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Three Essays on Population and Historical Legacies: Fertility, Income Inequality and Natural Resources

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To Margherita,

My source of endless love, light, encouragement and inspiration

To my beloved daughters Helena and Francesca Charlotte,

You are the reason behind all of my happiness.

Abstract

This dissertation provides three essays on population dynamics from the perspective of historical legacies. The objective is to study how some current population dynamics can be influenced by past events, some of them from a very long-term perspective. The dominant theories and empirical work on population dynamics usually consider current or proximate determinants generally observed from the 20th century onwards. However, this dissertation proposes that there are certain deeper determinants, rooted in history, that could have a powerful long-term influence.

The first essay studies the global convergence of fertility. The fertility transition idea is traditionally linked to the global convergence of fertility towards a single equilibrium. In this essay I use a recently developed methodological approach that allows for multiple equilibrium analysis and club identification. It is used data on 190 countries and territories, over a period from 1960 to 2019. The findings in this essay do not support global fertility convergence. Instead, a number of 'convergence clubs' emerges from the data. These findings are discussed in the light of various demographic theories, proposing that fertility trends in contemporary societies cannot be understood without taking into account the interplay between continuities and discontinuities rooted of historical legacies.

The second essay studies the link between population, extractive institutions, and income inequality for a particular historical period, from which long-term legacies could have emerged. Inequality in Latin America has been large, widespread and persistent. For some scholars, its origin dates back to the colonial period, when Europeans established extractive institutions that have lasted until the present. However, the analysis provided in this essay suggests that income inequality was already very high in the days of the Aztec Empire, so its roots lie in pre-Hispanic institutions. In 2021, it was five hundred years since Tenochtitlan fell by the Spanish troops in alliance with several peoples who rose up against the Aztec

Empire. However, little is known about the conditions of inequality and extraction prior to the arrival of Europeans. Indeed, such conditions might explain the imperial fall. It is analyzed income inequality in the 38 provinces of the Aztec Empire, showing how highly extractive conditions explain the ease with which the Spaniards promoted alliances with certain indigenous peoples to defeat the Aztecs. The same previous extractive conditions may have made it easier for Europeans to adapt the Aztec institutions for their own benefit during the early colonial period. It is concluded that colonialism in Latin America did not create economic inequality, it only exacerbated it.

The last essay explores the link between current population dynamics and the environment given by the presence of natural resources from a very long-term perspective. The influential literature on the "curse of natural resources" highlights that resource-rich countries, under certain circumstances, have poorer economic and political outcomes than other countries. The third essay proposes that the presence of non-renewable natural resources also has important implications and long-term effects for fertility and other social dynamics related to family change. In a country-level analysis, this work first documents how the presence of natural resources is highly associated with higher fertility rates across the world. Second, the long-term effects and persistence of this "social curse" are highlighted, by providing evidence at the subnational level that the presence of historic coal mines, dating back to the Industrial Revolution in Europe, can be influencing on current fertility behaviors and other outcomes that are determinants of social change.

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Introduction

In the last decades, demographic patterns have changed significantly across the world. These changes can be characterized as having a high degree of diversity and complexity. The literature has argued that this heterogeneity has been the result, among other aspects, of the adaptation of individuals to differentiated changes in economic, ideational factors, demographic, technological, cultural, gender roles conditions, uncertainty, with a variation in social, institutional, legal contexts (Thornton 2001; Sweeney 2002; Bianchi 2014; Furstenberg 2014; Cherlin 2016; Pesando et al 2019).

New empirical studies have focused on analyzing the diversity of transformations in families patterns, in order to explain demographic transformations. Some of these studies use to identify the key-drivers of such transformations, and assess whether or not these changes follow a global convergent pattern (e.g. Wilson 2001 and 2011; Dorius 2008; Rindfuss et al 2016). To a lesser extent, theoretical models have emerged to explain demographic change. There are theories developed from the 1960's to 1980's which suggest, for different reasons, that family patterns tend to converge towards a single family system (e.g. Goode 1963; Becker 1981; Lesthaeghe and van de Kaa 1986). On the other hand, the most recent ideas suggest the existence of a high degree of diversity and complexity in family change (e.g. Thornton 2001; Therborn 2004; Johnson-Hanks et al 2011; Esping-Andersen and Billari 2015).

However, in part of this literature, scholars have usually focused on studying determinants that are referring to recent times. In other words, the literature has focused on analyzing the effects generated by changes or events observed from the 20th century, mostly in those closest determinants, experienced only after the Second World War. In contrast, fewer studies have addressed the analysis of demographic change and family transformations, and their impacts on current trends from the perspective of deeper factors, which are rooted in history, and whose effects impact in the very long-term (e.g. Reher 1998; Thornton 2001, 2005; Greif 2006; Lesthaeghe and Lopez-Gay 2013; Alesina, Giuliano and Nunn 2013; Esteve and Lesthaeghe 2016; Aassve, Billari and Pessin 2016; Greif and Tabellini 2017; de Pleijt, van Zanden and Carmichael 2019).

In this dissertation, I study population dynamics from the perspective of long-term historical legacies. Historical events are discontinuities that can leave persistent effects on the behavior of families that, ultimately, impact on population dynamics. This approach is essential to understanding several domains in human societies that go beyond demographic change, reproduction, health or well-being per se. For instance, in the study of demographic change in the long term, family change represents a fundamental determinant. As an institution, the family represents a foundation of societies that, in parallel with other entities, for instance the state or the market, systematically shape human and social behavior. In this way, family change creates new incentives and expectations, which ultimately impact the broad development of societies (Esping Andersen 1990; Alesina and Giuliano 2013; Greif and Tabellini 2017). From this long-term perspective, some new contributions, although still rare, have begun to show how family change and its impact on population dynamics is the engine of several economic and social transformations. In these works, family dynamics is useful to explain, together with other factors, the gaps in economic growth and development among societies observed during centuries (Greif 2006a; Voigtlander and Voth 2006 and 2013;Greif and Tabellini 2010; De Moor and Van Zanden 2010; Foreman-Peck 2011). In this sense, the study of population dynamics from a perspective based on deeper factors, rooted in long-term historical determinants, can provide important contributions to explain current continuities and discontinuities, as well to better understand the heterogeneity in and development patterns.

A significant body of literature in sociology and demography has pointed to a strong relationship between population dynamics and socioeconomic development based on contemporary indicators (e.g, levels of education and health, technological change, industrialization, the Human Development Index, etc.). However, the empirical literature, especially in the fields of economic history and political economy, has recently moved from the study of immediate determinants to the analysis of deep-rooted long-term factors to explain the differences in development among contemporary societies (Spolaore and Wacziarg 2013). Several contributions are now shedding light on the long-term interactions among historical legacies, institutions and contemporary development (e.g. Acemoglu, Daron, Johnson and Robinson 2001, 2002, 2005a, 2005b; Engerman and Sokoloff 2002, 2005b, 2008, 2012; Nunn and Wantchekon 2011). One would therefore hypothesize that the long-term historical determinants that condition development in contemporary societies also influence population dynamics today. Furthermore, certain historical events, which were determined exogenously and have had long-term effects, would have the advantage of representing important instruments to better address the potential issue of endogeneity between population dynamics and cultural, institutional and development factors. The exploitation of these instrumental variables would facilitate placing at the center of the analysis the approach that considers current population dynamics as a relevant determinant.

The dissertation aims to study population dynamics from a perspective based on long-term historical determinants (historical legacies). I propose that these historical legacies have a significant impact on current population dynamics and lead to significant heterogeneity among countries and societies in family change. The ultimate goal of my research is to contribute to a better understanding of the effects of the continuities and discontinuities that unfold as a result of certain historical events across several family generations and its impact on population dynamics on the very long-term. By explicitly considering the persistence of historical events or geo-cultural factors, my research also aims to better understand, from a historical perspective, the implications of population dynamics in dimensions that go beyond demographic domains. To sum up, history matters to better understand the processes of demographic change that, ultimately, shape the differences that distinguish today's societies from one another in several domains.

This dissertation is divided in three Chapters which were prepared in a format to be submitted to its publication process in scientific journals. The first chapter studies the global convergence of fertility. The fertility transition idea is traditionally linked to the global convergence of fertility towards a single level of equilibrium. In this Chapter, I use a recently developed methodological approach that allows for multiple equilibria analysis and club identification. It is used data on 190 countries and territories, over a period from 1960 to 2019. The findings in this chapter do not support global fertility convergence. Instead, a number of 'convergence clubs' emerges from the data. These findings are discussed in the light of various demographic theories, proposing that fertility trends in contemporary societies cannot be understood without taking into account the interplay between continuities and discontinuities rooted of historical legacies.

Chapter 2 studies the link between institutions, population, and income inequality from a historical perspective. Inequality in Latin America has been large, widespread and persistent. For some scholars, its origin dates back to the colonial period, when Europeans established extractive institutions that have lasted until the present. However, the analysis in Chapter 2 suggests that income inequality was already very high in the days of the Aztec Empire, so its roots lie in pre-Hispanic institutions. In 2021, it was five hundred years since Tenochtitlan fell by the Spanish troops in alliance with several peoples who rose up against the Aztec Empire. However, little is known about the conditions of inequality and extraction prior to the arrival of Europeans. Indeed, such conditions might explain the imperial fall. It is analyzed income inequality in the 38 provinces of the Aztec Empire, showing how highly extractive conditions explain the ease with which the Spaniards promoted alliances with certain indigenous peoples to defeat the Aztecs. However, the same previous extractive conditions may have made it easier for Europeans to adapt the Aztec institutions for their own benefit during the early colonial period. Chapter 2 concludes that colonialism in Latin America did not create economic inequality, it only exacerbated it.

The third chapter explores the link between current population dynamics and the environment given by the presence of natural resources from a very long-term perspective. The influential literature on the "curse of natural resources" highlights that resource-rich countries, under certain circumstances, have poorer economic and political outcomes than other countries. Chapter 3 proposes that the presence of non-renewable natural resources also has important implications and long-term effects for fertility and other social dynamics related to family change. In a country-level analysis, this work first documents how the presence of natural resources is highly associated with higher fertility rates across the world. Second, the long-term effects and persistence of this "social curse" are highlighted, by providing evidence at the subnational level that the presence of historic coal mines, dating back to the Industrial Revolution in Europe, can be influencing on current fertility behaviors and other outcomes that are determinants of social change.

Chapter 1

Club Fertility Convergence

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ABSTRACT

The fertility transition idea is traditionally linked to the global convergence of fertility towards a single level of equilibrium. In this paper we study empirically fertility convergence, using a recently developed methodological approach that allows for multiple equilibria analysis and club identification. We use data on 190 countries and territories, over a period from 1960 to 2019. Our findings do not support global fertility convergence. Instead, a number of 'convergence clubs' emerges from the data. We discuss these findings in the light of various demographic theories, proposing that fertility trends in contemporary societies cannot be understood without taking into account the interplay between continuities and discontinuities rooted of historical legacies.

Keywords: Path Dependence, Global Fertility Convergence.

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1.1. Introduction

Different theoretical perspectives about population change imply global fertility convergence, i.e. that, in the long run, all countries and societies will eventually convergence towards a single fertility regime, or broadly speaking, some 'equilibrium' fertility rate. This idea is equally supported Demographic Transition theory, and by New Home Economics scholars (Davis 1945; Blacker 1947; Goode 1963; Becker 1960, 1965, 1973; Mincer 1962). The Second Demographic Transition, especially in its latter formulation, also somehow implies global fertility convergence, as fertility behavior is deemed to follow the global spread of ideas or postmodern values (Lesthaeghe and van de Kaa 1986; van de Kaa 1987; Lesthaeghe and Surkyn 1988; Lesthaeghe 2010, 2014, 2020). Building in particular on Wilson´s work (2001), an emerging literature has also used a variety of analytical methods to empirically test global fertility convergence. (e.g. Dorius 2008; Rindfuss et. al. 2016; Pesando et al. 2019; Castiglioni et al. 2020).

A different approach to fertility convergence points to the potential existence of two or more 'fertility regimes', groups, or clubs, or 'multiple equilibria'. Thus, the idea of global fertility convergence has not gone unchallenged, as other authors have been more skeptical and have suggested the presence of two or more fertility regimens (Hajnal 1965; Therborn 2004, 2014; Esping-Andersen and Billari 2015). In this case, traditional methodological approaches to testing convergence empirically, originally emerged in the field of economic growth, are less useful, since they need an ex ante classification of the countries in the definition of the clubs, with the convergence hypothesis tested within each group (Baumol 1986; Barro et al. 1991; Barro and Sala-i-Martin 1992; Sala-i- Martin 1996). That is, under certain criteria, scholars have usually first proceeded to form clubs of countries, to then test whether those countries converge in their fertility rates within the same club. Clearly, this is a limitation, as the ex-ante classification of countries inevitably conditions the results of the convergence test (Du 2018). The use of traditional methodologies can also have problems of heterogeneity and omitted variables, affecting the estimation of the coefficients, leading them to be biased and inconsistent (Phillips and Sul 2009). Other limitations already have been discussed by the literature (e.g. Dorius 2008; Friedman 1992; Quah 1993). Researchers have obtained heterogeneous results in terms of trends, 'convergence clubs', or pace and/or degree of fertility convergence (e.g. Dorius 2008; Rindfuss et. al. 2016; Pesando et al. 2019; Castiglioni et al. 2020).

Why is fertility convergence salient? In addition to its link with specific theories, it provides a clear framework within which fertility change can be projected, or forecasted, into the future. For these reasons, most population projections are based on the idea of fertility converging to a specific level in the future. Global fertility convergence, for instance, is embedded in the fertility projection model used by the United Nations (United Nations 2019), also in its more recent probabilistic version, where a Bayesian model helps to embed the demographic transition framework within fertility projections (Alkema et al 2011; Raftery et al 2012; Raftery, Alkema and Gerland 2014). Fertility projections have important implications for business, public policies, economic development, infrastructure, and services that will be required for future generations. In this sense, basing these projections on an idea of global fertility convergence can lead to different conclusions than if we made fertility projections based on an idea of global non-convergence, where instead the formation of clubs in countries with differentiated convergence in fertility rates is allowed.

This paper addresses a number of important questions on fertility convergence. Are societies converging globally towards a single level of fertility? Or are there groups of countries that follow different paths leading to different levels (the 'convergence club' hypothesis)? If there are clubs, how many are they, and how have they been formed? Where is long-term fertility heading in the world as various countries complete the fertility transition? Focusing on countries in which the fertility transition has been completed, can we expect convergence or persistent diversity? While some authors have already raised some of these questions in previous work (in particular, see Wilson 2001; Billari 2018), this paper addresses them in order to make two main contributions to the literature.

The first contribution of this paper is the application of a recently developed, data-driven methodological approach, which is capable of identifying both the existence of a single convergence equilibrium as well as multiple-equilibria fertility convergence (Phillips and Sul 2007). This methodology also allows for the influence of nonlinear time-varying factors, and for a wide range of possible temporal trajectories and individual heterogeneity. For this reason, this approach is useful in identifying possible changes in trends and patterns that lead to the identification of fertility convergence clubs of countries. In other words, countries and territories are not classified or conditioned ex-ante into specific clubs, but rather the observed dynamics of fertility in each country will determine the self-selection process and their membership in a specific club.

Secondly, this first chapter offers a theoretical discussion on the factors that can determine the existence of processes of convergence or divergence of fertility, focusing on the relevance of increasing or decreasing returns in the adoption of family behaviors related to fertility to through demographic history. Increasing returns occur when early family innovations that influence fertility have advantages in adoption processes, inducing more people to adhere to this emerging family behavior as time goes on. Therefore, divergent dynamics arise when increasing returns occur, which are determined by the interaction between continuities and discontinuities. Otherwise, convergence towards a single fertility equilibrium could only occur when there are diminishing returns, that is, as time passes, fewer people would adopt a family innovation. We open the discussion on the need to develop more theory on what would be the conditions that would influence the presence of certain returns associated with fertility (increasing or decreasing). The discussion highlights the role of path dependence processes and the interactions between discontinuities and continuities that influence family change over time and across different societies.

1.2. Global Fertility Convergence: Theory and Evidence

Broadly speaking, the dominant theories of fertility (and family) change have come in three different waves. We can characterize the first wave, from the 1960s onwards, as "modernization" theories, where global convergence is the consequence of the global diffusion of economic change, or ideational change, through societies. Goode (1963) hypothesized the convergence of family patterns as industrialization spread through societies. Kinship ties would weaken, leading families to adopt a conjugal system in which the nuclear family would become a more independent and widespread kinship unit. Goode's proposal is consistent with the neoclassical theory of economic growth, which claimed that the economies of all countries would converge in the long run (Solow 1956, 1958; Cass 1965). If economic growth follows a convergence path around the world, one can expect that family and fertility behaviors could also converge. In New Home Economics, the complementarity between partners in household production is a central assumption (Becker 1960, 1965, 1973; Mincer 1962). As technological change spreads through societies and weakens the aforementioned complementarity, home-based decision-making by the families are altered, which ultimately leads to a decline in fertility rates. In the Second Demographic Transition thesis, the erosion of traditional forms of family life that stem from changes in values towards greater individualism and self-realization, eventually ends up triggering the decline of fertility in a similar way across societies (van de Kaa 1987; Lesthaeghe and Surkyn 1988; Lesthaeghe 2010, 2014, 2020). The idea of fertility convergence that is implicit in this first wave of theories is consistent with the changes experienced between the 1960s and the 1990s

(Bongaarts y Watkins 1996; Bongaarts 2006; Ezeh, Bongaarts and Mberu 2012). Several countries experienced significant declines in fertility rates during those years, seeming to drive societies towards a single level. Even the United Nations used to estimate population's projections based on the idea of convergence towards a single fertility regime, whose medium scenario was initially 2.1 (Castiglioni et. al. 2020).

