect of covariates on conditional distribution of the dependent variable. This new technique is an advance in econometrics that facilitates analysis of the full, conditional distributional properties of the dependent variable, considering a possible differentiated effect estimated between variables depending on the τ th quantile considered in the analysis (Hao and Naiman 2007). In contrast to LRM, the CQR technique is quite useful when the conditional distribution of the dependent variable does not meet the normality assumption, as it improves the robustness of the estimates in the presence of outliers.

$$\widehat{Q}_Y(\tau) = \min_{\theta \in \mathbb{R}^K} \sum_i \rho_\tau(u_i)$$

where $\tau \in [0, 1]$ and $\rho_\tau(\cdot)$ is defined as:

$$\rho_\tau(u_i) = \begin{cases} \tau u_i, & \text{if } u_i \geq 0 \\ (1 - \tau)u_i, & \text{if } u_i < 0 \end{cases}$$

The CQR method minimizes the weighted sum of residuals, not the sum squared of these residuals often applied in LRM. The minimization problem stated in Eq. (2) is solved efficiently by the linear programming method.

Using panel data introduces a limitation for estimating CQR model. Quantiles are not linear operators, and it is difficult to envision an appropriate strategy for dealing with them (Abrevaya and Dahl 2008). Nevertheless, recent studies implement CQR with panel data, particularly Koenker (2004), Abrevaya and Dahl (2008), Galvao (2011) and Canay (2011). The present study uses the technique proposed by Canay (2011) to estimate a CQR model for panel data with fixed effects. As noted by Canay (2011: 368), fixed effects (α_i) can be viewed as *location shift variables* affecting all quantiles in the same way. Canay develops a simple two-step estimator for ensuring a consistent estimator of $\widehat{\theta}(\tau)$. The first step estimates $\widehat{\alpha}_i$ as expected difference between observed y_{it} and predicted $\widehat{y}_{it}$ as the dependent variable, obtaining the latter by applying the within-/fixed-effects estimator:

$$\widehat{\alpha}_i \equiv E[y_{it} - \widehat{y}_{it}]$$

$$\widehat{\alpha}_i \equiv E[y_{it} - X'_{it}\widehat{\theta}_\mu]$$

The second step consists of transforming the dependent variable to obtain a new random variable, which will be used to estimate $\widehat{\theta}(\tau)$ using QR:

$$\ddot{y}_{it} \equiv y_{it} - \widehat{\alpha}_i$$

The QR estimator is obtained by running the model on $\ddot{y}_{it}$.

4 Results

4.1 Development Levels and the J-shape

Concerning our first hypotheses *the existence of the J-shaped pattern between fertility and development when a certain level of development is attained*, Table 1 presents the results for the LRM¹¹ for the overall sample and the five subsamples (more detail on descriptive statistics, see Appendix 2, Tables 7, 8).

¹¹ Although we have applied Pooled-Ordinary Least Squares (Pooled-OLS) and fixed-effects OLS estimates of Eq. (1), Table 1 presents only the later for the sake of clarity and space. However, Pooled-OLS estimates are available upon request.

Table 1 Fixed-effects OLS models dividing the sample by OECD, non-OECD and income tertile

Dependent: TFR_{it}	151 countries	OECD	Non-OECD	First tertile [^]	Second tertile ^{^^}	Third tertile ^{^^^}
Log_GDPpc_{it}	-5.123*** (0.746)	-15.551*** (3.570)	-3.659*** (0.787)	0.679 (2.716)	-5.843 (5.167)	-14.716*** (3.506)
Log_GDPpc_{it}^2	0.302*** (0.043)	0.779*** (0.187)	0.210*** (0.048)	-0.106 (0.197)	0.343 (0.310)	0.775*** (0.174)
μ_i	Yes	Yes	Yes	Yes	Yes	Yes
Constant	26.351*** (3.189)	79.727*** (17.112)	21.233*** (3.247)	7.043 (9.353)	30.164 (21.466)	72.700*** (17.581)
Marginal effect: $\frac{dTFR_{it}}{d\text{Log_GDPpc}_{it}}$ Log_GDPpc in the sample						
Lower bound	-2.054*** (a)	-3.162*** (a)	-1.525*** (a)	-0.402 (a)	-0.626 (a)	-0.847* (a)
Upper bound	1.819*** (b)	2.050** (b)	1.168*** (b)	-0.936*** (b)	0.303 (b)	3.111*** (b)
Observations	6191	1148	5043	2063	2063	2065
R^2	0.648	0.615	0.689	0.631	0.761	0.495
F test (σ_u^2)	0.000	0.000	0.000	0.000	0.000	0.000