The second wave of theories on emerged from the 1990s, generally challenging the idea of global convergence, and focusing on the end-point of the fertility transition. During this period, changes in fertility patterns emerged, in particular with lowest-low fertility in Europe and subsequently in East Asia (Kohler, Billari and Ortega 2002; Billari and Kohler 2004). The emergence of lowest-low fertility has also been linked to the "postponement transition", which is fueled by various social interaction processes including social learning and social influence. The new empirical situation emerging during the 1990s led the United Nations to adjust the medium scenario for total fertility rates by lowering the global fertility convergence point to 1.85 (United Nations 2007). Subsequently, some countries experienced reversals in fertility trends, with evidence of a positive link between economic development and fertility in post-transitional, advanced societies (Myrskylä, Kohler and Billari 2009). The heterogeneity of post-transitional fertility patterns led some scholars to wonder whether advanced societies are heading toward fertility divergence (Billari 2018), thus generating conflicting positions vis-à-vis previous theoretical perspectives. Fertility theories that are centered on gender equity or equality have also emerged during this period, and have tended to describe multiple equilibria setting. McDonald (2000a, 2000b) highlights the interactions between levels of gender equity in individual-oriented social institutions and sustained gender inequity in family-oriented social institutions. This interaction can provide different outputs in reducing or increasing fertility, and therefore different convergence patterns. Esping-Andersen and Billari (2015) propose the existence of multiple equilibria in family behaviors, whose transitions are characterized by periods of uncertainty and normative confusion about gender roles and identities in family life. The dynamics of endogenous reinforcement in favor of gender-egalitarian norms lead to the emergence of a new and dominant family equilibrium. A critical mass is essential to promote the diffusion of normative expectations in favor of new family arrangements, which may impact on social institutions. These transitions determine the fertility patterns and, therefore, the non-convergence between societies.

Parallel to the second one, a third wave of theories has emphasized continuities in family behaviors. First, the theory of conjunctural action sees family change as explained by the interplay of virtual structures, given by materials and schemes, which determine fertility behaviors (Johnson-Hanks et al 2011). Since fertility itself is so deeply embedded in culture, explanations of fertility transition must also be cultural (Johnson-Hanks 2015). Second, "developmental idealism" proposes a cultural model in which a set of beliefs and values identify the goals of development and the ends for achieving these goals (Thornton, Dorius and Swindle 2015). These beliefs and values spread from its origins among the elites of northwest Europe to elites and ordinary people throughout the world during the last two centuries (Thornton 2001, 2005).

Although this theory proposes that the modern family is attainable, which is both a cause as and an effect of a modern society, developmental idealism refers to the existence of a variety of "packages" and "multiple modernities" (Thornton, Dorius and Swindle 2015). Finally, Therborn (2004, 2014) describes the existence of seven major family systems, based on power relations among spouses observed across generations as well as regulations and practices of sexuality. Therborn’s approach focuses on culture and religion in order to discern those large geo-cultural family areas of the world, in which contingent historical events given by critical junctures or discontinuities at macro level transformed social parameters relevant to family change. In these theories, the fertility convergence hypothesis would be remote as long as the effects of the continuities given in by cultural legacies persist.

A number of studies have directly addressed the issue of (global) fertility convergence, without developing an explicit consensus. The heterogeneity in findings arises as a consequence of the diversity of methodologies used, the periods analyzed, or the group of countries considered. While Wilson (2001) showed that demographic convergence towards low fertility has been an overwhelming trend in both rich and poor countries during the last five decades of the 20th century, Dorius (2008) argued that the evidence points to a divergence. Some recent empirical studies have found processes of divergence in global fertility patterns, but have highlighted the formation of fertility clubs in which certain countries converge with each other. For developed countries, Lanzieri (2010) finds convergence in fertility patterns among the countries of the European Union. In contrast, Rindfuss et al (2016) find a remarkable bifurcation in fertility levels after 2000, in which the group by Northern and Western Europe, Oceania and the United States shown fertility rates about 1.9, while the other group by Central, Southern, and Eastern Europe, and East and Southeast Asia was around 1.3. For developing countries, Salvini et al. (2015) find two clusters with a strong delay in the demographic transition, mostly in Sub-Saharan countries. The countries of Latin America and Asia that were previously part of the Soviet Union form a relatively homogeneous group, while a club formed by China and Iran have reached the last stage of the fertility transition, with total fertility rates below replacement level. Hendi (2017) finds globalization as a triggering factor for fertility convergence among countries that share trade and a connection through organizations. Castiglioni et. al. (2020) finds that differences among groups of homogeneous countries actually increase from 2000–2015.

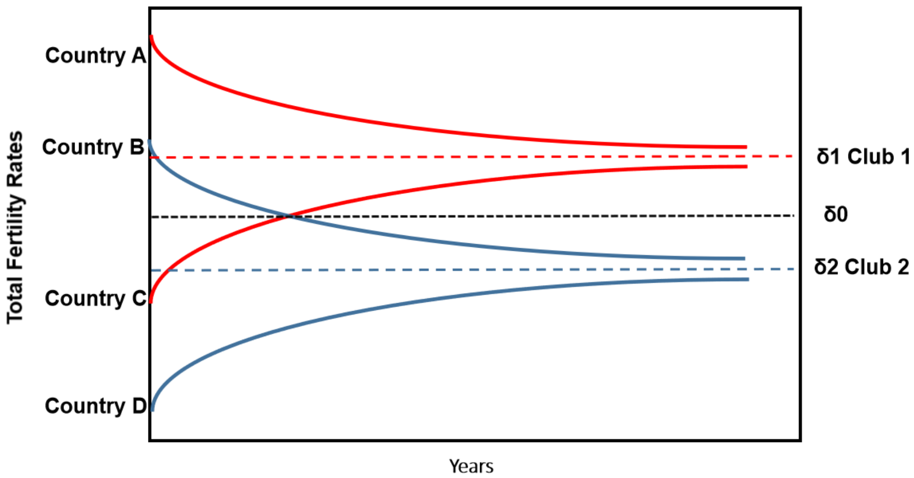
1.3. Club convergence: definition and empirical approach

Several studies have documented the fertility transition, i.e. the decline in fertility rates observed in most countries of the World since the 1960s (Bongaarts y Watkins 1996; Bongaarts 2006; Ezeh, Bongaarts and Mberu 2012). However, convergence goes beyond the general process of fertility decline. Several studies used conventional methodologies originally developed in the field of economic growth to be applied to demographic variables (Baumol 1986; Barro et. al. 1991; Barro y Sala-i-Martin 1992; Friedman 1992; Sala-i-Martin 1996). Dorius (2008) goes further by highlighting that convergence occurs in a specific demographic process across societies only if the variance around the mean decreases proportionally faster than the decrease in the mean. For this reason Dorius uses some standard measures of inequality in assessing convergence, such as the Gini coefficient, mean logarithmic deviation, and Theil's index.

In what follows, we build on to the methodological proposal developed by Phillips and Sul (2007). This approach is based on the idea developed by other models that consider the existence of both common global-level and country-specific patterns. Global-level patterns here represent the global fertility transition, as observed in almost all countries. A common factor, say μ_t, describes the evolution over time *t* of the fertility dynamics at the global level. Country-specific fertility patterns are captured by δ_i, i.e. the "idiosyncratic" component relative to country *i*. This component represents the distance between the common factor μ_t and the systemic part of the total fertility rates y_{it}. More generally, in the methodology proposed by Phillips and Sul (2007), one can also allow the country-specific idiosyncratic component to evolve over time, by considering it as a time-varying δ_{it}. In this approach, the convergence dynamics allows for heterogeneous country patterns, with total fertility rates analyzed as the interaction of common and individual components, which can change over time. This interaction can be linked to cultural, economic or technological influences as well as disruptions that spread across countries and that affect fertility rates. The global convergence of fertility occurs when the systematic idiosyncratic elements δ_i and the time-varying idiosyncratic elements δ_{it} of all countries tend to become constant and equal in the long term. In other words, both elements should converge towards a common value δ, for all countries analyzed. Therefore, global convergence occurs when, in the long term, for all countries, at least approximately $\delta_{it} = \delta_i = \delta$.

Global fertility convergence may not empirically happen. In this case, it is possible that fertility convergence occur only *within* a group of countries, or a 'club'. Within the *k* club of countries, the systematic idiosyncratic elements δ_i ,and the dynamic the time-varying idiosyncratic elements δ_{it} tend towards a fixed common value δ_k. Following Phillips and Sul (2007), we allow the data to show the presence of convergence clubs in our analyses of fertility convergence. Countries grouped in the same club might not have similar fertility dynamics during the past. What matters here is that the dynamics of the idiosyncratic elements tend towards the same common value. This concept of fertility club convergence is shown in Figure 1.

Figure 1: Convergence dynamics in the formation of two clubs



In Figure 1, countries A and B have initial levels closer to each other in their total fertility rates. Both countries have also shown a downward trend in their fertility levels, very similar to each other in previous years. However, these countries do not converge towards a fixed common value. The same occurs with countries C and D, which show similar upward dynamics in previous years. It would be countries A and C that will form a first Club (Club 1), since their transitions in the systematic idiosyncratic elements $\boldsymbol{\delta}_i$ and the time-varying idiosyncratic elements $\boldsymbol{\delta}_{it}$ lead both countries to converge towards a fixed common value $\boldsymbol{\delta}_1$. The same will happen with countries B and D, which converge towards a fixed common value $\boldsymbol{\delta}_2$, lower than $\boldsymbol{\delta}_1$. Finally, the value $\boldsymbol{\delta}_0$ will not be a point of fertility convergence for any country, although at first it would have seemed that all countries could converge towards that point.

It is possible that some countries that have shown upward dynamics in their fertility rates in recent years, as is the case of developed countries, converge with other countries that have had high fertility rates, but whose dynamics have been downward. This is the case in several low- and middle-income countries. It could also be possible that in several developed countries they have higher fertility levels than other countries that have traditionally had their high fertility rates, but which have had a considerable decline during the last decades, such as developing countries. Wilson (2011) already pointed out that we could not exclude the possibility of observing an inverted differential, with higher fertility in the rich world than in the poor. Later, this idea found additional evidence with Myrskylä et al. (2009). This possibility has important implications for theory. Some scholars have considered that convergence processes must imply normative equilibria, in which values, beliefs and attitudes on family change should also be in common between the countries that form the same club (e.g. Esping-Andersen and Billari 2015). In this paper we do not condition ex ante on cultural or geographical closeness. However, according to our empirical model, the convergence would be occurring when the idiosyncratic elements variable in time δ lead the countries to converge towards a fixed common value $\delta 1$.

1.4. Data and Methods

The main variable in our analysis is the Total Fertility Rate (TFR). We use the annual time series provided by World Bank, as part of the World Development Indicators[3]. It is worth noting that World Bank TFR estimates build on different sources such as: (1) United Nations Population Division. World Population Prospects; (2) Census reports and other statistical publications from national statistical offices; (3) Eurostat Demographic Statistics; (4) United Nations Statistical Division Population and Vital Statistics Report; (5) U.S. Census Bureau International Database, and (6) Secretariat of the Pacific Community Statistics and Demography Programme. We can therefore analyze 190 countries and territories, for a period that spans from 1960 to 2019.

The 190 countries and territories analyzed are divided into two sets of countries. On the one hand, they are taken by countries that in 1960 had a clear demographic transition, either advanced or late expanding, where low mortality rates were reflected, as well as significant and forceful falls in fertility rates. On the other hand, there is a group of countries which, in 1960, were not yet entering the demographic transition or were at a very early expanding stage, characterized by high mortality rates and slight decreases in their fertility rates.

[3] Last updated date was February 17, 2021.

In the first set, 71 countries were identified, while in the second set, 119 countries were identified.

This division of countries does not imply the *ex-ante* formation of clubs. These will be formed from the dynamics observed in the period from 1960 to 2019 based in the proposed methodology. The idea of having into two large groups of countries lies in considering the initial conditions in which the countries were in terms of their demographic transition at the beginning of the period. analyzed (1960). From a historical legacies perspective, initial conditions have important value in explaining demographic dynamics for later periods.

The indicators on Birth Rate Crude (per 1,000 people) and Death Rate Crude (per 1,000 people), both provided by the World Bank, are also used. These indicators provide, respectively, the number of live births occurring during the year, per 1,000 population estimated at midyear and the number of deaths occurring during the year, per 1,000 population estimated at midyear. By subtracting the crude death rate from the crude birth rate provides the rate of natural increase, which is equal to the rate of population change in the absence of migration. A detailed analysis of each country was carried out to identify its position in 1960 regarding the demographic transition. First, it is considered that countries that had an advanced or vigorous demographic transition in 1960 observed a crude mortality rate of less than 13.5. Likewise, it was considered that the countries observe significant falls in their total fertility rates, or in their birth rate crude in subsequent years to 1960. Likewise, the population change rate is considered in the absence of migration, which should be decreasing in the years after 1960. The criteria used to divide the countries into two sets according to the stage of the demographic transition in which they were in 1960 are set out in the Appendix 1 as well as the details addressed in the division of the countries into two sets.

We apply the econometric approach developed by Phillips and Sul (2007) to analyze convergence and divergence of fertility rates among countries[4]. This approach allows to: i) test, formally, the global fertility convergence hypothesis (null hypothesis), considering the 190 countries and territories; and ii) if a global fertility convergence towards a single regime is not found (null hypothesis is not hold), to identify convergence clubs among countries that share behaviors in their time-varying idiosyncratic elements. In this methodology, the relative size of the population of a country does not matter. The advantage here is that it focuses on the relative transition behaviors.

Empirical analysis are based on a panel data model which is decomposed in order to represent both the systemic components, represented by g_{it}, and the transitory components, expressed by a_{it}. The former embodies systematic components of fertility, including permanent common components that result in cross section dependence, while the latter represents those factors that do not have a lasting influence on the long-run evolutionary path of each country's fertility. We formalize this idea as follows:

$$y_{it} = g_{it} + a_{it} \qquad (1)$$

[4] This paper uses the algorithm for STATA developed by Du (2017).

From this expression (1) the common components, which represents a common aggregated pattern on fertility behavior among all countries, are separated from idiosyncratic components (defined in the previous section). Therefore, expression (1) becomes in the following representation (2):

$$y_{it} = \left(\frac{g_{it}+a_{it}}{\mu_t}\right)\mu_t = \delta_{it}\mu_t \qquad (2)$$

μ_t represents the common components and δ_{it} expresses the time-varying idiosyncratic components, which measures the deviation or distance of each observation of total fertility rates from the common components μ_t as a consequence of the transitory elements. Since the common factor μ_t is the same across the panel of countries, it is removed from y_{it}, in order to obtain the relative transition path of each country i through time t, expressed by h_{it}, which is shown by the following equation (3):

$$h_{it} = \frac{y_{it}}{N^{-1}\sum_{i=1}^{N} y_{it}} = \frac{\delta_{it}}{N^{-1}\sum_{i=1}^{N} \delta_{it}} \qquad (3)$$

This relative path traces the total fertility rate of a particular country i in relation to the average of the countries analyzed, by measuring the time-varying idiosyncratic component relative to the panel average at time t. Thus, the attention is focused on the time-varying idiosyncratic component which allows considering a wide range of possible temporal trajectories and individual heterogeneity. The fertility dynamics of each country are captured, either divergent or convergent with respect to the fertility trajectory followed by the group of countries in the long term. Equation (3) would somehow indicate that the cross-sectional mean of h_{it} is 1.

H_t is the cross-sectional variance of the relative transition path h_{it} in equation (3), and it is represented as:

$$H_t = \frac{1}{N} \sum_{i=1}^{N} (h_{it} - 1)^2 \qquad (4)$$

Global fertility convergence implies two conditions:

$$\lim_{t \sim \infty} \frac{y_{it}}{y_{jt}} = 1, \quad fo\ all\ i\ and\ j \qquad (5)$$

$$\lim_{t \sim \infty} \delta_{it} = \delta, \quad fo\ all\ i \qquad (6)$$

The identity in (5) implies that the Total Fertility Rates between countries *i* and *j* would be the same, in the long term. The identity in (6) is defined as the relative convergence and it implies that the time-varying idiosyncratic component for country *i* will convergence to an stable value in the long term (it would be stationary).

The convergence test focuses on the decision rule given by the following hypotheses:

Ho : $\delta_i = \delta$ and $\alpha \geq 0$ (global fertility convergence)

Ha : $\delta_i \neq \delta$ or $\alpha < 0$ (no global fertility convergence)

The hypothesis test of convergence focuses on two elements: i) δ_i, the systemic idiosyncratic element, and ii) α, the decay rate associated to a pattern of convergence. The first element δ_i is close related with the "time varying idiosyncratic element" δ_{it}, based on the semiparametric form as expressed in (7). In this expression, ξ_{it} represents a stochastic element which is independent and identically distributed with mean and variance (0,1); *L(t)* represents a slowly time-varying function, which is increasing and divergent at infinity and $\alpha \geq 0$ is the rate of decay [$L(t) \rightarrow \infty$ and $\delta_{it} \rightarrow \delta_i$ as $t \rightarrow \infty$].

$$\delta_{it} = \delta_i + \sigma_{it}\,\xi_{it}\,; \qquad \text{where } \sigma_{it} = \frac{\sigma_i}{L(t)t^{\alpha}}; \quad t \geq 1; \quad \sigma_i > 0 \quad \text{for all i} \tag{7}$$

The second relevant element in the hypothesis test is the decay rate, expressed in by α, which is a relevant component in the decision rule, as well as to estimate the speed of convergence. If the null hypothesis, Ho, is hold, on the one hand it implies that $\delta_i = \delta$ (the time varying idiosyncratic element for a country i will be the same that the systemic idiosyncratic element). On the other hand, and considering (7), if $\alpha \geq 0$, as is stated by the null hypothesis, δ_{it} converges to δ_i as $t \rightarrow \infty$, derived from $\sigma_{it} \rightarrow 0$. Therefore, this implies that it would be observed a global convergence in the fertility rates of all countries y_{it} as when observing that $\delta_{it} = \delta_i = \delta$ in the long-term.