The estimates present robust standard errors. In marginal effects null hypothesis: $\frac{dTFR_{it}}{d\text{Log_GDPpc}_{it}} = 0$. [^] GDP pc interval for first tertile [160.7 \$ -1974 \$], ^{^^} second tertile (1974 \$ -7634 \$), and ^{^^^} third tertile (7634 \$ -98,024 \$). (a) It uses the lower bound of the Log_GDP pc distribution when calculating the marginal effect value. (b) It uses the upper bound of the Log_GDP pc distribution when calculating the marginal effect value

* Significant at .1; ** significant at .05; *** significant at .01

To correctly interpret the relationship between fertility rate and GDP pc, we should not use β_1 and β_2 estimated coefficients from Eq. (1). The nonlinearity of this equation forces us to use the *marginal effects*, which are the derivatives of TFR_{it} by Log_GDPpc_{it} , providing the following continuous function:

$$\frac{d\text{TFR}_{it}}{d\text{Log_GDPpc}_{it}} = \beta_1 + 2 * \beta_2 * \text{Log_GDPpc}_{it} \quad (3)$$

Therefore, the correct shape of the relationship between fertility and development will come from Eq. (3) when giving values to log GDPpc_{it} . In this regard, we have considered two values of the sample of log GDPpc_{it} (minimum—*lower bound*—and maximum—*upper bound*—).

The analysis of the *marginal effects* shows an initial negative and significant relationship between development and fertility for the *lower bound* and a positive and significant relationship between these two variables for the *upper bound*, and this happens for all the subsamples except the first and second tertiles.¹² These results suggest that only in the three significant subsamples the relationship between fertility and development is negative up to a GDP pc threshold, beyond which the correlation becomes positive. Thus, we can confirm that the inverse J-shaped pattern exists in these subsamples.

The GDP pc threshold estimated is calculated from the solution of the following equation: $\frac{d\text{TFR}_{it}}{d\text{Log_GDPpc}_{it}} = \beta_1 + 2 * \beta_2 * \text{Log_GDPpc}_{it} = 0$, obtaining a value for the GDP pc in which the relationship between fertility and GDP pc turns from negative to positive. The estimates of the values of threshold are US\$ 21,524.70 (PPP) for the OECD subsample, US\$ 6066.89 (PPP) for the non-OECD, and US\$ 13,185.31 (PPP) for the third tertile of GDP pc.

These first results are consistent with the ones obtained by Myrskylä et al. (2009) and Luci-Greulich and Thévenon (2014), who using panel data for a sample of 140 countries and the OECD countries in the period 1975–2005 and 1960–2007, respectively, found empirical evidence for the J-shape only in the most developed countries. They found that the historical downward trend in fertility is reversed as countries attain an advanced level of development. Beyond a specific threshold, there is a positive relationship between fertility rate and HDI (Myrskylä et al. 2009) and GDP pc (Luci-Greulich and Thévenon 2014). Unlike these papers, our sample division provides an accurate distinction of the observations, which is different to the OECD/non-OECD administrative division. Previous papers had some issues concerning the sampling method remained unclear (i.e. why some developed countries deviate from the expected inverse J-shaped path). Consequently, to provide a different and deeper analysis of this relationship, we have introduced a new sample division not focusing on countries—as the observation unit—but on the income levels attained by the countries in a specific moment. Following our results, we posit that the OECD/non-OECD division does not allow us to identify if a country attains the level of income to experience the J-shaped pattern. On the

¹² Table 6 in “Appendix 1” provides the division of the sample by tertiles of income.

contrary, the tertiles of income division help to understand the J-shape pattern as a phenomenon that occurs only in the highest income level (third tertile).

Our results differ from those of Bongaarts (2008), Westoff and Cross (2006), Schoumaker (2009) and Shapiro and Gebreselassie (2007), who find reversals in fertility decline in many developing countries (especially sub-Saharan African countries) since the early 2000s.

Our results also differ from those of Furuoka (2009, 2013) and Harttgen and Vollmer (2014), who using LRM¹³ find no evidence of the J-shape for any country in the world. These studies found a negative relationship between TFR and HDI for all of the countries and no reversal or threshold value beyond which the fertility–development relationship becomes positive.

4.2 Fertility Levels and the J-shape

Considering the results obtained in previous section, to test our second objective “does the J-shape depends on fertility levels?” we run a quantile panel-data regression (Canay 2011) only in OECD, non-OECD and third tertile subsamples.¹⁴ As Fig. 1 shows, the fertility rate distribution for these three subsamples does seem to follow a long-tailed distribution, similar to a Chi square. Further, the number of countries in the group of non-OECD countries is probably too large to find a coherent result, reinforcing our tertile sample division. This introduces substantial problems in the application of LRM estimates to test the relationship between development and fertility.

According to Koenker and Baset (1978: 34), *the extreme sensitivity of the least squares estimator to modest amounts of outlier contamination makes it a very poor estimator in many non-Gaussian, especially long-tailed, situations*. Then, the use of the quantile technique is justified as an alternative methodological strategy that provides more robust estimators to test the second hypothesis.

Tables 2, 3 and 4 present the results of the CQR estimates.¹⁵ As in the LRM estimates, we have included the *marginal effects* for having an accurate interpretation of the relationship between fertility and GDP pc. Analysing the marginal effects at the *lower bound*, we can highlight the negative and significant coefficient for all the estimates, thus confirming the initial decrease of fertility when GDP pc tends to rise up—similar to the outcomes obtained for LRM. Nevertheless, these negative effects

¹³ Furuoka (2009, 2013) uses threshold regression strategy and Harttgen and Vollmer (2014) applies difference-in-differences estimation methodology.

¹⁴ Although we do not consider the first and second tertiles of income group in this new analysis, we applied additional estimates to test for the linear relationship between fertility and income, and whether this relationship differs for different fertility levels, or quantiles. To do so, we applied a new CQR fixed-effects panel-data analysis (Canay 2011), estimating the following equation:

$$\text{TFR}_{it} = \beta_0 + \beta_1 \text{Log_GDPpc}_{it} + \alpha_i + \delta_t + \varepsilon_{it}.$$

The outcomes obtained indicate a significant and negative relationship between fertility and income, where the slope estimated is greater for the higher levels of fertility (Q.75 and Q.90). Thus, countries with a higher number of children born per woman suffer a greater negative impact of a variation in GDP pc on their fertility level in both tertile groups. Results from this additional analysis are available upon request.

¹⁵ Estimations for first and second tertiles of GDP pc are not included in the paper because their results were not statistically significant in previous subsection. Nevertheless, they are available upon request.

Fig. 1 Histogram for fertility rate in OECD, non-OECD and third tertile subsample. *Source:* Developed by the authors

Table 2 CQR fixed-effects panel-data estimators for OECD countries

Dependent: TFR_{it}	Q.10	Q.25	Q.50	Q.75	Q.90
Log_GDPPc_{it}	-12.651*** (1.146)	-13.403*** (0.726)	-14.427*** (0.601)	-16.892*** (0.891)	-16.463*** (0.962)
Log_GDPPc_{it}^2	0.639*** (0.058)	0.676*** (0.036)	0.723*** (0.030)	0.841*** (0.044)	0.814*** (0.047)
μ_t	Yes	Yes	Yes	Yes	Yes
Constant	64.278*** (5.576)	68.200*** (3.576)	74.029*** (2.945)	87.055*** (4.450)	85.759*** (4.887)
Marginal effect: $\frac{dTFR_{it}}{d\text{Log_GDPPc}_{it}}$ Log_GDPPc in the sample					
Lower bound	-2.481*** (a)	-2.643*** (a)	-2.931*** (a)	-3.508*** (a)	-3.509*** (a)
Upper bound	1.797*** (b)	1.884*** (b)	1.906*** (b)	2.123*** (b)	1.942*** (b)
Observations	1148	1148	1148	1148	1148
R^2	0.250	0.284	0.374	0.521	0.626
Groups	28	28	28	28	28

400 bootstrap replications. See "Appendix 3" for the coefficients of the different quantile regression parameter estimates of Log_GDPPc_{it} and Log_GDPPc_{it}^2 . * Significant at .1; ** significant at .05; *** significant at .01. (a) It uses the lower bound of the Log_GDPPc distribution when calculating the marginal effect value. (b) It uses the upper bound of the Log_GDPPc distribution when calculating the marginal effect value

Table 3 CQR fixed-effects panel-data estimators for non-OECD countries

Dependent: TFR_{it}	Q.10	Q.25	Q.50	Q.75	Q.90
Log_GDPPc_{it}	-3.645*** (0.131)	-3.609*** (0.092)	-3.815*** (0.084)	-3.827*** (0.125)	-4.005*** (0.149)
Log_GDPPc_{it}^2	0.210*** (0.008)	0.208*** (0.005)	0.219*** (0.005)	0.218*** (0.007)	0.229*** (0.009)
μ_t	Yes	Yes	Yes	Yes	Yes
Constant	20.290*** (0.522)	20.447*** (0.381)	21.852*** (0.341)	22.476*** (0.510)	23.649*** (0.588)
Marginal effect: $\frac{dTFR_{it}}{d\text{Log_GDPPc}_{it}}$ Log_GDPPc in the sample					
Lower bound	-1.504*** (a)	-1.493*** (a)	-1.588*** (a)	-1.609*** (a)	-1.677*** (a)
Upper bound	1.197*** (b)	1.178*** (b)	1.221*** (b)	1.190*** (b)	1.261*** (b)
Observations	5043	5043	5043	5043	5043
Pseudo R^2	0.505	0.513	0.514	0.494	0.468
Groups	123	123	123	123	123

400 bootstrap replications. See "Appendix 3" for the coefficients of the different quantile regression parameter estimates of Log_GDPPc_{it} and Log_GDPPc_{it}^2