The log t regression model is used to perform the analysis through which the estimators are obtained to implement the hypothesis test. This regression model is represented by the following expression (8):

$$Log\left(\frac{H_1}{H_t}\right) - 2logL(t) = \hat{a} + \hat{b}logt + \hat{u}_t \qquad (8)$$

L(t) is the slowly time-varying function defined as L(t) = log(t)[5]. H_t is the cross-sectional variance of the relative transition path defined in equation (4), and H_1/H_t is the cross sectional variance ratio. For the global fertility convergence to be hold, the cross-sectional variance of the relative transition path h_{it} would satisfy the following condition:

$$H_t = \frac{1}{N}\sum_{i=1}^{N}(h_{it}-1)^2 \rightarrow 0 \text{ if } \quad lim_{t\rightarrow\infty}\delta_{it} = \delta, \text{for all country i} \qquad (9)$$

The above condition simply states that as the time-varying idiosyncratic element δ_{it} approaches a constant value at which other countries converge, the cross-sectional variance H_t of the relative transition parameter, h_{it}, converges towards zero.

The null hypothesis Ho is tested based on a inequality α ≥ 0, which implies a one-sided t test[6]. The decision rule to support or reject the null hypothesis Ho at the 5% level centers on the value −1.65. If the outcome reports a coefficient

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5 In which t is modeled as the following dynamics:

For t = $[rT], [rT]+1, \ldots, T$ with r > 0

In which r is the selection of the initiating sample fraction. According to Phillips and Sul (2007) and Du (2017), based on Monte Carlo experiments, r ranges from 0.2 to 0.3 in which the former would apply for T ≤ 50 sample. In our case, we will use an r = 0.2 following Phillips and Sul (2007) and Du (2017).

6 The estimator for b, obtained in the regression model in (8), is b = 2α. In the hypothesis test, the one-sided t test is based on the next t statistic and its variance would be:

$$t_b = \frac{\hat{b}-b}{S_b}; \qquad \text{with N ~ (0, 1)} \qquad (A.1)$$

$$S_b^2 = l\widehat{var}(\hat{\varepsilon}_t)\left[\sum_{t=[rT]}^{T}\left(\log(t) - \frac{1}{T-[rT]+1}\sum_{t=[rT]}^{T}\log(t)\right)^2\right]^{-1} \qquad (A.2)$$

Where $l\widehat{var}(\hat{\varepsilon}_t)$ is a conventional Heteroskedasticity and Autocorrelation Consistent (HAC).

whose t value is less than −1.65, the null hypothesis Ho cannot be sustained, therefore the possibility of having a global convergence dynamic of fertility is rejected. Otherwise, if the t-value of the coefficient estimated by the regression model (8) is greater than −1.65, the null hypothesis would hold, so we would conclude that there is a global convergence dynamic of fertility. From the regression model expressed in (8), we obtain an estimator for the coefficient b. The sign of this estimator represents whether fertility rates among the countries examined are convergent, if this sign is positive. Otherwise, if the sign is negative, the fertility rates of these countries would be diverging. The magnitude of the estimator for b provides the speed of convergence or divergence, since the estimator of the decay rate would be $\alpha = b/2$, which represents the rate of fertility convergence or divergence among countries.

The convergence of total fertility rates among certain countries, known as convergence clubs, is carried out through a procedure that is repeated sequentially. First, a "cross-section sorting" is carried out, by ordering the countries in the panel in descending order according to their observations in the last period, in our case it would be the total fertility rate observed in 2019. Subsequently, the first two countries with the highest total fertility rates in 2019 would be selected (that is, starting with K = 2 where k would be the number of countries considered in the first club). The hypothesis test based on the regression model given by (8) would be applied to this first group. As long as the null hypothesis Ho continues to hold, that is, if there is a convergence of fertility between the first two countries considered, the next countries in the descending ordered series would be added, until said null hypothesis cannot be hold. At that time, the first fertility convergence club would be obtained, and the same procedure would be developed again to identify new clubs. It means, we will find the first k (or number of countries) such that the test statistic of the log t regression $t_k > -1.65$ for the club with countries {k, k + 1, … k + j}. This exercise would be repeated over and over to find the following fertility convergence clubs. A particular case would be when in this iterative process no k is found that satisfies $t_k > -1.65$. In this case, the algorithm developed by Phillips and Sul (2007) would conclude that there are no convergence clubs in the panel.

1.5. Results

The 190 countries and territories analyzed are not converging towards a single fertility pattern during the period analyzed from 1960 to 2019. The result of the Log t regression test is presented in the following Table 1.

Table 1: Results of the Log t regression test, global fertility convergence 1960-2019

Stage of Demographic Transition	*Variable*	*Coefficient*	*SE*	*T-statistic*
Advanced or late expanding	*log(t)*	*-0.8725*	*0.0338*	*-25.8422*
Not advanced or early expansion	*log(t)*	*-2.1330*	*0.0274*	*-77.8050*

Note: The T-statistics are so far from the non-rejection threshold. Therefore, it is not possible to hold the null hypothesis Ho ($\delta_{it} = \delta_i = \delta$), so we end up holding the alternative hypothesis Ha ($\delta_{it} \neq \delta_i \neq \delta$).

Some studies have subdivided the periods in order to analyze whether the convergence patterns have changed as a result of certain observed events. For instance, Castiglioni et. al. (2020) analyze two different periods, 1985-2000 and 2000-2015, observing different patterns in the convergence dynamics, arguing that various events, such as the fall of the Iron Curtain, affected fertility patterns. For this reason, using the same methodology developed by Phillips and Sul (2007), it is analyzed whether any fertility convergence pattern occurred in previous periods (from 1960 to 1990, 2000, and 2010, and 2019 is also included). The results are presented in the following Table 2, also divided between the set of countries with late-expanding or advanced demographic transitions and countries with early-expanding or not-advanced demographic transitions in 1960.

Table 2: Results of the Log t regression test for global fertility convergence, different periods from 1960

Countries with late-expanding or advanced demographic transitions in 1960				
Variable	***Period***	***Coefficient***	***SE***	***T-statistic***
log(t)	*1960-1990*	*-1.1460*	*0.0039*	*-293.9535*
log(t)	*1960-2000*	*-1.3012*	*0.0711*	*-18.2911*
log(t)	*1960-2010*	*-1.2182*	*0.0219*	*-55.6630*
log(t)	*1960-2018*	*-0.8725*	*0.0338*	*-25.8422*
Countries with early-expanding or not-advanced demographic transitions in 1960				
Variable	***Period***	***Coefficient***	***SE***	***T-statistic***
log(t)	*1960-1990*	*-2.2246*	*0.0084*	*-264.5694*
log(t)	*1960-2000*	*-2.3062*	*0.0354*	*-65.1369*
log(t)	*1960-2010*	*-2.3187*	*0.0052*	*-448.6806*
log(t)	*1960-2018*	*-2.1330*	*0.0274*	*-77.8050*

Note: The T-statistic is so far from the non-rejection threshold in all cases (-1.645). Therefore, it is not possible to hold the null hypothesis Ho ($\delta_{it} = \delta_i = \delta$), so the alternative hypothesis Ha ($\delta_{it} \neq \delta_i \neq \delta$) is hold.

In no period is global fertility convergence found. Table 2 shows significant variations in T-Statistic, although in the four periods analyzed there is no evidence of having global fertility convergence processes. The estimators that mark the degree of convergence or divergence are different for countries with late-expanding or advanced demographic transitions versus those countries with early-expanding or not-advanced demographic transitions in 1960. However, it is significant that for both cases of countries, the period from 1960 to 2000 was a period in which disparities appear to be decreasing, since the T-statistic value decreased from -293.9535 to -18.2911, for the first set of countries, and from -264.5694 to -65.1369 for the second set of countries. However, this possible narrowing of the disparity ended in 2010 in both sets of countries, possibly as a consequence of the Great Recession and other disruptions during that period.

Since no evidence was found to support the existence of a global fertility convergence, the same methodology is used to identify the convergence clubs between countries that have trajectories towards the same fertility level. The following Table 3 presents the results of the 12 convergence clubs that were identified, while Table 4 lists the countries that make up the same membership for each of the 12 clubs. The order of the clubs are organized according to fertility levels, from highest to lowest. Likewise, two non-convergence clubs are added (A and B). The first is formed by South Korea, Puerto Rico and Singapore, which are countries that had an advanced or late expanding demographic transition in 1960. The second non-convergence country is Niger, which since 1960 has been in an early expansion of the demographic transition.

Table 3: Fertility Convergence Clubs, 1960-2019

		Countries with late-expanding or advanced demographic transitions in 1960			
Club	***Coefficient***	***t-Stat***	***α = b/2***	***No. of countries***	***Dynamics***
1	*-0.040*	*-0.856*	*-0,02*	*51*	*Convergence*
2	*-0.106*	*-1.370*	*-0,053*	*13*	*Convergence*
3	*-1.284*	*-0.888*	*-0,642*	*2*	*Convergence*
4	*-1.958*	*-1.297*	*-0,979*	*2*	*Convergence*
A	*-2.267*	*-33.169*	*-1,1335*	*3*	*No Convergence*
		Countries with early-expanding or not-advanced demographic transitions in 1960			
Club	***Coefficient***	***t-Stat***	***α = b/2***	***No. of countries***	***Dynamics***
1	*0.367*	*6.707*	*0,1835*	*4*	*Convergence*
2	*-0.028*	*-0.306*	*-0,014*	*8*	*Convergence*
3	*-0.084*	*-1.556*	*-0,042*	*33*	*Convergence*
4	*-0.162*	*-1.646*	*-0,081*	*25*	*Convergence*
5	*-0.103*	*-0.944*	*-0,0515*	*7*	*Convergence*
6	*-0.149*	*-0.984*	*-0,0745*	*28*	*Convergence*
7	*-0.035*	*-0.150*	*-0,0175*	*11*	*Convergence*
8	*-0.807*	*-0.754*	*-0,4035*	*2*	*Convergence*
B	-	-	-	*1*	*Single country (Niger)*

Note: The T statistic must be greater than -1.645 in order to have a fertility convergence club.

In Table 3, the speed of convergence between the countries within the same club is shown by the parameter α, which is obtained by dividing the coefficient obtained by the log t regression model by 2 (α = b/2).

Table 4: Countries by Fertility Convergence Clubs, 1960-2019

Countries with late-expanding or advanced demographic transitions in 1960		
Club 1	51 countries	| Albania | Argentina | Armenia | Aruba | Australia | Austria | | Azerbaijan | Bahamas, The | Barbados | Belarus | Belgium | | Brazil | Bulgaria | Canada | Channel Islands | Chile | Colombia | | Costa Rica | Croatia | Czech Republic | Denmark | Estonia | | Finland | France | French Polynesia | Georgia | Germany | | Iceland | Ireland | Korea, Dem. People's Rep. | Latvia | | Lebanon | Lithuania | Luxembourg | Malaysia | Mexico | | Montenegro | Netherlands | New Zealand | Norway | Paraguay | | Philippines | Romania | Russian Federation | Slovenia | Sweden | | Switzerland | United Kingdom | United States | Uruguay | | Venezuela, RB |
Club 2	13 countries	| Cyprus | Greece | Hungary | Italy | Japan | Malta | | North Macedonia | Poland | Portugal | Slovak Republic | Spain | | Thailand | Ukraine |
Club 3	2 countries	| Bosnia and Herzegovina | Moldova |
Club 4	2 countries	| Hong Kong SAR, China | Macao SAR, China |
A (No converging)	3 countries	| Korea, Rep. | Puerto Rico | Singapore |
Countries with early-expanding or not-advanced demographic transitions in 1960		
Club 1	4 countries	| Chad | Congo, Dem. Rep. | Mali | Somalia |
Club 2	8 countries	| Angola | Burkina Faso | Burundi | Central African Republic | | Gambia, The | Mozambique | Nigeria | Uganda |
Club 3	33 countries	| Afghanistan | Benin | Cameroon | Comoros | Congo, Rep. | | Cote d'Ivoire | Equatorial Guinea | Eritrea | Ethiopia | | Gabon | Guinea | Guinea-Bissau | Israel | Kiribati | Liberia | | Madagascar | Malawi | Mauritania | Rwanda | Samoa | | Sao Tome and Principe | Senegal | Sierra Leone | | Solomon Islands | South Sudan | Sudan | Tanzania | | Timor-Leste | Togo | Tonga | Vanuatu | Yemen, Rep. | Zambia |
Club 4	25 countries	| Antigua and Barbuda | Botswana | Egypt, Arab Rep. | Eswatini | | Fiji | Ghana | Guam | Guyana | Haiti | Iraq | Jordan | | Kazakhstan | Kenya | Kyrgyz Republic | Lesotho | | Micronesia, Fed. Sts. | Namibia | Oman | Pakistan | Panama | | Papua New Guinea | Syrian Arab Republic | Tajikistan | | Turkmenistan | Zimbabwe |
Club 5	7 countries	| Algeria | Bolivia | Djibouti | Guatemala | Mongolia | | Sri Lanka | Suriname |
Club 6	28 countries	| Bangladesh | Belize | Cabo Verde | Cambodia | Cuba | | Dominican Republic | Ecuador | El Salvador | Grenada | | Honduras | India | Indonesia | Jamaica | Kuwait | Lao PDR | | Libya | Morocco | Myanmar | Nepal | New Caledonia | Nicaragua | | Peru | Saudi Arabia | South Africa | Tunisia | Turkey | | Uzbekistan | Virgin Islands (U.S.) |
Club 7	11 countries	| Bahrain | Bhutan | Brunei Darussalam | China | | Iran, Islamic Rep. | Maldives | Mauritius | Qatar | | St. Vincent and the Grenadines | Trinidad and Tobago | Vietnam |
Club 8	2 countries	| St. Lucia | United Arab Emirates |
B (No converging)	1 country	| Niger |

The identified clubs show different dynamics in their total fertility rates. For countries with late-expanding or very advanced demographic transitions in 1960, there are basically two large clubs, the first with 51 countries and the second with 13. The first fertility club has countries that demographically had very different fertility rates from each other in 1960, but whose dynamics observed in recent decades shows significant convergence, averaging 1.69 in 2019, and approaching total fertility rates between 1.5 and 1.6 (Figure 2). The second fertility club is formed by countries The second club is made up of countries mostly in the Mediterranean region, or close to this geographical area, such as Ukraine and the Slovak Republic, and having only two Asian countries: Japan and Thailand. This club averaged a total fertility rate of 1.36 in 2019, and it appears that fertility rates in these countries will remain around this level (Figure 3).

Total Fertility Convergence Clubs 1 – 4
Countries with late-expanding or advanced demographic transitions in 1960

Figure 2: Club 1 (some selected countries)

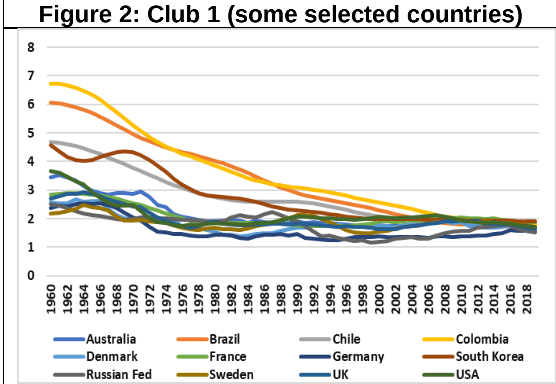


Figure 3: Club 2 (some selected countries)

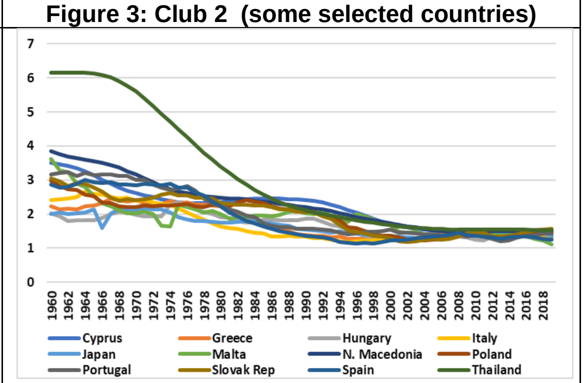


Figure 4: Club 3

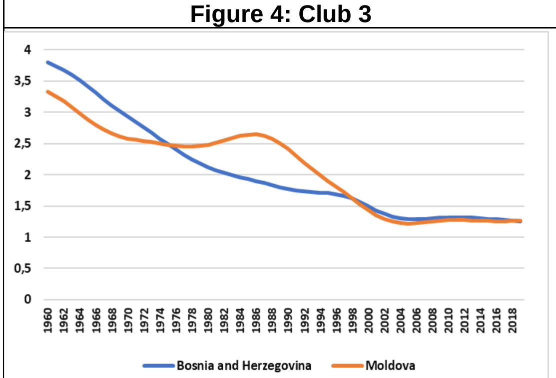
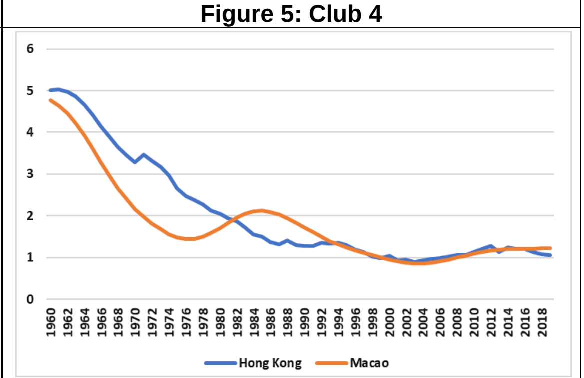
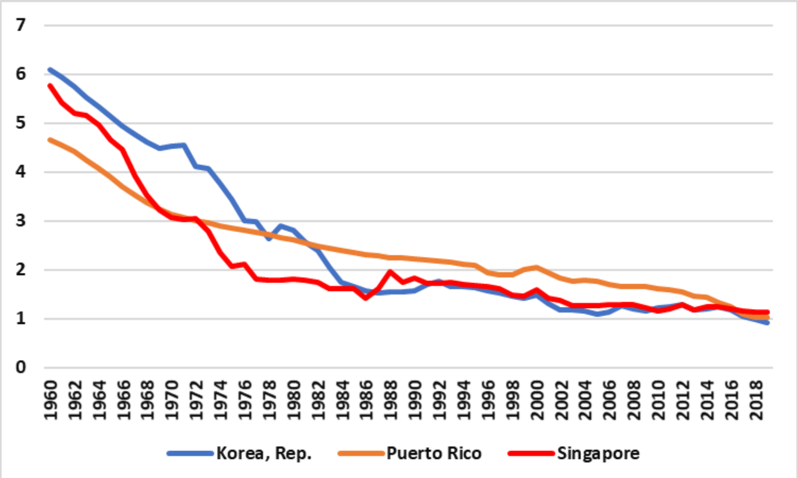


Figure 5: Club 4



The two remaining clubs in countries with late-expanding or advanced demographic transitions in 1960, clubs 3 and 4, are made up of only two countries each. Club 3, made up of Bosnia and Herzegovina and Moldova, averaged a total fertility rate of 1.26 in 2019 (Figure 4), while Club 4, made up of Hong Kong and Macau, averaged a total fertility rate of 1.13 (Figure 5). It should be noted that the countries of this club 4 observed total fertility rates below 1 between 1999 and 2008, but in the last 5 years these rates have increased to be around 1.1. Finally, there is a group of three countries that are not converging in the formation of any club, but their total fertility rates are very low and continue to decline. In 2019, these countries averaged a total fertility rate of 1.03. These three countries, South Korea, Puerto Rico and Singapore, are likely to form a fertility club with rates below 1 in the coming years (Figure 6).