* Significant at .1; ** significant at .05; *** significant at .01. (a) It uses the lower bound of the Log_GDPPc distribution when calculating the marginal effect value. (b) It uses the upper bound of the Log_GDPPc distribution when calculating the marginal effect value

Table 4 CQR fixed-effects panel-data estimators for third tertile of GDP pc

Dependent: TFR_{it}	Q.10	Q.25	Q.50	Q.75	Q.90
Log_GDPPc_{it}	-12.516*** (0.841)	-11.606*** (0.813)	-13.159*** (0.843)	-15.081*** (0.929)	-16.617*** (1.291)
Log_GDPPc_{it}^2	0.665*** (0.042)	0.618*** (0.040)	0.694*** (0.042)	0.786*** (0.047)	0.858*** (0.065)
μ_t	Yes	Yes	Yes	Yes	Yes
Constant	61.159*** (4.115)	56.906*** (4.033)	65.187*** (4.177)	75.478*** (4.580)	84.073*** (6.352)
Marginal effect: $\frac{dTFR_{it}}{d\text{Log_GDPPc}_{it}}$ Log_GDPPc in the sample					
Lower bound	-0.621*** (a)	-0.550*** (a)	-0.748*** (a)	-1.014*** (a)	-1.267*** (a)
Upper bound	2.774*** (b)	2.606*** (b)	2.794*** (b)	3.001*** (b)	3.115*** (b)
Observations	2065	2065	2065	2065	2065
Pseudo R^2	0.408	0.382	0.337	0.349	0.381
Groups	69	69	69	69	69

400 bootstrap replications. See "Appendix 3" for the coefficients of the different quantile regression parameter estimates of Log_GDPPc_{it} and Log_GDPPc_{it}^2 .
 * Significant at .1; ** significant at .05; *** significant at .01. (a) It uses the lower bound of the Log_GDPPc distribution when calculating the marginal effect value. (b) It uses the upper bound of the Log_GDPPc distribution when calculating the marginal effect value

Table 5 Breaking point in J-shaped relationship for each quantile (values in US\$ PPP at constant prices for 2005). *Source:* Developed by authors using estimates from Tables 2, 3 and 4

Group	Q.10	Q.25	Q.50	Q.75	Q.90
OECD	19,683.23 \$	19,934.61 \$	21,471.72 \$	22,728.21 \$	24,361.52 \$
Non-OECD	5711.42 \$	5788.29 \$	6036.30 \$	6412.09 \$	6248.31 \$
3rd tertile	12,178.87 \$	11,909.84 \$	13,092.55 \$	14,550.16 \$	15,972.63 \$

Fig. 2 J-shaped relationship between TFR and GDP pc in OECD countries. *Source:* Developed by the authors using estimates from Table 2

are different depending on the level of fertility. In this regard, for the lower fertility level (Q10) the observed negative effect is lower in comparison with the results obtained for the highest one (Q90) in all the estimates. Therefore, at the *lower bound* the growth of GDP pc reduces fertility, and the segment of the J-shape with a negative slope decreases faster as we move from Q10 to Q90.

Differences between the quantile coefficients—interquantile regression—and their significance have been contrasted and reported in Tables 9 in “Appendix 4”. The differences between Q90–Q10 and Q75–Q25 are statistically significant. Thus, there are evidences of a differentiated intensity of the effect of GDP pc on fertility in countries with a high fertility rate (Q75 and Q90) in comparison with countries with a lower rate (Q10 and Q25). We have also test whether the J-shape function for each quantile (J-shape_{Q_n}), which is the marginal effect calculated in each quantile estimate ($\frac{dTFR_{it}}{dLog_GDPpc_{it}} = \beta_1 + \beta_2 Log_GDPpc_{it}$ by Q_n, being $n = 10, 25, 75, 90$),¹⁶ is statistically different using the *Wilcoxon Signed-rank test* (W test). The results provided in Table 10 in “Appendix 4” confirm that the J-shape is different by levels of fertility.

Therefore, both tests prove the usefulness of CQR estimates in these subsamples, confirming Hypothesis 2 that different J-shapes along the conditional distribution of the fertility rate exist when a country attains a high level of development.

¹⁶ The Log_GDPpc_{it} adopts different values in OECD and third tertile subsamples.

Fig. 3 J-shaped relationship between TFR and GDP pc in non-OECD countries. *Source:* Developed by the authors using estimates from Table 3

Fig. 4 J-shaped relationship between TFR and GDP pc in third tertile. *Source:* Developed by the authors using estimates from Table 4

Table 5 shows the income thresholds at which the relationship between TFR and GDP pc reverses from negative to positive (when $\frac{dTFR_{it}}{d\text{Log_GDPpc}_{it}} = 0$). Figures 2, 3 and 4 summarize all of the results graphically.

As it can be seen in Table 5 and Figs. 2, 3 and 4, the threshold increases as fertility rate increases (as one moves from Q10 to Q90). In the countries with the lowest fertility rate (Q10), the threshold occurs at a lower income level (US\$ 12,178.87 (PPP) for the third tertile of GDP pc, US\$ 5711.42 (PPP) for non-OECD and US\$ 19,683.23 (PPP) for OECD countries). In contrast, countries with the highest fertility rate (Q90) reach their threshold at a higher income (US\$ 15,972.63

(PPP) for the third tertile of GDP pc, US\$ 6248.31 (PPP) for non-OECD and US\$ 24,361.52 (PPP) for OECD countries).¹⁷

Analysing the marginal effects in Tables 2, 3 and 4 at the *upper bound*, we can highlight the positive and significant coefficient for all the estimates, thus confirming the TFR—GDP pc relationship becomes positive after the GDP pc threshold. Again in this case, these positive effects are different depending on the level of fertility. The *marginal effects* at the *upper bound* show that the segment of the J-shape with a positive slope grows faster in countries with a high fertility rate (Q90) than in countries with a low rate (Q10) (see Tables 2, 3, 4).¹⁸

These results suggest an important finding. The positive and negative slopes of the J-shape and the GDP pc threshold at which fertility decline reverses differ depending on the fertility level. Using the CQR approach instead of other methodologies such as threshold regression analysis (Furuoka 2009, 2013) or other linear approaches (Harttgen and Vollmer 2014; Luci-Greulich and Thévenon 2013, 2014; Myrskylä et al. 2009), to examine the J-shaped pattern gives us additional information from the data used, while taking into consideration the distributional properties of the dependent variable.¹⁹ The methodology applied in our study thus allows us to confirm that the relationship between fertility rate and GDP pc is different for the different fertility quantiles. In countries where the number of children born per woman is very high (Q90), the J-shape's threshold and the negative and positive slopes are higher than in countries with low fertility (Q10). This means that, faced with the same increase in GDP pc, the fertility rate in Q90 changes more than in Q10. The same marginal increase in GDP pc will cause a greater change in Q90's fertility rate than the same change would cause in Q10's fertility rate. This different fertility behaviour—among countries situated in

¹⁷ We repeated the same analysis with the whole sample to prove that the CQR results are not driven by the subsamples selected. This robustness check, available upon request, shows that the main qualitative findings still hold, although the threshold points are lower (US\$ 4794.36 for the Q10 and US\$ 5092.14 for the Q90). In this regard, we consider our tertile division CQR analysis adequate in order to calculate the threshold points, since the differentiated J-shape pattern by tertile of income is significant, something that is not considered when applying an analysis for the whole sample.

¹⁸ Since GDP per capita is only available from 1990 for some countries, we have also repeated the same analysis with a larger sample of 167 countries and a shorter time period (1990–2010) to confirm our results. This robustness check, available upon request, shows that, although the main qualitative findings still hold, the results for the third tertile of income show a positive and significant relationship between fertility and GDP pc. When reducing the time period in the new sample and including the most recent years and the most highly developed countries, we find the final positive segment of the J-shape curve. This result highlights the importance of considering the time period in fertility studies, as it conditions the results. Further research is needed to analyse this issue in greater depth.

¹⁹ The difference between our outcomes, obtained using the CQR approach, and those obtained by Furuoka (2009, 2013) using the threshold regression methodology (Hansen 2000), is that the later does not find any J-shape relationship, while we do. Our approach can perform a different analysis for the different levels of fertility, something not possible with Furuoka's methodology. The threshold regression method determines a threshold value or breaking point in the fertility–development (defined by the HDI) relationship. Considering the different levels of fertility in the sample jointly, the threshold value is calculated by dividing the independent variable into two groups (this value is calculated by minimizing the concentrated sum of squared errors of the estimated single threshold equation), avoiding the need to differentiate the presence of several J-shaped patterns between the countries with high fertility levels from those of the lower ones.

different fertility quantiles but at the same GDP pc level—indicates that something other than GDP pc is explaining fertility behaviour. The J-shape relationship between development and fertility must be conditioned by other factors driving these different fertility rates. Following Luci-Greulich and Thévenon (2013, 2014), Myrskylä et al. (2011) and Esping-Andersen and Billari (2015), female employment, family and social policies, and gender equality could explain why fertility patterns are situated on different fertility levels and why the positive and negative slopes of the J-shape are higher for the Q90 countries. It will be important for future lines of research to investigate whether the stronger reduction and re-increase of fertility in Q90, as compared with Q10, involves an institutional context more favourable to female employment, investments in family and reconciliation policies, a gender equality context or specific cultural norms in each country.

Finally, the results also suggest that dividing the sample by income tertiles—a broader and more homogeneous classification of observations by income level than the OECD/non-OECD division used in prior literature—improves knowledge of the J-shape (Brakman et al. 2009). These results thus demonstrate that the GDP pc threshold at which the J-shape changes from negative to positive is much lower than in the sample of OECD countries.