Figure 6: Countries that are not converging towards any club
Countries with late-expanding or advanced demographic transitions in 1960



In the group of countries with early-expanding or not-advanced demographic transitions in 1960, we have 8 fertility convergence clubs. The first two clubs are characterized by having countries with high fertility rates. Club 1 is made up of four countries (Chad, Democratic Republic of Congo, Mali and Somalia) which have maintained total fertility rates above 6 during almost the entire period analyzed. Even between the years 1985 and 2004, this club of countries observed average fertility rates above 7. It is only after 2016 that Chad reduced its rates to a level below 6, followed by Mali in 2017, Democratic Republic of Congo in 2018 and Somalia in 2019 (Figure 7). Club 2 is made up of 8 countries (Angola, Burkina Faso, Burundi, Central African Republic, Gambia, Mozambique, Nigeria and Uganda). This club averaged a total fertility rate of 5.07 in 2019. All of its countries started showing rates just below 6 as of 2013, although some countries such as Mozambique, the Central African Republic or the Gambia, started doing so much earlier (Figure 8).

Fertility Convergence Clubs 1 and 2
Countries with early-expanding or not-advanced demographic transitions in 1960

Figure 7: Club 1

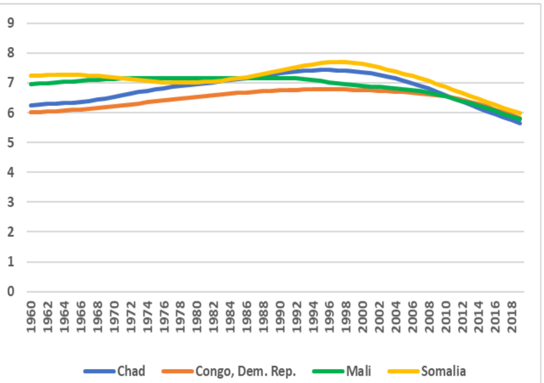
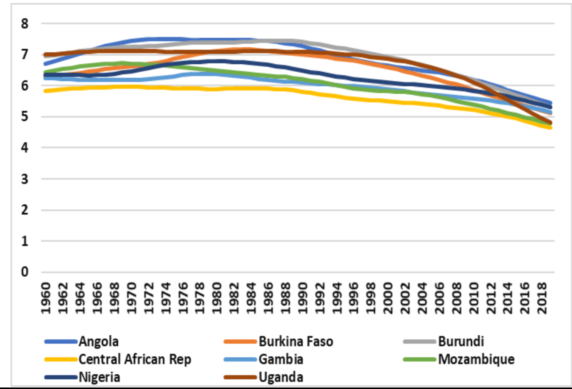


Figure 8: Club 2



The following clubs in the set of countries with early or late expansion demographic transitions in 1960, clubs 3, 4, 5 and 6, are found in 93 countries and are characterized by having total fertility rates around 2 to 4. Club 3 is made up of 33 countries, mostly from the African continent, and averaged a total fertility rate of 4.19 (Figure 9). Club 4 is formed by f 25 countries, from different continents (Africa, Latin America and the Caribbean and Asia) and averaged a total fertility rate of 3.01 (Figure 10). Club 5, made up of just 7 countries, averaged 2.66 in their total fertility rates, while Club 6, made up of 28 countries, averaged a total fertility rate of 2.20 in 2019 (Figures 11 and 12).

Total Fertility Convergence Clubs 3 – 6
Countries with early-expanding or not-advanced demographic transitions in 1960

Figure 9: Club 3 (some selected countries)

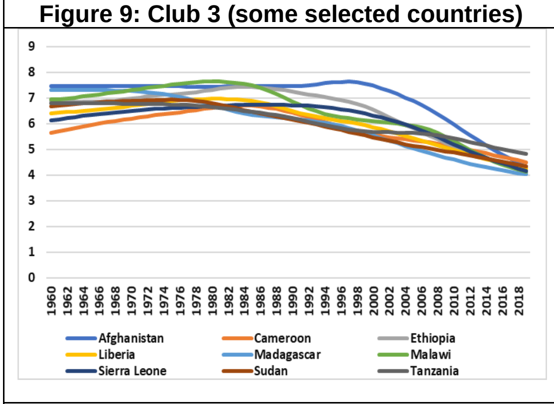


Figure 10: Club 4 (some selected countries)

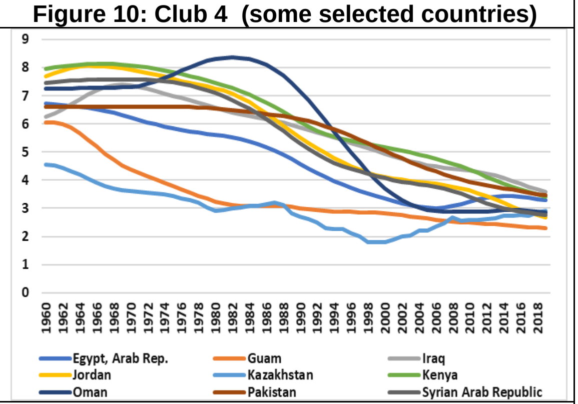


Figure 11: Club 5

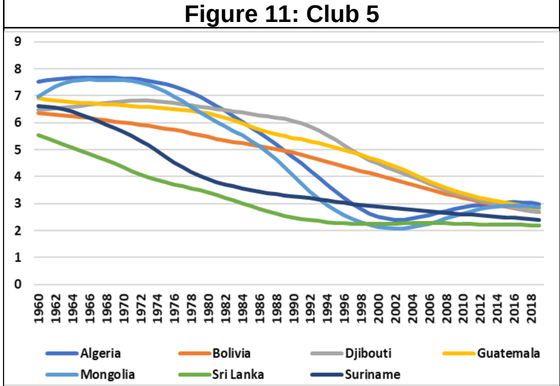
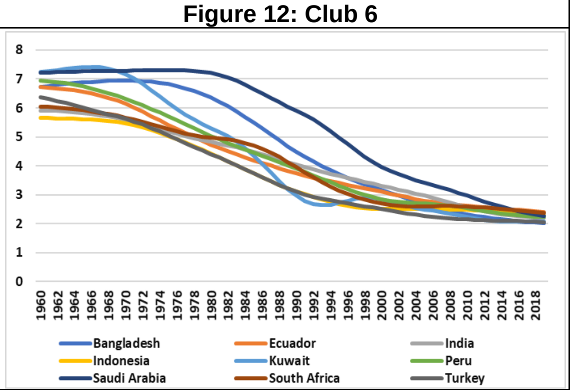


Figure 12: Club 6



In countries with early-expanding or not-advanced demographic transitions in 1960, there are two clubs with total fertility rates that are beginning to decline significantly. Club 7, made up of 11 countries, averaged a total fertility rate of 1.84, while club 8 has only 2 countries and averages 1.40 their total fertility rates. Furthermore, there is only one country, Niger, which did not show a convergent behavior in its total fertility rates with any other country.

Fertility Convergence Clubs 7 and 8
Countries with early-expanding or not-advanced demographic transitions in 1960

Figure 13: Club 7

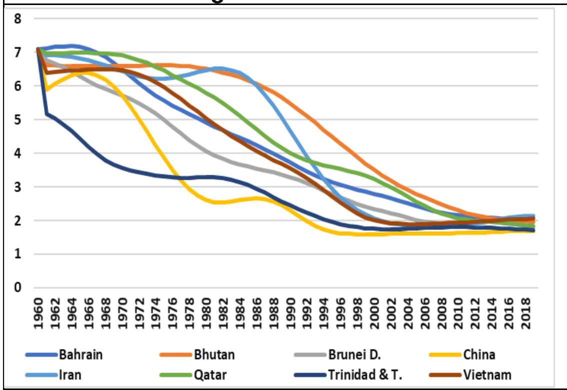
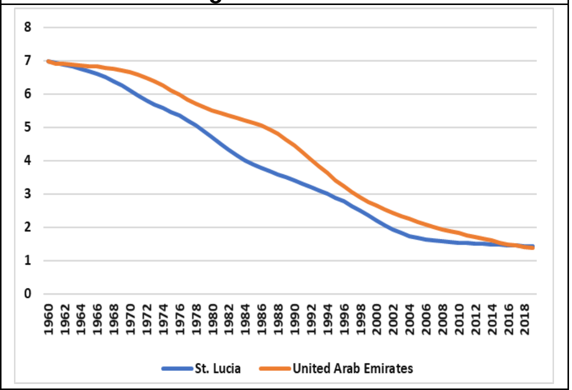


Figure 14: Club 8



Our results show the following findings. First, the convergence in fertility does not necessarily imply that the countries that are grouped in the same club share a similar demographic background. Some developed countries that experienced their demographic transition several decades ago and that have had upward reversals in their total fertility rates during the 1990s are now converging with certain emerging, which had significant declines in fertility in years previous. This is particularly observed in clubs 1 and 2 in the set of countries with late-expanding or advanced demographic transitions in 1960, where 51 and 13 countries are grouped respectively, whose demographic backgrounds were very different but during the last decades has been approaching among them in their fertility rates. Second, countries that have recently started their demographic transition tend towards different total fertility rates, and they tend to cluster into 8 different clubs. Countries with high current fertility rates will continue to maintain differentiated dynamics in the coming years. Third, as the long-term fertility transition comes to an end, post-transitional countries are heading for differentiated equilibria. Some of these countries show that total fertility rates increase towards different levels (such several countries with late-expanding or advanced demographic transitions in 1960), while others remain at lowest-low fertility levels.

1.6. Why convergence or divergence of fertility rates among countries

The patterns of convergence or divergence in fertility among countries could be associated with the presence of what is known as diminishing returns or increasing returns, respectively, that would occur in the processes of adopting family behaviors over time. Increasing returns arise when certain disruptions or discontinuities destabilize existing normative equilibria on fertility and trigger advantages from the adoption of a specific family innovation that is adopted during initial conditions. These discontinuities could be due to epidemics, wars, economic crises, technological changes or economic processes such as industrialization or globalization. Therefore, as a result of a discontinuity, various options could arise regarding family behaviors associated with fertility which could compete with each other, in addition to also having to compete with the incumbent family pattern. The earliest emerging family behavior that is adopted by a particular group of people may have advantages over other options of family behaviors. Thus, the increasing returns would occur when, by attracting a greater proportion of adopters at an early stage, the new emerging pattern will have advantages among potential adopters in the subsequent stages. In contrast, diminishing returns would occur when the increase in adopters of an specific family behavior is less as time passes. This can occur, for instance, when a family behavior has been dominant for several years, but with the passage of time, the increase in adopters is less and less as time passes.

The divergence in the total fertility rates would occur when there is the presence of increasing returns in the adoption of family behaviors. Otherwise, the presence of diminishing returns in the adoption of family behaviors associated with fertility would imply the convergence processes in total fertility rates. This relationship has been widely studied in dynamic economic models. For instance, it is the case of economic growth theories, neoclassical models consider diminishing returns between inputs and production, resulting in convergent processes towards a single equilibrium (Cass 1965; Solow 1956, 1958). In contrast, endogenous models that assume the presence of increasing returns given by innovation or human capital imply divergent results and the presence of multiple equilibria (Romer 1986; Lucas 1988; Rebelo 1991).

In recent decades, some theories on family change and fertility transition have highlighted the role played by the diffusion of innovations that impact family change, which consist of processes through which new ideas, behaviors and attitudes are disseminated within families. societies (Bongaarts 2017). This would be the case of the Second Demographic Transition thesis, in which the diffusion of ideas associated with changes in values towards greater individualism and self-realization plays a relevant role (van de Kaa 1987; Lesthaeghe and Surkyn 1988; Lesthaeghe 2010, 2014, 2020). Thornton's (2001, 2005) developmental idealism could also be considered, in which development beliefs and values that spread from the elites of northwestern Europe to ordinary people around the world have significantly influenced certain family behaviors. However, these diffusion processes can be characterized by having different speeds among countries, where some societies are early and faster adopters of emerging family behaviors than others. This issue has been theoretically addressed by Esping-Andersen and Billari (2015) in which the size of a critical mass, endogenous reinforcement processes and the creation of expectations that generate institutional changes are essential in the speed of reaching a new equilibrium. Thus, the study of increasing or diminishing returns in the adoption of family behaviors could complement these theories that highlight the role played by the processes of diffusion of innovations that impact on family change and on fertility dynamics. This would enrich our understanding of convergent and divergent dynamics, as well as the formation of fertility clubs between certain countries.

The concept of path dependence could also be useful in our understanding of the convergence and divergence processes in fertility. This concept has already been considered in the literature as an important determinant in fertility outcomes and family change (Kohler 2001; Casterline 2001; Johnson-Hanks et al 2011). In the presence of path dependence, past events (or historical discontinuities) could have persistent effects on fertility dynamics (thus generating continuities that affect fertility in the long term). Culture, for instance, could depend to a great extent on past history, which is why it has been considered a determinant of long-term fertility behavior (Hammel 1990; Pollak and Watkins 1993; Watkins 2001; Fernández and Fogli 2006, 2009; Hayford and Morgan 2008; Bachrach 2014; Johnson-Hanks 2015). Beliefs, values and meanings that influence fertility are generated and rooted in societies over long periods, since they can be transmitted from generation to generation (Bisin and Verdier 2001; Alesina, Giuliano and Nunn 2011). Family systems referred to by Therborn (2014) could also be conceived as continuities whose processes have non-ergodic properties, in the sense that it is very difficult to escape the influence of its history. In an extreme case, continuities can lead societies to lock-in states, in which the dynamics of fertility are "captured" and can only be escaped through the intervention of an exogenous force occurs which can alter the previous configuration. What is most relevant for our study is that historical continuities have significant effects on the dynamics of convergence or divergence in fertility. Path dependence implies dynamics with increasing returns in the adoption process over time (David 1985, 2001, 2007; Arthur 1989, 1990, 1994; Arrow 2000). Thus, as long as there are effects of path dependence, the dynamics in total fertility rates among countries could not converge towards a single equilibrium, but rather towards multiple equilibria.

1.7. Discussions and Conclusions

This paper addressed a number of questions about fertility convergence. Our results suggest that societies are not converging globally towards a single fertility level, but rather are following differentiated dynamics that lead to different levels of convergence (the "convergence club" hypothesis). This paper employs a novel approach, developed by Phillips and Sul (2007) to test the global fertility convergence hypothesis, which allows the influence of nonlinear time-varying factors, and considers a wide range of possible temporal trajectories and individual heterogeneity. This approach also provides a methodology for identifying fertility clubs, where the countries and territories are not classified or conditioned ex ante in specific clubs. Unlike other studies, the observed fertility dynamics in each country determines its membership in a specific club.

Theories about family change developed between 1960 and 1990 pointed to the possibility of finding a convergence in global fertility patterns (Goode 1963; Becker 1960, 1965, 1973; Lesthaeghe and van de Kaa 1986; van de Kaa 1987; Lesthaeghe 2010, 2014;). However, the global fertility convergence hypothesis is not supported by the findings of this paper. Instead, 12 clubs were identified in which countries are converging with each other in their total fertility rates, as well as a non-convergence club (formed by South Korea, Puerto Rico and Singapore, which is characterized by having non-convergent lowest-low fertility), and a single country that does not follow any pattern of convergence with any country, given its still high fertility rates (Niger). These results are consistent with some theories developed during the second and third wave of theories on family change, in which the presence of fertility convergence clubs occurs, instead of having a single equilibrium. (Therborn 2004, 2014; Johnson-Hanks et al 2011; Esping-Andersen and Billari 2015; Thornton, Dorius and Swindle 2015).