5 Conclusions

This paper has analysed the relationship between development and fertility to investigate whether it follows an inverse J-shaped pattern, and, if so, whether it depends on both development and fertility levels. The study results confirm the existence of a J-shaped relationship between these two variables. The division of the sample by income introduced in this paper is highly relevant and provide accurate information for having a better knowledge about the J-shaped pattern. When dividing the sample in tertiles of income—a more homogeneous classification of the observations—results show the J-shape pattern occurs only in the highest development level (third tertile of income).

However, thanks to the innovative quantile regression approach, this study has found an important additional result: the J-shape depends also on the fertility level. The GDP pc threshold at which the relationship between fertility and development changes from negative to positive differs among fertility quantiles. It increases as the fertility rate increases. The higher the fertility rate, the higher the GDP pc needed to reverse fertility decline. Also, the negative and positive segments of the J-shape fall and rise faster in countries with high fertility rate than in countries with low fertility. In countries where the number of children born per woman is very high, the J-shape's threshold and the negative and positive slopes are higher than in the countries with low fertility. A change in the GDP pc will thus cause a greater change in the former's fertility rate than the same change would cause in the latter's. In other words, factors other than GDP pc drive fertility behaviour.

Further research on the factors explaining the reversal in the development–fertility relationship is needed to better understand the factors driving fertility behaviour at the different fertility levels reached by these different societies. To test

this hypothesis would require designing a different empirical analysis focus on countries and not on development levels as this one.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

Appendix 1

See Table 6.

Table 6 List of countries grouped by OECD ^(a) and income tertile

List of 151 countries (1970–2010)					
Country	Tertile 1	Tertile 2	Tertile 3	Country	Tertile 1 Tertile 2 Tertile 3
Afghanistan	1970–2010			Egypt	1970–1984 1985–2010
Albania		1970–2010		El Salvador	1970–2010
Algeria		1970–2010		Eq. Guinea	1970–1996 1997–2000 2001–2010
Angola	1982–1984, 1986, 1987, 1990, 1991, 1993–1995	1970–1981, 1985, 1988, 1989, 1992, 1996–2010		Ethiopia	1970–2010
Antigua and Barb.		1970–1982	1983–2010	Fiji	1970–2010
Argentina		1970, 1982, 1985, 1986, 1988–1991	1971–1981, 1983, 1984, 1987, 1992–2010	Finland ^a	1970–2010
Australia ^a			1970–2010	France ^a	1970–2010
Austria ^a			1970–2010	Gabon	1970–2010
Bahamas			1970–2010	Gambia, The	1970–2010
Bahrain			1970–2010	Germany ^a	1970–2010
Bangladesh	1970–2010			Ghana	1970–2009 2010
Barbados			1970–2010	Greece ^a	1970–2010
Belgium ^a			1970–2010	Grenada	1970–1986
Belize		1970–1999	2000–2010	Guatemala	1970–2010
Benin	1970–2010			Guinea	1970–2010

Table 6 continued

List of 151 countries (1970–2010)							
Country	Tertile 1	Tertile 2	Tertile 3	Country	Tertile 1	Tertile 2	Tertile 3
Bhutan	1970–1996	1997–2010		Guinea-Bissau	1970–2010		
Bolivia		1970–2010		Guyana		1970–2010	
Botswana	1970, 1971	1972–1998	1999–2010	Haiti	1970–2010		
Brazil		1970–2006	2007–2010	Honduras		1970–2010	
Brunei			1970–2010	Hong Kong		1970, 1971	1972–2010
Bulgaria		1970–2002	2003–2010	Hungary ^a			1970–2010
Burkina Faso	1970–2010			Iceland ^a			1970–2010
Burundi	1970–2010			India	1970–2000	2001–2010	
Cambodia	1970–2010			Indonesia	1970–1988	1989–2010	
Cameroon	1970–1977, 1988–2010	1978–1987		Iran		1980–2002	1970–1979, 2003–2010
Canada ^a			1970–2010	Iraq	1991, 1992, 1995	1970–1990, 1993, 1994, 1996–2010	
Cape Verde	1970–1996	1997–2010		Ireland ^a			1970–2010
Central African Rep.	1970–2010			Israel			1970–2010
Chad				Italy ^a			1970–2010
Chile	1970–2010	1970–1994	1995–2010	Jamaica		1979–1988	1970–1978, 1989–2010
China	1970–1992	1993–2009	2010	Japan ^a			1970–2010
Colombia		1970–2010		Jordan		1970–2010	

Table 6 continued

List of 151 countries (1970–2010)							
Country	Tertile 1	Tertile 2	Tertile 3	Country	Tertile 1	Tertile 2	Tertile 3
Comoros	1970–2010			Kenya	1970–2010		
Congo, Demo. R.	1970–2010			Kiribati		1974, 1975	1970–1973, 1976–2010
Congo, Rep. of	1970–1980	1981–2010		Korea, Rep. of ^a		1970–1985	1986–2010
Costa Rica		1970–1976, 1981–2006	1977–1980, 2007–2010	Laos	1970–2006	2007–2010	
Ivory Coast	1970–2010			Lebanon		1976–1984, 1988–1992	1985–1987, 1993–2010
Cuba		1970–1981, 1992–2002	1982–1991, 2003–2010	Lesotho	1970–2010		
Cyprus		1970–1977		Liberia	1970–2010		
Denmark ^a				Luxembourg ^a			1970–2010
Djibouti	1991, 1998, 2001–2003	1970–1990, 1992–1997, 1999, 2000, 2004–2010	1970–2010	Macao		1970–1972	1973–2010
Dominican Rep.		1970–2004	2005–2010	Madagascar	1970–2010		
Ecuador		1970–2010		Malawi	1970–2010		
Malaysia		1970–1993	1994–2010	Sudan	1970–2006	2007–2010	
Maldives	1970–1989	1990–2010		Suriname		1970, 1971, 1974, 1993–1995, 1999–2002	1975–1992, 1996–1998, 2003–2010
Mali	1970–2010			Swaziland	1970–1973	1974–2010	
Malta		1970–1977	1978–2010	Sweden ^a			1970–2010

Table 6 continued

List of 151 countries (1970–2010)							
Country	Tertile 1	Tertile 2	Tertile 3	Country	Tertile 1	Tertile 2	Tertile 3
Mauritania	1970–2005, 2008–2010	2006, 2007		Switzerland ^a			1970–2010
Mauritius	1971	1970, 1972–2001	2002–2010	Syria	1970, 1971, 1973	1972, 1974–2010	
Mexico ^a				Tanzania	1970–2010		
Micronesia, Fed.		1970–1972	1973–2010	Thailand	1970–1975	1976–2009	2010
Mongolia	1970–1974, 1993, 1994	1975–1992, 1995–2010		Togo	1970–2010		
Morocco	1970–1976, 1978, 1981, 1983	1977, 1979, 1980, 1982, 1984–2010		Tonga		1970–2002, 2007, 2009, 2010	2003–2006, 2008
Mozambique	1970–2010			Trinidad and Tob.			1970–2010
Namibia		1970–2010		Tunisia		1970–2010	
Nepal	1970–2010			Turkey ^a		1970–1996, 2001	1997–2000, 2002–2010
Netherlands ^a				Uganda	1970–2010		
New Zealand ^a				UK ^a			1970–2010
Nicaragua	1992–1998	1970–1991, 1999–2010		USA ^a			1970–2010
Niger	1970–2010			Uruguay		1970–1993, 2002	1994–2001, 2003–2010
Nigeria	1970–2010			Vanuatu		1970–2010	
Norway				Venezuela		2003	1970–2002, 2004–2010

Table 6 continued

List of 151 countries (1970–2010)					
Country	Tertile 1	Tertile 2	Tertile 3	Country	Tertile 1 Tertile 2 Tertile 3
Oman		1970–1974	1975–2010	Vietnam	1970–2004 2005–2010
Pakistan	1970–2004	2005–2010		Zambia	1970–2010
Panama		1970–2004	2005–2010	Zimbabwe	1970–2010
Papua New G.	1980–1991	1970–1979, 1992–2010			
Paraguay		1970–2010			
Peru		1970–2010			
Philippines	1970–1972	1973–2010			
Poland ^a		1970–1975, 1982, 1983, 1990–1992	1976–1981, 1984–1989, 1993–2010		
Portugal ^a			1970–2010		
Puerto Rico			1970–2010		
Romania		1970–2003	1970–2010		
Rwanda	1970–2010		2004–2010		
Samoa		1970–2010			
Sao Tome and Pr.	1970–1977, 1980–2010	1978, 1979			
Senegal	1970–2010				
Sierra Leone	1970–2010				
Singapore		1970	1971–2010		
Solomon Islands	1970–1994, 1996–2009	1995, 2010			

Table 6 continued

List of 151 countries (1970–2010)							
Country	Tertile 1	Tertile 2	Tertile 3	Country	Tertile 1	Tertile 2	Tertile 3
Somalia	1970–2010						
South Africa		1970–2010					
Spain ^a			1970–2010				
Sri Lanka	1970–1991	1992–2010					
St. Lucia		1970–1987	1988–2010				
St. Vincent and G.	1975	1970–1974, 1976–2010					

^a OECD countries

Appendix 2

See Tables 7 and 8.