Our findings show, first, that fertility convergence does not necessarily imply that countries grouped in the same club share long-term demographic backgrounds. We found some clubs in which several countries converged in their total fertility rates, although some of their members had a very advanced demographic transition in 1960, while other countries were not in such a situation, but quickly adopted the patterns generated by the former. This is evident in Clubs 1 and 2 of the first group of countries analyzed (with late-expanding or advanced demographic transitions in 1960). A second finding is that countries that have recently begun their demographic transition tend to have highly differentiated total fertility rates. A third finding is that those countries that have completed their demographic transition are heading towards differentiated equilibria.

We propose that a possible explanation for finding patterns of convergence and divergence in total fertility rates, both globally and in the different fertility clubs, lies in the presence of increasing returns and decreasing returns in the adoption processes of family innovations over time. Considering the discussions given in the field of economic growth theory and path dependence, the patterns of convergence or divergence in fertility among countries could be associated with the presence of what is known as diminishing returns or increasing returns, respectively, that would occur in the processes of adopting family behaviors over time. We mentioned that increasing returns arise when certain disruptions or discontinuities destabilize existing normative equilibria on fertility and trigger advantages from the adoption of a specific family innovation that is adopted during initial conditions. These discontinuities could be due to certain historical events or new disruptions. With these discontinuities, various options could arise regarding family behaviors associated with fertility which could compete with each other, in addition to also having to compete with the incumbent family pattern. The earliest emerging family behavior that is adopted by a particular group of people may have advantages over other options of family behaviors, attracting a greater proportion of adopters at an early stage, and providing to the new emerging pattern with advantages among potential adopters in the subsequent stages. Diminishing returns would occur when the increase in adopters of an specific family behavior is less as time passes. The divergence in the total fertility rates among countries would occur when there is the presence of increasing returns in the adoption of family behaviors. Otherwise, the presence of diminishing returns in the adoption of family behaviors associated with fertility would imply the convergence processes among certain societies.

It is also highlighted in this Chapter 1 that the analysis of global fertility convergence stands out, for two reasons. First, more theory is required on this complex issue on the possibility or not of achieving global fertility convergence. On the other hand, it is highlighted that the existence or non-existence of a global pattern of fertility convergence contributes significantly to making viable a framework within which future fertility changes can be projected or predicted. It was mentioned that several of the population projections are based on the idea that global fertility will converge to a specific level in the future. Global fertility convergence, for instance, is embedded in the fertility projection model used by the United Nations (United Nations 2019), also in its more recent probabilistic version, where a Bayesian model helps to embed the demographic transition framework within fertility projections (Alkema et al 2011; Raftery et al 2012; Raftery, Alkema and Gerland 2014).

Furthermore, fertility projections have important implications for business, public policies, economic development, infrastructure, and services that will be required for future generations. In this sense, basing these projections on an idea of global fertility convergence can lead to different conclusions than if we made fertility projections based on an idea of global non-convergence, where instead the formation of clubs in countries with differentiated convergence in fertility rates is allowed. Based on the findings in Chapter 1, that there is a differentiated convergence in different fertility clubs, it will imply the need for differentiated economic and social policies at the global level. In addition, it can be observed that some countries that just a few decades ago were demographically very different from each other, are now beginning to approach each other in their fertility behaviors (for instance, Clubs 1 and 2 in countries that had a late-expanding or advanced demographic transitions in 1960). This would also bring the need that many social policies could also get even closer to address common problems of low fertility. In sum, testing the hypothesis of global fertility convergence, or analyzing whether fertility convergence patterns in the world follow differentiated paths through the formation of clubs, is relevant for future demographic projections and, therefore, has important implications for several economic and social policies.

Another relevant discussion would be about how much the conclusions of this Chapter could be affected by the limitations that some authors have indicated for the Total Fertility Rate indicator (TFR). This indicator at the country-level is usually defined as the average number of children that a woman would have is she were to live to the end of her reproductive years (ages 15-49) and bear children in accordance with age-specific fertility rates in a specified year or period. Therefore, the TFR represents a hypothetical measure because no real group of women has experienced these specific rates and it considers a quantum and a tempo component. The quantum component would be the TFR that would have been observed in the absence of changes in the timing of childbearing during the period in which the TFR is measured, while the tempo component equals the distortion that occurs due to timing changes. Bongaarts and Feeney (1998) highlight that criticisms of the total fertility rate involve several common themes, such as "the problems posed by changes in the timing of childbearing; the relationship between period and cohort measures; the nature and validity of period measures interpreted as 'hypothetical' cohorts; and the extent to which fertility measures should embody controls not only for age but also for such variables as parity, duration of marriage, or other demographic variables". However, these same authors highlight that the Total Fertility Rate has certain advantages, such as the ease of understanding and interpretation over other measures, its generalized use than any other demographic indicator on the birth rate and, in particular, the fact of that this indicator gives up-to-date information on levels and trends in fertility.

Regarding its implications on its limitations to be used in the fertility convergence analysis, it is important to highlight that this type of analysis requires knowing trends in the long term. Thus, changes in the timing of motherhood by cohort, changes in marriage stability, changes in adulthood, and other family changes could alter the trajectories of global fertility divergence and club formation. However, the methodology used in this Chapter precisely allows for the influence of nonlinear time-varying factors, and for a wide range of possible temporal trajectories and individual heterogeneity. These properties of the methodology used in this paper can moderate the possible biases generated by disruptive changes that affect family change and, therefore, fertility. In fact, various authors who have studied the convergence of fertility have used the Total Fertility Rate as the central measure of analysis (e.g. Wilson 2001, 2011; Dorius 2008; Hendi 2017; Castiglioni, Dalla-Zuanna and Tanturri 2020). However, these studies use conventional convergence analysis methodologies, which do not consider these possible changes in fertility dynamics.

Another specific challenge for convergence hypotheses in population projection has to do with the implications of crises, or, more in general, of discontinuities at the social and economic level. Examples of such crises are economic recession, such as the Great Recession of 2008-09, or the one induced by the Covid-19 pandemic, which could exacerbate differences in fertility rates (Sobotka et. al. 2011; Cherlin et. al. 2013; Schneider 2015; Aassve et. al. 2020;

Luppi et. al. 2020). Technological change, such as the contraceptive revolution started in the 1960s or the digital revolution of the 2000s are examples of other discontinuities influencing fertility dynamics (Hendi 2017; Guldi and Herbst 2017; Billari et. al 2019, 2020). To what extend do these 'events' cause persisting differences? It has been argued, for instance, that differences in advanced societies might become persistent, and lead to a "Great Divergence" in fertility (Billari 2018; Reher 2019; Castiglioni et. al. 2020).

From our point of view, the configuration of fertility convergence clubs will continue to change as disruptive events occur in family change, which have the possibility of altering normative equilibria in fertility decisions. The role that increasing and decreasing returns play in the adoption and diffusion of new family behaviors related to fertility, that emerge from these discontinuities, could be relevant to understanding this complex problem of the convergence of fertility among contemporary societies.

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Chapter 2

Income Level and Inequality in the Aztec Empire on the Eve of the Spanish Conquest

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ABSTRACT

Inequality in Latin America has been large, widespread and persistent. For some scholars, its origin dates back to the colonial period, when Europeans established extractive institutions that have lasted until the present. However, this paper suggests that income inequality was already very high in the days of the Aztec Empire, so its roots lie in pre-Hispanic institutions. In 2021, it was five hundred years since Tenochtitlan fell to Spanish troops in alliance with several peoples who rose up against the Aztec Empire. However, little is known about the conditions of inequality and extraction prior to the arrival of Europeans. Indeed, such conditions might explain the imperial fall. This paper analyzes income inequality in the 38 provinces of the Aztec Empire, showing how highly extractive conditions explain the ease with which the Spaniards promoted alliances with certain indigenous peoples to defeat the Aztecs. However, the same previous extractive conditions may have made it easier for Europeans to adapt the Aztec institutions for their own benefit during the early colonial period. Colonialism in Latin America did not create economic inequality, it only exacerbated it.

Keywords: Income Inequality, Income Distribution, Poverty, Subsistence, Economic History, Human Development, pre-Colombian populations

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2.1. Introduction

Exactly 500 years after the Spanish Conquest of the Aztec Empire, Latin American countries stand out for their relatively high levels of economic inequality (1, 2, 3). A large social science literature has argued that this is the long-run consequence of the extractive institutions imposed by the European elite (4, 5, 6). But here we show that in the Aztec area inequality levels were relatively high from well before the Conquest. Based on the available historical and archaeological evidence, we provide a new estimate of income inequality in the late Aztec Empire, which spanned most of the territory occupied by nowadays Mexico and parts of Guatemala (7, 8, 9). High inequality was the consequence of extractive institutions meant to advantage primarily the Aztec imperial elite (9, 10, 11). When they arrived, the Spanish profited from the discontent that high imperial extraction had generated in many provinces, leading Mesoamerican peoples to ally themselves to Cortés against their Aztec rulers (12). As we argue, after the Conquest the European elite could build upon pre-conquest extractive institutions to establish their own kind of colonial extraction.

On August 13, 1521 the city of Tenochtitlan fell after a long siege carried out by a small number of Spanish troops and thousands of indigenous allies who tried to free themselves from the yoke of the Aztec Empire (12). This event marks the beginning of 300 years of European colonial domination. Five centuries after the fall of the most powerful empire in Mesoamerica, several questions remain concerning the level of oppression that the Aztec Empire exerted in its domains, and its possible long-term consequences. To determine the levels of inequality and of imperial extraction across the vast territories under Aztec rule, we use information about the conditions prevailing in each province to estimate their average income level. Thereafter we devise a detailed social table, representative of the highly hierarchical social-economic stratification of the Empire, and use it to estimate interpersonal income inequality. This is found to have been relatively high, especially in those provinces which suffered the most disadvantaged situation under the imperial rule – which were exactly those more likely to rebel and to ally with the Spaniards. The extractive institutions characterizing the Aztec Empire paved the ground for subsequent colonial extraction. As we argue, the relatively high levels of income inequality that came to characterize Latin America could not be considered to have been the sole consequence of the initial conditions imposed by the Spaniards, for example through the system used to ensure an extensive supply of native labor known as *encomienda* (13). Nor could they simply come from the predatory attitudes and institutions of the colonial elite (4, 5). Instead, colonization exacerbated further the highly extractive conditions that had come into being from before the Conquest, and ensured their continuation for centuries thereafter.

2.2. The historical context

Formed by the "Triple Alliance" between the city-states of Tenochtitlan, Texcoco and Tlacopan, the Aztec Empire ruled over 38 provinces. These were subject to a highly developed imperial tax system. This, due to its institutional refinement and the ability to collect taxes on a regular basis, approached a proper fiscal state of the kind that Western Europe developed from about the same period (14, 15). And yet, other characteristics of the Aztec Empire are generally considered to have been relatively backward, so that it is difficult to classify its institutions based on typologies developed for Eurasian states (14).

This mixture of relatively advanced and backward traits characterizes the Aztec Empire also in other regards. On the eve of the Spanish conquest, it was the most militarily, politically and economically powerful state in Mesoamerica (8, 12). It had a highly productive agriculture, based on a technologically-advanced irrigation system and on highly developed domestication of plants (11, 14). But its economy also required intensive use of human energy, lacking a wheel transport system and beasts of burden. Division of labour, the source of Smithian growth, was very limited: except for those involved in the production of luxury goods and in foreign trade, the vast majority of the population was occupied in seasonal pluriactivity. Finally, although some specific goods were also used as money (cloths –mantas– or cocoa beans), many provinces were characterized by a barter economy (11, 16).

In the run-up to the Conquest, Central Mexico experienced a tremendous increase in population and substantial economic growth (14). In 1492, the Basin of Mexico had the highest population density of all the Americas (17, 18). Demographic pressure had increased competition for resources and pushed the Triple Alliance to expand to more remote regions. Intense factional competition shaped many aspects of society (19). The continued state of war, a tax system growing ever more extractive and pro-elite political reforms exacerbated social stratification across the Empire. The nobility appropriated the land and controlled the commoners through several mechanisms (20), which led to a clear demarcation between landowning and landless classes. On the positive side, imperial expansion intensified trade and fostered markets integration. This, however, was largely to the advantage of the original provinces of the Triple Alliance. In many cases, the Aztec expansion led to a decline in the revenues of the provincial elites (21). Elsewhere, the collusion between the imperial and the provincial elites generated profits for both in a win-win game resulting from the new imperial tributary system, to the detriment of the peasants (8, 22).

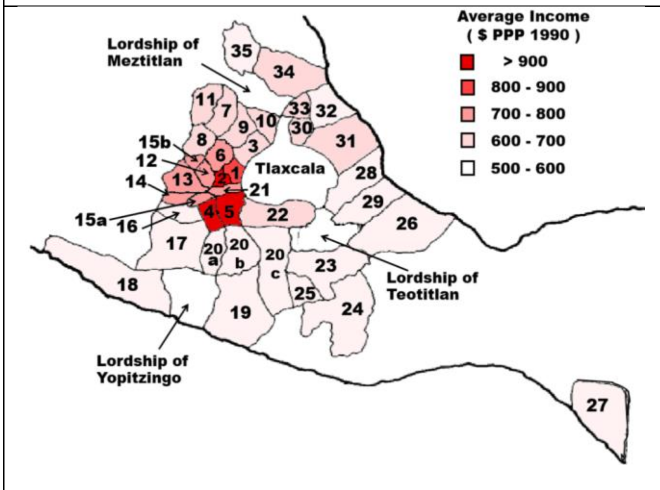
2.3. Income levels across the Empire

The relatively advanced Aztec administration provides us with historical documentation sufficient to produce estimates of the average income level within each province of the Empire. We first produced estimates of population density at the provincial level (Table 1, Column A). As there exists a positive correlation between population density and average income which tends to be similar across ancient societies (4, 23, 24), we could estimate the relevant parameter and used it to infer approximate income levels from our demographic data (Table 1, Columns B and C). It is generally accepted that the original variation in population density across Mesoamerica was determined by differences in land productivity (25, 26, 27). In the more densely populated areas, greater competition among human groups led to the emergence of stronger states (19). Stronger state institutions and the positive externalities associated to agglomeration economies had a positive impact on income per capita.

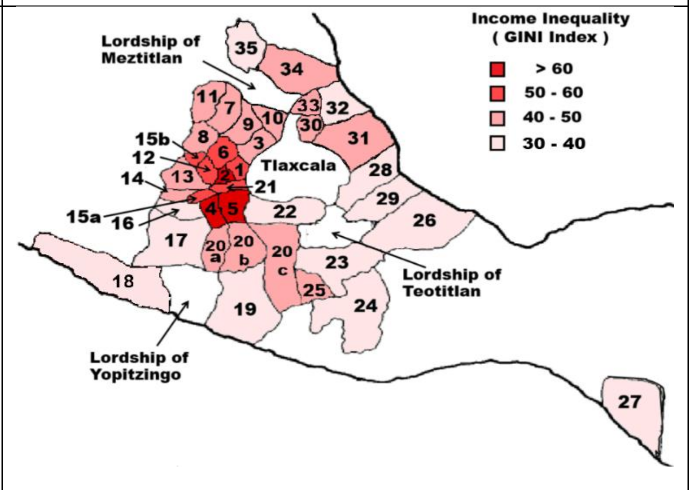
In our estimate, the average income of the Empire was about 690.1 PPP dollars 1990 on the eve of the Conquest. This is comparable to the income level estimated for the Euro-Mediterranean region at 150 CE or for Byzantium around 1000 CE (5,9). However, it is much lower than the $800-900 of late-fifteenth century Spain, let alone the average income of the most advanced areas of Western Europe like North Italy and the Low Countries (28, 29). Additionally, there was significant variation within the Empire. Of the 38 provinces, the four richest (Tlatelolco, Huaxtepec, Cuauhnahuac and Petlacalco) had an average income of over $900 (Figure 1, Panel A). Tenochtitlan, the imperial capital city which enjoyed special administrative status, stood out with an income of $1,980.