Table 7 Fertility rate descriptive statistics by group analysed. *Source:* Developed by the authors with data from WDI Database and PWT

Group	Year	Average	SD	Max.	Min.
151 countries	1970	5.35	1.82	8.2	1.8
	1990	4.17	1.90	7.8	1.3
	2010	3.09	1.53	7.6	1.0
Non-OECD	1970	5.94	1.39	8.2	2.0
	1990	4.69	1.70	7.8	1.3
	2010	3.40	1.53	7.6	1.0
OECD	1970	2.77	1.13	6.7	1.8
	1990	1.86	0.47	3.4	1.3
	2010	1.73	0.32	2.3	1.2
First income tertile	1970	6.66	0.71	8.2	4.3
	1990	6.05	1.15	7.8	2.5
	2010	5.08	1.17	7.6	2.3
Second income tertile	1970	5.31	1.60	7.9	2.0
	1990	3.98	1.17	6.1	1.8
	2010	3.13	0.89	6.2	1.7
Third income tertile	1970	3.20	1.35	6.5	1.8
	1990	2.29	1.09	7.2	1.3
	2010	1.93	0.65	5.1	1.0

Table 8 GDP pc (in \$ PPP 2005 at constant prices) descriptive statistics by group analysed. *Source:* Developed by the authors with data from WDI Database and PWT

Group	Year	Average	SD	Max.	Min.
151 countries	1970	5785.34	7379.59	51,630.49	350.28
	1990	8424.32	10,147.86	46,913.29	346.84
	2010	12,291.36	14,319.52	75,589.76	240.46
Non-OECD	1970	3784.50	6033.98	51,630.49	350.28
	1990	4997.74	6735.63	46,913.29	346.84
	2010	7664.56	10,041.48	55,838.63	240.46
OECD	1970	14,732.91	6009.03	29,439.14	2829.28
	1990	23,476.80	8868.42	44,733.98	6648.07
	2010	32,616.21	12,555.07	75,589.76	10,439.91
First income tertile	1970	1018.44	385.60	1760.28	350.28
	1990	1036.17	438.44	1938.66	346.84
	2010	1044.58	444.78	1939.38	240.46
Second income tertile	1970	4000.84	1585.24	7615.49	2012.21
	1990	4369.53	1610.19	7627.43	1996.59
	2010	4425.96	1669.19	7538.37	1976.04
Third income tertile	1970	16,539.35	8115.62	51,630.49	7768.61
	1990	21,084.60	9415.76	46,913.29	8124.90
	2010	24,070.25	14,395.12	75,589.76	7746.06

Appendix 3

See Figs. 5 and 6.

Fig. 5 Quantile regression for different models using the OECD sample (see Table 2). *Vertical axes* show coefficient estimates of Log_GDPpc_{it} and Log_GDPpc_{it}^2 variables; *horizontal axes* depict the quantiles of the dependent variable. Quantile regression *error bars* correspond to bootstrapped 95 % confidence (400 bootstrap replications)

Fig. 6 Quantile regression for different models using the third tertile of income sample (see Table 3). *Vertical axes* show coefficient estimates of Log_GDPpc_{it} and Log_GDPpc_{it}^2 variables; *horizontal axes* depict the quantiles of the dependent variable). Quantile regression *error bars* correspond to bootstrapped 95 % confidence (400 bootstrap replications)

Appendix 4

See Tables 9 and 10.

Table 9 Interquantile regression

Group	Quantile compared	Q90–Q10	Q.75–Q.25
OECD countries	Log_GDPpc _{it}	−3.812*** (1.324)	−3.488*** (1.002)
	Log_GDPpc _{it} ²	0.175** (0.066)	0.165*** (0.050)
Non-OECD countries	Log_GDPpc _{it}	−0.360* (0.201)	−0.217* (0.129)
	Log_GDPpc _{it} ²	0.018 (0.012)	0.009 (0.008)
Third tertile of GDPpc	Log_GDPpc _{it}	−4.100*** (1.611)	−3.475*** (1.087)
	Log_GDPpc _{it} ²	0.193** (0.193)	0.168*** (0.055)

400 bootstrap replications

* Significant at .1; ** significant at .05; *** significant at .01

Table 10 Wilcoxon Signed-rank test for contrasting the equality of distributions of J-shape curves by quantiles (1). *Source:* Developed by authors using estimates from Tables 2 and 4

Group	Q.90–Q.10	Q.75–Q.25
OECD (<i>p</i> value)	0.000	0.000
Non-OECD (<i>p</i> value)	0.000	0.000
Third tertile (<i>p</i> value)	0.000	0.000

(1) H^0 : J-shape($Q.n$) − J-shape($Q.m$) = 0

The *Wilcoxon Signed-rank test* (W test) is a nonparametric test (which does not assume any probability distributions of the variables compared) useful for contrasting differences in the distribution of two variables (see Wilcoxon 1945). The null hypothesis is that both distributions are the same, which means that there are no differences in the behaviour of the variables compared, so there are no differences in the J-shape by fertility levels:

$$H^0 : \text{J-shape}(Q.n) = \text{J-shape}(Q.m) \quad (4)$$

Table 10 presents the results of W test rejecting the null, thus confirming that the J-shape is different by levels of fertility.

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