Figure 1: Average Income and Inequality in the Aztec Empire

Panel A: Average Income



Panel B: Income Inequality



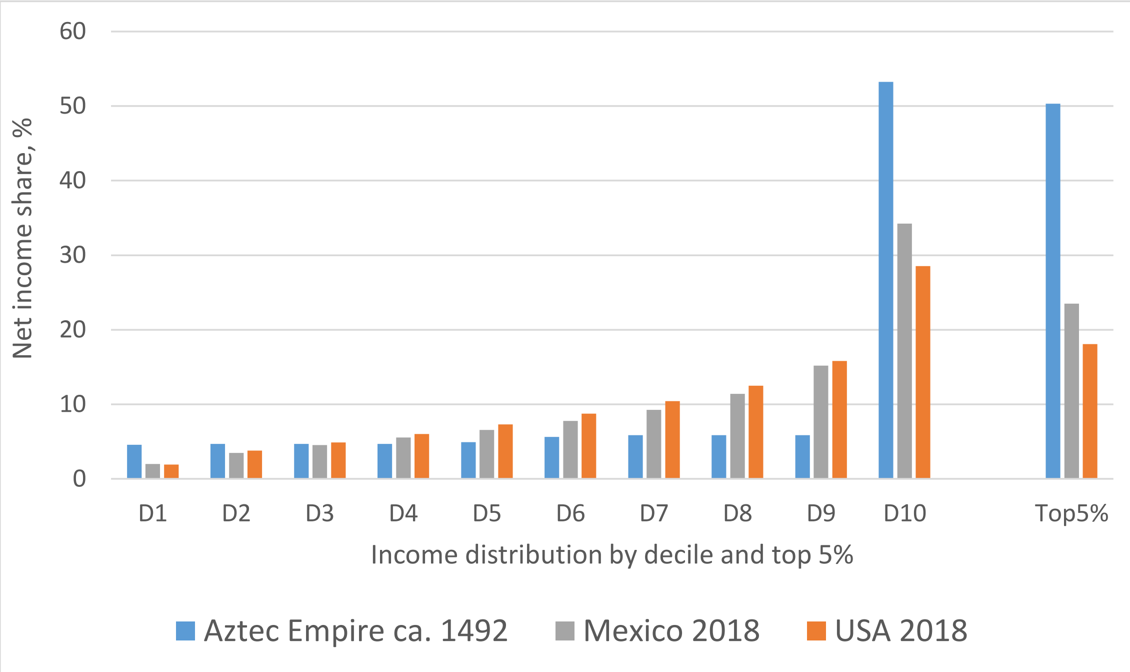
2.4. Income inequality

Archeology has established that wealth inequality was generally higher in post-Neolithic Eurasia than in the Americas. This, due to the availability of large domesticated mammals, which led to a more profitable agriculture benefiting some over others, and also led to the development of a mounted warrior elite (30, 31). However, even without large domesticated mammals, the societies that emerged in Central Mexico were highly hierarchical and stratified (32). The primary social distinction in the Aztec Empire was between the nobility, the commoners and the slaves. Then, significant differences existed within each group (10). The elite controlled the commoners by holding sole control over productive resources. Since they were not allowed to own farmland, commoners had to acquire access to it from the nobles in exchange for labor or for a part of the produce (calpulli/teccalli system). Among the commoners, the sources of economic inequality were labor specialization and chiefly the specific mechanisms through which they gained access to land (7). Among the nobility, inequality depended upon juridical status (imperial vs provincial nobility), the economic potential of their respective provinces and the extraction levels imposed locally by the imperial institutions. In particular, the taxes established by the Triple Alliance for each province were variable, depending on how the province had become part of the Aztec Empire. Those peoples that had militarily resisted the Aztec Empire, once conquered, suffered the highest imperial tax rates. Hence, high economic inequality in the Empire was also the result of an unequal distribution of political power, similarly to what found elsewhere (33).

Based on the available historical evidence, we developed social tables for each province and for the Triple Alliance cities (see Supplementary Information) as well as for the Empire as a whole and used them to measure income inequality (Table 1, Column D and Figure 1, Panel B) by means of the Gini index. For the Aztec Empire as a whole, we estimated that on the eve of the Conquest the richest 1% earned 41.8% of the total income, growing to 50.8% if the richest 5% is considered. As the income share of the poorest 50% was just 23.2%, this makes for a very skewed income distribution (Figure 2). The income share of the richest, in particular, was much higher in the Aztec Empire than in modern American states. Interestingly, also the income share of the poorest was higher – but in the Aztec Empire, the 4.5% earned by the poorest 10% (a social stratum composed for one-third by slaves) corresponded to a situation of mere subsistence, which is clearly not true for the poorest 10% citizens of today United States even if their income share is just 1.9%.

Overall, the Aztec Gini index of income inequality amounted to 50.5. This is higher than the 36-39 found in the Roman Empire in 14 CE, the 41-43 reported for Byzantium ca. 1000 CE and the 33-37 of England and Wales in 1290, but in line with the 50 of the northern Low Countries ca. 1500 and the 52 of the southern Low Countries ca. 1550 (34, 35, 36, 37, 38). However, the Aztec Empire was much poorer than the Low Countries, hence similar Gini indexes have deeply different implications. This is revealed by inequality extraction ratios, which measure how close a society is to the maximum inequality that it could theoretically experience without pushing all of its members (bar for a single super-rich) below subsistence (34, 38). With a ratio of 89.1%, the Aztec Empire was much closer to the boundary than the northern Low Countries (71%), which implies a social organization strongly tweaked in favor of a small elite. Within the Empire, inequality reached even higher peaks: >60 in some of the richest provinces, and almost 80 in the city of Tenochtitlan.

Figure 2: income distribution in the Aztec Empire compared to modern American states



2.5. Extraction and the fall of the Empire

The imperial ruling class of the Triple Alliance, the provincial ruling class and the non-ruling nobles amounted to less than 2% of the total population, but concentrated 46.6% of the total income. Taken singularly, these social categories extracted 4.5%, 28.4% and 13.7% of GDP respectively (Table 2). This might seem favourable to the provincial ruling class, but as the imperial ruling class was a much smaller group it enjoyed a much larger per-capita income: on average, almost 5 times that of the provincial ruling class and 70 times that of the non-ruling nobles (Supplementary Information, Table 44A). This is why the level of imperial extraction is indicative of why discontent against the Empire might have arisen in the provinces, and helps to understand the quick formation of anti-imperial alliances upon the arrival of the Europeans.

Also in this case, there was high variation across the Empire. In some established provinces on the Gulf of Mexico coast, such as Tochpan, Cihuatlan and Tepequacuilco, imperial extraction was very high. In Cuetlaxtlan [Table 2, ID 29], where (in the lordship of Cempoala) Cortés made his first alliance against the Aztecs, taxes paid to the Triple Alliance amounted to 8.9% of GDP. But the maximum, 14% of GDP, was touched in Tepeyacac [ID 22], which also allied with the conquerors.

Although at first the Spanish faced resistance from certain native peoples, they soon came to enjoy the support of various cities against the Aztec Empire. Before arriving in Tenochtitlan, Cortés already had the backing of Cempoala, Cholula, and Tlaxcala, the latter an independent confederation and staunch enemy of the Aztecs. In the Basin of Mexico, the Spaniards had forged a powerful alliance with different cities that paid taxes to the Aztecs, such as the Otomies of Teocalhueyacan, as well as the residents of Texcoco, Chalco, and other towns in the provinces of Petlacalco and Acolhuacan. It is interesting to note that Tlatelolco [ID 1], a city-state that supported the Aztecs until the end of their fall, suffered much lower imperial extraction compared to other provinces: 1.3% of GDP.

2.6. Final discussion: after the Fall

Our estimates suggest that high inequality in Mexico was not originated by the new institutions established in colonial times, but preceded the Conquest. Consequently, our findings challenge some influential works that have argued that the Europeans, and especially the Iberians, unilaterally determined the institutional framework of the New World, bringing to Latin America their inefficient and/or predatory institutions (4, 5, 39). These works share a crucial limitation: they ignore the institutional context set by the pre-Conquest societies and consequently, they fail to consider how this context might have contributed to shape the colonial institutions. Indeed, this literature, as it argues that the European institutions were responsible for generating high inequality in Latin America, implicitly suggests that they replaced relatively "inclusive" pre-Conquest institutions. This position is difficult to hold. High imperial extraction and certain obligations imposed by the Aztecs (for example, the obligatory provision of children and youths to be sacrificed in rituals) were deeply resented by the provinces. Thus, inequality levels almost as high as the theoretical maximum contributed to making the Aztec society less resilient against a new and unexpected threat.

Undoubtedly, the Conquest, the redistribution of political power and the subsequent dramatic demographic crisis marked a radical discontinuity with the preceding situation (40, 41, 42). After the Conquest, Europeans brought various institutions to the Americas, but this does not exclude that pre-existing "native" institutions transcended, or merged with, the colonial ones. Additionally, the existence of previous extractive institutions made it easier for the Europeans to introduce their own system of extraction, even through direct adaptation of those native institutions. Well-documented cases of pre-Conquest institutions hijacked by the Europeans include the mita, a forced-labor system used by the Inca Empire (43). Others have argued, in a more general way, that institutional, economic and social transformations during the colonial period were largely influenced by pre-Conquest institutions (44). However, the idea that after the Conquest native peoples were simply the recipients of Spanish policies and institutions has remained prevalent among social scientists.

For the Aztec area, our estimates of income inequality levels provide strong support to the view that pre-Conquest institutions were important landing strips for colonial institutions. Since pre-Conquest nobles and lords were the sole owners of the farmland, the several layers of extraction previously imposed on commoners to control access to resources made it easier for the Spaniards to appropriate lands and labor. The encomienda indiana and later the repartimiento, or the cuatequil -a forced-labour system similar to the mita- took advantage of these mechanisms. Surely, for the native populations of Mesoamerica being required to provide labour to their rulers was not a new idea introduced with the encomienda/repartimiento system. Additionally, the Spanish inherited directly the collection methods of the Aztecs, at least in early colonial times.

Overall, the Conquest shows a combination of institutional continuities and discontinuities. The highly hierarchical pre-Conquest social stratification survived in the colonial period, leaving many nobles with multiple privileges and entitled to extract a large share of the income from the commoners, to their own benefit as well as to that of the new European elite. Hierarchical stratification and social-economic inequality, however, were further exacerbated by the new caste system and by the economic activities introduced by the Spaniards. By 1790, New Spain had a Gini index of income inequality of 63.5: significantly higher than most contemporary societies, and basically as high as it could have been without compromising the simple survival of large masses of the population (34). This being said, and without negating the plight and terrible sufferance that the Conquest caused to the native population, we conclude that colonial institutions did not create high inequality in Latin America, they only exacerbated it.

Table 1: Estimated Average Income and Inequality in the Aztec empire

ID	Province	Location	(A) Population Density	(B) Average Income $PPP 1990	(C) Average Income in Minimum Subsistence	(D) Gini Coefficient
-	Aztec Empire (overall)	-	42	690.1	1.7	50.5
-	Tenochtitlan	-	-	1980.0	5.0	79.9
-	Texcoco	-	-	990.0	2.5	65.0
-	Tlacopan	-	-	990.0	2.5	65.2
1	Tlatelolco	Center	157.6	925.4	2.3	62,3
2	Petlacalco	Center	251.5	1015.0	2.5	64,0
3	Acolhuacan	Center	37.6	696.8	1.7	46,3
4	Cuauhnahuac	Center	199.3	969.3	2.4	62,2
5	Huaxtepec	Center	210.9	980.2	2.5	62,6
6	Quauhtitlan	North	40.3	706.6	1.8	50,3
7	Axocopan	North	32.8	678.3	1.7	46,7
8	Atotonilco de Pedraza	North	32.8	678.3	1.7	47,6
9	Hueypochtlan	North	35.0	687.3	1.7	48,3
10	Atotonilco el Grande	North	32.8	678.3	1.7	46,8
11	Xilotepec	West	35.3	688.2	1.7	47,1
12	Quahuacan	West	67.4	782.2	2.0	54,5
13	Tollocan	West	40.3	706.6	1.8	49,4
14	Ocuillan	West	40.3	706.6	1.8	49,9
15a	Malinalco	West	40.3	706.6	1.8	50,3
15b	Xocotitlan	West	40.3	706.6	1.8	51,1
16	Tlachco	South	16.8	594.6	1.5	38,7
17	Tepequacuilco	West	14.2	575.2	1.4	34,3
18	Cihuatlan	West	14.2	575.2	1.4	33,6
19	Tlauhpan	South	14.2	575.2	1.4	38,1
20a	Tlalcozauhtitlan	South	14.2	575.2	1.4	40,0
20b	Quiauhteopan	South	14.2	575.2	1.4	40,0
20c	Youaltepec	South	16.7	593.5	1.5	41,9
21	Chalco	South	97.2	840.9	2.1	58,6
22	Tepeyacac	South	25.3	644.3	1.6	38,5
23	Coaixtlahuacan	South	15.4	584.2	1.5	38,4
24	Coyolapan	South	14.2	575.2	1.4	38,8
25	Tlachquiauhco	South	14.2	575.2	1.4	40,0
26	Tochtepec	South	14.2	575.2	1.4	36,6
27	Xoconochco	South	6.7	496.2	1.2	31,2
28	Quauhtochco	East	14.2	575.2	1.4	39,4

29	Cuetlaxtlan	East	14.2	575.2	1.4	35,0
30	Tlapacoyan	East	25.3	644.3	1.6	45,4
31	Tlatlauhquitepec	East	22.5	629.7	1.6	40,7
32	Tochpan	East	14.2	575.2	1.4	33,0
33	Atlan	East	25.3	644.3	1.6	44,0
34	Tziuhcoac	East	22.2	627.9	1.6	42,5
35	Oxitipan	East	14.2	575.2	1.4	35,9

* Gini coefficient expressed in percentages.

** ID according to Broda (45).

Table 2: Extraction level by province (for Imperial Ruling Class, Provincial Ruling Class and non-ruling Nobles; measured as % of GDP earned).

ID*	Province	(A) Total Extraction (B+C+D) % GDP*	(B) Extraction Imperial Ruling Class % GDP	(C) Extraction Provincial Ruling Class % GDP	(D) Extraction non-ruling Nobles % GDP
-	Aztec Empire	46.6	4.5	28.4	13.7
1	Tlatelolco	60.5	1.3	44.4	14.8
2	Petlacalco	64.0	5.9	43.6	14.5
3	Acolhuacan	47.6	8.6	29.3	9.8
4	Cuauhnahuac	89.1	8.8	60.2	20.1
5	Huaxtepec	62.8	6.1	42.5	14.2
6	Quauhtitlan	48.3	2.5	34.3	11.4
7	Axocopan	46.2	5.5	30.5	10.2
8	Atotonilco de Pedraza	46.2	3.8	31.8	10.6
9	Hueypochtlan	46.9	3.7	32.4	10.8
10	Atotonilco el Grande	46.2	5.3	30.7	10.2
11	Xilotepec	47.0	6.1	30.6	10.2
12	Quahuacan	53.3	3.6	37.3	12.4
13	Tollocan	45.6	3.6	31.5	10.5
14	Ocuillan	48.3	3.4	33.7	11.2
15a	Malinalco	48.3	2.5	34.3	11.4
15b	Xocotitlan	48.3	0.8	35.6	11.9
16	Tlachco	38.6	5.4	24.9	8.3
17	Tepequacuilco	36.5	9.8	20.1	6.7
18	Cihuatlan	36.5	10.7	19.3	6.4
19	Tlauhpan	36.5	4.2	24.3	8.1
20a	Tlalcozauhtitlan	36.5	1.2	26.5	8.8
20b	Quiauhteopan	36.5	1.1	26.6	8.9
20c	Youaltepec	38.5	1.1	28.1	9.4
21	Chalco	56.6	1.4	41.4	13.8
22	Tepeyacac	43.3	14.0	22.0	7.3
23	Coaixtlahuacan	37.5	5.2	24.3	8.1
24	Coyolapan	36.5	3.1	25.0	8.3
25	Tlachquiauhco	36.5	1.0	26.6	8.9
26	Tochtepec	36.5	6.5	22.6	7.5
27	Xoconochco	26.4	0.2	19.7	6.6
28	Quauhtochco	36.5	2.1	25.8	8.6
29	Cuetlaxtlan	36.5	8.9	20.7	6.9
30	Tlapacoyan	43.3	2.8	30.4	10.1
31	Tlatlauhquitepec	42.0	8.6	25.1	8.4

32	Tochpan	36.5	11.6	18.7	6.2
33	Atlan	43.3	5.4	28.5	9.5
34	Tziuhcoac	41.9	5.5	27.3	9.1
35	Oxitipan	36.5	7.6	21.7	7.2

* Total Extraction is the percentage of total GDP that is extracted or "earned" by the 3 richest groups of the Aztec society (see Supplementary Information).

** ID according to Broda (45).

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Chapter 3

The Social Curse of Natural Resources: Historical Legacies in Fertility

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ABSTRACT

The influential literature on the "curse of natural resources" highlights that resource-rich countries, under certain circumstances, have poorer economic and political outcomes than other countries. This paper proposes that the presence of non-renewable natural resources also has important implications and long-term effects for fertility and other social dynamics related to family change. As a first approach, a country-level analysis is first carried out where it is documented how the presence of natural resources is highly associated with higher fertility rates throughout the world. Second, the long-term effects and persistence of this "social curse" are highlighted, by providing evidence at the subnational level in Europe. The presence of historic coal mines, dating back to the Industrial Revolution in Europe, could have some effect on current fertility behaviors, as higher reproductive rates are observed in such regions. Possible transmission mechanisms and persistence of such effects are discussed. The results are discussed in the light of different theoretical perspectives by which the fertility transition would be delayed in the presence of non-renewable natural resources

Keywords: Natural Resources, Fertility, Family Change.

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3.1. Introduction

An influential literature in the fields of economics and political science has contributed significantly to understanding how the presence of non-renewable resources may affect economic and political outcomes. Widely discussed over the last decades, this literature has provided solid empirical evidence to document the impact of such resources on development, economic growth, the quality of governments, and political conflicts (Sachs and Warner 1995, 1999a, 1999b, 2001; Ross 1999, 2001, 2004, 2012, 2018; van der Ploeg 2011; Brollo et al. 2013). This issue has been known as the "curse of natural resources" in which it is highlighted that resource-rich countries (e.g. fossil fuels and minerals), under certain circumstances, tend to perform poorly economically and politically than resource-poor countries (Sachs and Warner 2001).

However, the literature in sociology and demography has paid less attention to the potential effects that natural resources could have on family change and its outcomes, such as total fertility rates. If the presence of natural resources influences economic, development and political outcomes, and given that these represent also determinants of fertility, therefore we could argue that the presence of such resources could also have effects on total fertility rates. For this reason, there could also be a social curse derived from the presence of non-renewable natural resources, in the sense that family change and its outcomes, such as the transition in fertility, can be significantly delayed. Even the presence of non-renewable natural resources could also have persistent effects, where their impacts on the social dynamics related to family change and fertility would be seen in the very long term.

This paper seeks to shed some light on this issue, exploring the possible existence of a “social curse”, in which fertility behaviors and other dynamics related to family change could be altered by the presence of non-renewable natural resources. In particular, it looks at how the presence of non-renewable natural resources, such as fossil fuels and minerals, could have a causal and long-term effect on fertility behaviors. For this analysis, a broader and more inclusive idea of the resource curse is taken, provided by Ross (2018), such as "the perverse effects of a country's natural resource wealth on its economic, social, or political well-being".

It is proposed that the conditions of economic development, generated by the effects of natural resources, could be a relevant transmission channel in family change. Economic development can modify family decision-making and alter fertility patterns, causing those societies with better environments in their economic development to accelerate the fertility transition derived from the family change that arises from industrialization processes, as well as the greater levels of education and health. However, when this development is generated by the presence of fossil fuels and minerals, as well as extractive industries related to natural resources, this environment can alter female participation in the labor force, promoting greater masculinization in job opportunities (Ross 2018; Shepard, Betz and Snyder 2019). These labor market mechanisms would lead to a widening of gender gaps, modifying fertility behaviors, despite the fact that society has higher levels of development. The literature has documented that certain labor market environments can alter gender gaps (Goldin 2006, Bongaarts, Blanc and McCarthy 2019; Behrman and Gonalons-Pon 2020). However, the traditional view in this literature considers that advances in gender are evolutionary, in the sense that it would be rare to see setbacks. However, with the presence of non-renewable natural resources, it could generate adverse environments and reverse the conditions in gender gaps, derived from masculinization processes. An unexpected discovery of an oil, coal or natural gas field could substantially modify the economic environment, resulting in an unfavorable alteration in employment opportunities for women.

The first contribution of this paper is to provide an empirical analysis at the country-level to document how the presence of natural resources is highly associated with higher fertility rates and other social outcomes. Second, the long-term effects and high persistence of this social curse are highlighted, by providing evidence that the presence of historic coal mines, dating back to the Industrial Revolution in Europe, is associated with certain contemporary fertility behaviors. Finally, the results are discussed in the light of different theoretical perspectives by which the fertility transition would be delayed in the presence of non-renewable natural resources.

The remainder of the paper is organized as follows. In Section 2, the related literature on this issue is discussed. In Section 3 the data and the empirical strategy used in this work are presented. Section 4 presents the results at the country level. Section 5 analyzes the long-term effects of this social curse at subnational level and discusses the possible transmission mechanisms of this social curse. Section 6 provides final discussions of the findings in this paper and some future directions for research.

3.2. Related literature

The effects of non-renewable natural resources on fertility patterns could be linked through some channels already foreseen in different strands of literature on development, gender, cultural transmission and persistence, and fertility. First, there is an important body of literature that highlights how non-renewable natural resources, under certain circumstances, affect development, growth, and other economic and political outcomes (Sachs and Warner 1995, 2001; Ross 1999, 2001, 2004, 2012, 2018)). Market mechanisms are highlighted in this literature as the first transmission channel, since natural resources windfalls impact on the appreciation of the local currency, which affects the competitiveness of other economic sectors and their labor market, and therefore in development (Sachs and Warner 1999a, 1999b). The second transmission channel given by the resource curse is the mechanism related to government failures, such as rent seeking or patronage (Torvik 2002; Robinson, Torvik and Verdier 2006). These channel establish strong incentives that generate higher levels of corruption or even political conflicts derived from the struggle for power between groups,, which ultimately end up affecting development levels. In this literature, the quality of institutions is decisive for the presence of a resource curse (Mehlum, Moene and Torvik 2006).

On the other hand, a second strand of literature useful for our analysis could be found in the fields of economics, sociology and demography, in which socioeconomic development stands out as a fundamental determinant of fertility (Becker 1960, 1981; Becker and Barro 1988; Barro and Becker 1989; Becker, Murphy and Tamura 1990; Thornton 2001, 2005; Boldrin and Jones 2002; Myrskylä, Kohler and Billari 2009; Browning, Chiappori and Weiss 2014; Chiappori, Salanié and Weiss 2017; Chiappori, Pierre-André 2020). This literature shows that fertility trends change because socioeconomic transformations provide new incentives for family formation, the age of marriage, the age at first birth, and to invest in children (Bongaarts 2016; Pesando et al 2019; Furstenberg 2019). Other sociodemographic theories point to the spread of ideas about motherhood in society linked to high levels of development. The Second Demographic Transition (Lesthaeghe and van de Kaa 1986; van de Kaa 1987; Lesthaeghe and Surkyn 1988; Lesthaeghe 2010, 2014, 2020) and Development Idealism (Thornton 2001, 2005; Thornton, Dorius and Swindle 2015) have focused on the role of ideational factors have played in driving the spread of family change. Johnson-Hanks, Bachrach, Morgan and Kohler (2011) recently proposed a theory, based on Sewell's (1992) structure and transformation theory, where the duality in the structure, given by the combination of schemes and materials issues, determines family change and therefore fertility. This last theory will be central to the discussions in this paper.

The presence of natural resources indirectly may affect fertility rates through the widening of gender gaps caused by changes in the allocation of female versus male labor. Natural resources windfalls usually keep the local currency overvalued, and affect other economic sectors related to the production of tradable goods not related to natural resources, for example, manufacturing which is intensive in female labor. This major market failure is known as Dutch Disease, widely documented in the literature on natural resources (Corden 1984; Sachs and Warner 2001). Additionally, the economic sectors related to the extraction of non-renewable natural resources tend to demand more male labor in their activities, so this effect also widens the gender gap in job opportunities. As a result, this reassignment in the labor market could lead to widening gender gaps, thus modifying fertility behaviors (Goldin 2006, Bongaarts, Blanc and McCarthy 2019; Behrman and Gonalons-Pon 2020).

Finally, the analysis in this paper also considers the literature related to the long-term effects of historical legacies on development, as well as some works that highlight cultural transmission and persistence across generations. On the one hand, an important body of the literature in economic history is shedding light on the long-term effects that historical events, institutions, and geographical conditions have on contemporary development (Hall and Jones 1999; Acemoglu, Johnson and Robinson 2001, 2002; Nunn 2007, 2020; Dell 2010; Engerman and Sokoloff 2012; Spolaore and Wacziarg 2013). These works highlight various long-term transmission channels, ranging from the persistence of institutions to processes of path dependence and lock-in states. On the other hand, there is a literature that focuses on cultural persistence in the very long term which affects gender roles, social norms, trust or attitudes (Nunn and Wantchekon 2011; Voigtlander and Voth 2012; Alesina, Giuliano and Nunn 2013). This cultural persistence is transmitted from parents to children, as well as through the influence and molding that occurs from interactions with society, which ultimately affect family behaviors (Bisin and Verdier 2000, 2001; Fernández and Fogli 2009).

Considering the aforementioned literature, this work proposes the existence of long-term effects of non-renewable natural resources on fertility. The reasoning behind this approach is based on the fact that activities and industries related to these types of resources are established for long periods of time. The growing literature on the economics of geography provides evidence on path dependence processes on the persistence of industry location (Krugman 1991a, 1991b; Ellison and Glaeser 1999; Fujita, Krugman and Venables 1999). The presence of economic activities related to non-renewable natural resources, in addition to having an impact on long-term development, would also generate a gender gap in the labor market, given a greater demand for male labor, which may prevail for many years. In addition, these economic activities could promote attitudes, social norms, gender roles and family behaviors with long-term effects. Following Johnson-Hanks, Bachrach, Morgan and Kohler (2011), the effects of natural resources in the long term could determine the dual structure that affects family change, by modifying the allocation of labor in productive activities and in generating new schemes. The literature on the curse of natural resources emphasizes that the effects generally begin to be seen in economic and political outcomes around two decades after a natural resource windfall occurs (Sachs and Warner 2001). However, new contributions are emerging from a perspective in which natural resources have long-term effects (Fernihough and O'Rourke 2014; Abramson and Esposito 2020).

3.3. Data and empirical strategy

This section describes a variety of datasets and the empirical strategy used in this paper. Section 3.1 describes the data collected at both the national and subnational levels, in which contemporary and historical variables are presented. Section 3.2 presents, first, the econometric model to be used in the analysis at the country level, with contemporary data and, second, the identification strategy at the subnational level. In the latter, historical information is used to address the possible endogeneity problems that may arise between economic development, female participation in the labor force, and fertility.

3.3.1. Data

3.3.1.1. Contemporary data at the country-level.

Contemporary data comes from a variety of databases. The primary outcome variable in this study (the dependent variable) is the *Total Fertility Rate* at the country-level, which represents the 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 age-specific fertility rates of the specified year. This indicator is provided annually by the World Bank, as part of the World Development Indicators whose last updated date was July 10, 2019. For this purpose, the World Bank considers different sources such as: (1) United Nations Population Division. World Population Prospects: 2019 Revision; (2) Census reports and other statistical publications from national statistical offices; (3) Eurostat: Demographic Statistics; (4) United Nations Statistical Division.

Population and Vital Statistics Report (various years); (5) U.S. Census Bureau: International Database, and (6) Secretariat of the Pacific Community: Statistics and Demography Programme.

From the World Development Indicators is also taken the variable *Total Natural Resources Rents* (% of GDP), which is the sum of oil rents, natural gas rents, coal rents (hard and soft), mineral rents, and forest rents. These estimates are based on sources and methods described in "The Changing Wealth of Nations: Measuring Sustainable Development in the New Millennium" (World Bank, 2011). Annual Unemployment Rates are also considered, based on the *Total Unemployment* (% of total labor force, modeled ILO estimate), *Female Unemployment*, and *Male Unemployment*. It is used the *real GDP per capita* (the annual Gross Domestic Product per capita, constant 2010 US$ dollars); the *growth rate of GDP per capita*; and the classification of the type of economies made by the World Bank according to their income levels. A categorical variable is set with the last indicator, *Income Class Country*, in which 4 represents high income, 3 upper middle income, 2 lower middle income, and 1 low income. The demographic variables given by the World Development Indicators are used: *the Median age of population*; and *Total Life Expectancy at Birth* (years).

In addition, the country-level analysis consider indicators provided by other sources. It is used the *Gender Inequality Index* (GII) of the Human Development Report issued by the United Nations Development Programme. The closest available data is taken for certain countries that do not have this indicator for certain specific years. The variable *Uncertainty* refers to the Economic Policy Uncertainty Index developed by Baker, Bloom and Davis (2016), available at https://www.policyuncertainty.com/index.html. It is also considered the variable *Democracy* by using the indexes developed by the V-Dem Institute. The indicators used are v2x_polyarchy, v2x_libdem, v2x_partipdem, v2x_partip and v2x_egaldem, which are explained at www.v-dem.net.

3.3.1.2. Contemporary Data at Subnational-level.

The main outcome variable is the *Total Fertility Rate* (births per woman) at subnational level (NUTS 2 region), provided by Eurostat. This indicator represents the mean number of children that would be born alive to a woman during her lifetime if she were to survive and pass through her childbearing years conforming to the fertility rates by age of a given year. The last updated date of this indicator was October 9, 2020. It also used *Regional gross domestic product per capita* (GDP purchasing power standards -PPS- per inhabitant by NUTS 2 regions[11]); *Youth unemployment rate* by sex, age and NUTS 2 regions, which age class is from 15 to 29 years[12]; *Gender employment gap* by NUTS 2 regions[13] obtained by the difference between the employment rate of male and female at age group 20-64; *Life expectancy at birth by sex* and NUTS 2 region[14]; and *Population aged 25-64 by educational attainment level, sex* and NUTS 2 regions (%)[15]. A variable *gap_gender_high_education* is created, which is obtained from

[11] This indicator reflects the total value of all goods and services produced less the value of goods and services used for intermediate consumption in their production. PPS (purchasing power standards) eliminates differences in price levels between countries. According to Eurostat, calculations on a per inhabitant basis allow for the comparison of economies and regions. https://ec.europa.eu/eurostat/web/products-datasets/-/tgs00005

[12] https://ec.europa.eu/eurostat/databrowser/view/yth_empl_110/default/table?lang=en

[13] https://ec.europa.eu/eurostat/databrowser/view/tepsr_lm220/default/table?lang=en

[14] https://ec.europa.eu/eurostat/web/products-datasets/product?code=tgs00101

[15] https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=edat_lfse_04&lang=en

the difference between the percentage of the male population aged 25-64 with tertiary education or more, and the same indicator but for the female population.

3.3.1.3. Historical Data.

Two main historical variables on natural resources are used, which are taken from the work of Abramson and Esposito (2019). The first variable is called "Historical Coal-Mining" which these authors obtained them based on the information about the historical coal deposits documented by the Atlas Les Houilléres Européennes, de Chatel and Dollfus (1931) as well as the information from the European Route of Industrial Heritage (ERIH) database[16]. The second historical variable is called "Carboniferous Strata", which is exogenous and considers the underlying geological conditions originated in the Carboniferous Period (approximately between 270 and 350 million years ago). This variable has the advantage of being used as an instrumental variable, in order to challenge the possible endogeneity problems that may arise among different variables. For instance, there could be an endogenous relationship among economic development, technological progress and the number of coal mines during the Industrial Revolution. Another endogenous relationship could emerge between economic development, the gender gap in job opportunities, and fertility rates. For this analysis, categorical variables are used for each of the two aforementioned indicators. The variable *Historical Coal-Mining* has a range from

[16] In the information in the Atlas Les Houilléres Européennes, the historical coal deposits are found, in which Abramson and Esposito highlight the existence of 130 polygons / coalfields, spanning across 104 regions, that is, almost a third of the regions analyzed. NUT2 level. These historic coal mines were in Northern Europe, where almost half of the regions had at least one coal deposit. The second source contains information on industrial heritage sites in Europe related to various economic sectors.

1 to 10, based on the residual variation of the estimate made by Abramson and Esposito (2019). Level 10 indicates a higher concentration of *Historical Coal-Mining* while 1 indicates the non-existence of such natural resources. The variable *Carboniferous Strata* has a range from 1 to 7, which the latter indicates a higher concentration of Carboniferous while 1 indicates low levels of such natural resources. Using both variables has the advantage that historical coal deposits and the underlying geological conditions are collected in a systematic way, which generates comparable information on historical coal extraction between different regions in Europe. The purpose of using these variables is to distinguish those regions with historical carbon abundance.

Table 1 reports the summary statistics of outcome, main explanatory variables, and controls used in the analysis at the country level. Table 2 presents the variables used in this paper at subnational level.

Table 1: Summary Statistics at National Level

	Count	Mean	SD	Min	Max
Variable Country-Level					
Total fertility rate	142	3.279496	1.760768	0.901	8.606
Total Natural Resources Rents	142	8.532509	11.83394	0	86.45256
Total Unemployment	142	8.292734	6.291949	0.122	44.157
Female Unemployment	142	7.612621	5.790933	0.054	39.95
Male Unemployment	142	9.781132	7.835523	0.147	54.817
real GDP per capita	142	11355.48	16868.09	115.7941	91617.28
growth rate of GDP per capita	142	2.051842	6.425687	-64.9963	122.9683
Income Class Country	142	2.352113	1.145848	1	4
Median age of population	142	26.40051	8.508851	14.3	47.06
Total Life Expectancy at Birth	142	67.46066	10.20393	27.61	84.27805
Gender Inequality Index (GII)	142	0.4400348	0.2057393	0.011528	.83
Uncertainty	142	0.1643202	0.1453254	0	1.34288
Democracy (v2x_polyarchy)	142	0.517	0.2663819	0.015297	0.939980
Use of Internet (% Population)	142	18.51346	26.55818	0	97.99999
Mobile Cellular Subscriptions (per 100 people)	142	45.69923	50.87784	0	249.0243
Broadband Subscriptions (per 100 people)	142	4.325821	9.099113	0	45.42234

Note: Count in Panel A refers to the number of countries analyzed (142 countries).

Table 2: Summary Statistics at Subnational Level

	Count	Mean	SD	Min	Max
Variable Subnational-Level	**Count**	**Mean**	**SD**	**Min**	**Max**
Total Fertility Rate (NUTS 2)	311	1.630676	0.3379158	0 .95	3.91
Historical Coal-Mining	311	4.874587	2.765817	1	10
Carboniferous Strata	311	4.15894	2.073747	1	7
Regional gross domestic product per capita purchasing power standards -PPS-	311	25809.26	13302.53	4400	190500
Gender employment gap	311	13.26861	10.8041	- 1,5	59.9
Male employment rate at age group 20-64	311	76.52167	6.6844	53.5	93.4
Female employment rate at age group 20-64	311	62.00402	13.46679	3.2	86.1
% Total Tertiary educational attainment level (25-64 years old)	311	30.54670	74.7	7.1	18.2

Note: Count in Panel B refers to Europeans regions at subnational level NUTS 2 analyzed (311 regions).

In Tables 1 and 2 there is wide variation in different variables considered in the analysis. Table 1 reports the summary of the statistics of the variables at the country level, in which 142 countries are analyzed for a period that spans from 1990 to 2018. The main outcome is the Total Fertility Rates whose mean is 3,28 children that would be born to a woman if she were to live to the end of her childbearing years. However, in the set of countries analyzed the minimum Total Fertility Rate is 0.90 while the maximum is 8.6. The main explanatory variable is the Total Natural Resources Rents, which is expressed in terms of the percentage that the rents generated by oil, natural gas, coal (hard and soft), mineral, and forest are in the country's GDP. This indicator also has a wide variation between countries, where the minimum income from natural resources is 0, that is, a country that does not have any type of income derived from natural resources, while the maximum income represents 86.45 percent of GDP from a country. In the rest of the independent variables, all controls also show wide variability.

Table 2 reports the summary of the statistics of the variables at the subnational level, in which 311 regions in Europe are analyzed for a period that spans from 2007 to 2018. The Total Fertility Rate has a mean of 1.63, much lower than the mean observed for the 142 countries in Table 1. However, its variability at subnational level is still very wide since the minimum value is 0.95 while the maximum is 3.91 children. The Carboniferous Strata variable ranges from 1 to 7, in which 7 implies that the region in more abundant in its underlying geological conditions originated in the Carboniferous Period. This indicator will be used in the analysis as an instrumental variable in order to control the potential endogeneity problems pointed out in other sections of this paper. The rest of the variables at the subnational level used as controls also have wide variability.

3.3.2. Empirical Strategy

First, a country-level analysis will be carried out by exploiting the variation observed around the world in *Total Natural Resources Rents (% of GDP)*. Subsequently, the effects of non-renewal natural resources on fertility at the subnational level are analyzed, by exploiting the observed variation in *Historical Coal Mining* and *Carboniferous Strata* throughout the different regions of Europe. In general, both the analysis at the country level and at the subnational level, the estimates are obtained using the following equation:

$$\boldsymbol{Outcome_{i\,t}} = \beta_0 + \beta_1 \boldsymbol{NatResources_{i\,k}} + \boldsymbol{X'_{i\,t}\delta} + \boldsymbol{\gamma_i} + \boldsymbol{\lambda_t} + \boldsymbol{\varepsilon_{i\,t}} \qquad [1]$$

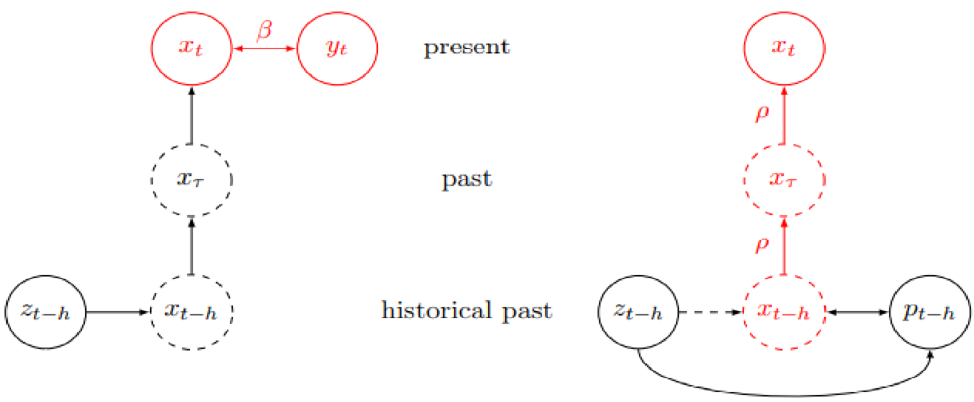
On the one hand, at the country-level analysis, the dependent variable is the *Total Fertility Rate* at country-level in year *t*, in which *i* represents an specific country. The analysis period would be from 1990 to 2018. On the other hand, at subnational-level analysis, the dependent variable would be the *Total Fertility Rate* at region level NUT2 in Europe in year *t*, where *i* represents an specific region. The estimation equation in (1) is also used for other outcomes, such as *GDP per capita* and the employment gap between men and women, both at subnational level, which are fundamental in identifying transmission channels. The analysis period for subnational-level would be from 2007 to 2018.

In equation (1), the key explanatory variable is *NatResource*, where *k* represents the period in which natural resources are extracted. At the country-level analysis, *NatResource* is indicated by the *Total Natural Resources Rents (% of GDP)* in the country *i*, in year k = t (therefore, from 1990 to 2018). At the subnational-level, the key explanatory variable would be the *Historical Coal-Mining*, in a region *i*, in the period k ≠ t referring to the times of the Industrial Revolution. **X** includes economic, social and demographic exogenous controls. Fixed effects by location (country or region) and by year are considered. Standard errors are clustered by region/country and year to address possible heteroskedasticity and serial correlation.

However, there could be potential endogeneity between development, gender gaps in employment and fertility. Some regions in Europe that were more developed may have had strong incentives during the Industrial Revolution to improve their technology. In this sense, those regions with the highest economic development have already embarked on an early demographic transition, which also impacted in turn on economic development and gender gaps. For this reason, instrumental variables are used to analyze the possible causality and long-term persistence of the presence of non-renewable natural resources at the subnational level in Europe.

The use of instrumental variables incorporated through Two-Stage Least Squares (2SLS) Regression Analysis are used extensively in long-term persistence studies in order to identify causality between two variables, as well as to control for possible endogeneity problems. Persistence studies developed in the field of economic history provide methodologies to empirically document how certain historical phenomena or geographic factors have long-term effects on current economic performance. These studies usually focus on two types of empirical strategies (Bisin and Moro 2021). On the one hand, a body of methodologies analyzes some phenomena in the present by identifying the causal relationships between its variables based on the use of one of more instruments observed in the past (causality models on current variables, also known as apples-on-oranges models according to Voth 2021). The relationship between these historical treatments and current outcomes, given through persistence effects, is essential to achieve more convincing results on causality. On the other hand, this literature also uses a set of methodologies to document the persistence of the same variable at two distant moments in history (named as pure persistence studies, also known as apples-on-apples models according to Voth 2021). These strategies are also used to identify the transmission channels that generate the persistence of some treatment in the long term on a current variable. The following Figure 6 presents the two general strategies used by empirical models to study cultural persistence.

Figure 1. Empirical models of persistence



(a) Causality models on current variables **(b) Pure persistence models**

Source: This figure is taken from Bisin and Moro (2021), in which circles indicate variables observed by the investigator while dashed circles indicate unobserved variables. Solid arrows indicate directions of causality. Double arrows indicate endogeneity or any other factor preventing the identification of a causal effect (omitted variables, selection bias, etc.). Dashed arrows indicate potential causal links. Highlighted in red are the relationships of interest.

Both models represented in Figure 1 (a) and (b) are developed through Two-Stage Least Squares (2SLS) Regression Analysis, in which Z_{t-h} may represent an instrumental variable, X_t the explanatory variable, Y_t the outcome and P_{t-h} is a proxy of X_t. The regression models mentioned above are considered in this sections to analyze the effects of long-term determinants of natural resources on current fertility behaviors. The use of instrumental variables can provide important clues about the causality generated by the presence of natural resources, as well as the transmission channels through which the persistence can operating in societies.

The analysis will explore, on the one hand, the effect of *Historical Coal Mining* on current Total Fertility Rates by the use of Carboniferous Strata, as instrumental variable. The later variable is determined independently of the level of development in the regions of Europe, since it is exogenous in the way that the underlying geological conditions were originated in the Carboniferous Period, approximately between 270 and 350 million years ago. In this way, it is guaranteed that the relationship between historical non-renewable natural resources is not spurious. On the other hand, we use the instrumental variable approach in order to identify possible transmission channels through which the impact of natural resources can be persistent over across years. Two potential transmission channels are analyzed. The first channel would be economic development, expressed by the levels of *GDP per capita*. The second channel would be the *Gender Gap in the Employment Rate* between men and women of the age group 20-64. The estimates are proposed in two stages, using the following equations (2) and (3).

First Stage:

$$\boldsymbol{Outcome_{i\,t}} = \boldsymbol{\alpha_0} + \boldsymbol{\alpha_1 Instrumental\ variable}_{\,i\,k} + \boldsymbol{X'_{i\,t}\Psi} + \eta_i + \theta_t + \xi_{i\,t} \quad [2]$$

Second Stage:

$$\boldsymbol{Total\ Fertility\ Rate_{i\,t}} = \boldsymbol{\pi_0} + \boldsymbol{\pi_1 Predict\ Outcome_{i\,t}} + \boldsymbol{X'_{i\,t}}\sigma + \tau_i + \varphi_t + \epsilon_{i\,t} \quad [3]$$

The first stage would estimate, on the one hand, the effects of the Carboniferous Strata on Historical Coal Mining variable. This is in order to analyze causality of Historical Coal Mining variable on fertility. On the other hand, the irst stage would also estimate the effects of the Historical Coal Mining variable on GDP per capita and on the Gender Gap in the Employment Rate in order to analyze the potential transmission channels. Variable Historical Coal Mining has a high correlation with variable Carboniferous Strata. It is used also as a different variable of natural resources for the transmission channels. The second stage is represented in equation (3), which it would estimate the effects of the predicted values of the dependent variables obtained in equation (2): Historical Coal Mining, *GDP per capita* and the *Gap in the Employment Rate* on *Total Fertility Rates*. Years are expressed by t, and regions are indicated by i.

The *Historical Coal Mining* variable is considered for each region i but for a single period t = k, which refers to the times of the Industrial Revolution. The *Carboniferous Strata* variable is also considered for each region i and a single period t = k, determined approximately between 270 and 350 million years ago, when the underlying geological conditions were created. X contains the exogenous economic, social and demographic controls. In order to control the possible heterogeneity over time and regions, as well as time effects common to all regions, fixed effects for regions and years are included in equations (2) and (3). Standard errors are grouped by region and year to control the possible problems of heteroscedasticity and serial correlation.

The exclusion restriction is applied, which is generally used in the analysis of instrumental variables. This restriction indicates that a good instrument z affects the dependent variable y only through x. Therefore, the natural resources variables (*Historical Coal Mining* and *Carboniferous Strata*) by themselves would not have direct effects on fertility, but only through the two transmission channels mentioned above.

$$\boldsymbol{Fertility}_{it} = \boldsymbol{a_0} + \boldsymbol{a_1 NatResources}_{ik} + \boldsymbol{X'}_{it}\boldsymbol{\varpi} + \boldsymbol{\varrho}_i + \boldsymbol{\phi}_t + \mathbf{e}_{it} \qquad [4]$$

3.4. A first approach: a country-level analysis

At the country level, some economic, political and sociodemographic indicators suggest the existence of significant differences between resource-rich and resource-poor countries. In Table 3, those countries that have levels of *Total Natural Resource Rents* above 10 percent of their GDP, generally have lower per capita economic growth rates than the rest of the countries. These differences become evident when countries are classified based on the income levels according to the World Bank (low, lower middle, upper middle and upper income countries). The indicators on democracy also reflect enormous differences, in which the rich-resources countries have significant lags versus the rest of the countries. These preliminary results are consistent with the findings shown in several studies on the curse of natural resources, with the exception of the GDP per capita indicator, in which resource-rich countries here have higher levels.

However, there are also significant differences in some social indicators. Table 3 also shows differences in fertility, gender, levels of labor force female and life expectancy. Resource-rich countries face significant differences in fertility, where the rates of this indicator are generally higher than the rest of the countries. For instance, the high-income countries that are also rich in natural resources show an average of 2,92 in the total fertility rate during the period of 1990-2018, while in this high-income level the resource-poor countries show an average of 1,62. The same differential occurs in countries with different income levels, where significant gaps are also observed in their total fertility rates. Indicators on gender equity (GII) show that rich countries in natural resources have lags with respect to the rest of the countries, although this difference is not so wide. Differences are also observed in those indicators on the female labor force and life expectancy, in which resource-rich countries also show social lags.

Table 3. Resource-rich countries versus resource-poor countries (classified according to income level): Some economic, political and social indicators

Economic and Political Indicators								
Income Level	***Total Natural Resources Rents***		***Growth rate of GDP per capita***		***Real GDP per capita***		***Democracy***	
(World Bank Classification)	Resource-rich countries	Resource-poor countries	Resource-rich countries	Resource-poor countries	Resource-rich countries	Resource-poor countries	Resource-rich countries	Resource-poor countries
Low	14,43	2,33	1,62	1,61	711,19	711,97	0,35	0,38
Lower Middle	18,89	2,07	2,30	2,99	3078,23	2718,04	0,39	0,47
Upper Middle	18,63	1,70	1,93	2,85	9095,12	81122,67	0,45	0,71
High	29.93	0,59	0,21	1,86	46156,90	35,385,06	0,24	0,83

Social Indicators								
Income Level	***Fertility***		***Gender (GII)***		***Labor Force Female***		***Life Expectancy***	
(World Bank Classification)	Resource-rich countries	Resource-poor countries	Resource-rich countries	Resource-poor countries	Resource-rich countries	Resource-poor countries	Resource-rich countries	Resource-poor countries
Low	5,41	4,38	0,63	0,60	45,37	37,36	55,11	66,75
Lower Middle	3,77	2,65	0,58	0,49	35,90	38,36	64,23	69,55
Upper Middle	2,69	2,07	0,39	0,38	39,15	40,97	70,80	72,38
High	2,91	1,62	0,43	0,16	21,51	44,07	74,93	78,48

Note: Resource-rich countries in this table are those whose Total Natural Resources Rents (generated by oil, natural gas, coal, mineral, and forest) represent 10% or more of the country's GDP. *Democracy* indicates that countries close to 1 have better levels in this indicator. *Fertility* is documented by the Total Fertility Rates. *Gender (GII)* implies that countries close to zero have better conditions in gender equality. *Labor Force Female* represent the percentage of women that are in he job market. Resource-rich countries have significant lags also in indicators related to the digital revolution, such as the use of internet, broadband, and the use of cell phones (See the classification of countries in Table 1A in the Appendix of this Chapter 3).

Figures 2 and 3 show the associations between Total Natural Resource Rents versus Total Fertility Rates and GDP per capita, respectively, all expressed in logarithms. Figure 2 shows a positive relationship between Natural Resources Rents and Total Fertility Rates, which is the central thesis of this paper. In contrast, Figure 3 shows a negative relationship between Natural Resources Rents and GDP per capita, as has been documented by the literature on the curse of natural resources. However, natural resources would also be associated negatively with *Female Labor Force Participation* (Figure 4) and positively with the *Gender Inequality Index* -GII- (Figure 5). It would appear that both gender indicators are affected by Natural Resource Rents.

Figure 2 ***Resources Rents and Fertility***

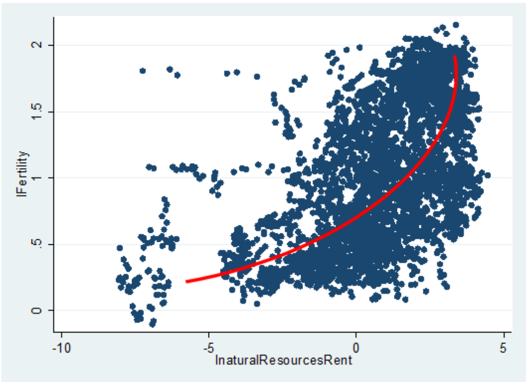


Figure 3 ***Resources Rents and GDP per capita***

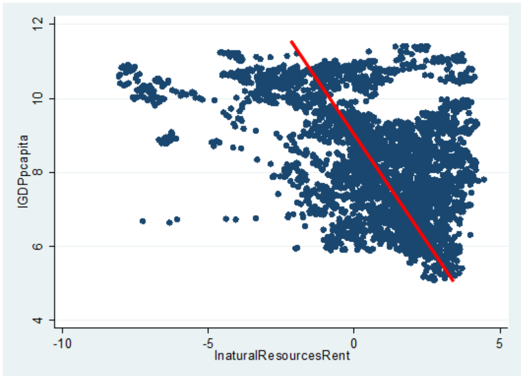


Figure 4 ***Resources Rents and Female Labor Force Participation***

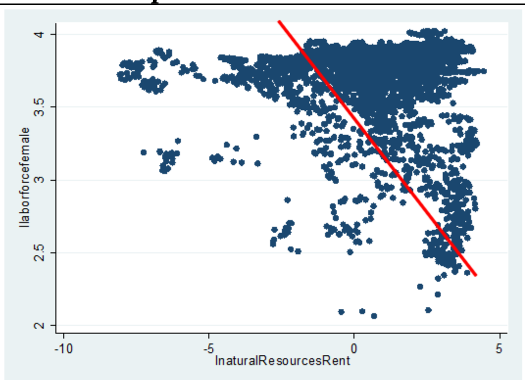
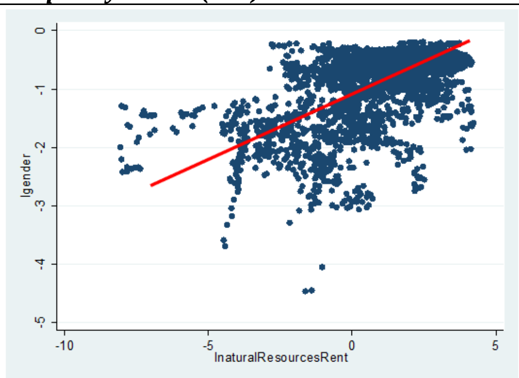


Figure 5 ***Resources Rents and Gender Inequality Index (GII)***



Note: All variables are expressed in logarithms. The Gender Inequality Index (GII) variable indicates that the higher the levels of this index, the greater the gender inequality.

A more formal analysis is provided at the country level, through 4 different estimates shown in Table 4. Logarithms are used for the variables of *Total Fertility Rate* and *Total Natural Resources Rents*. Estimates of the model (1) are made with Ordinary Least Squares (OLS), using the *Total Natural Resources Rents*, expressed in percentages of GDP, as a explanatory variable. Model (3) applies the same OLS methodology, but uses the logarithm of the *Total Natural Resource Rents* variable as the explanatory variable. Models (2) and (4) use a data panel method, where both year and country fixed effects are considered. Models (1) and (2), uses the *Total Natural Resource Rents* expressed as a percentage of GDP as focal explanatory variable, while models (3) and (4) use the logarithms of said variable.

The four estimates show that the *Total Natural Resources Rents* have significant effects on the *Total Fertility Rates*, whose relationship is positive. The higher the *Total Natural Resources Rents*, the higher the *Total Fertility Rates*. This positive and significant association is also observed through the effects generated by *Gender Inequality* (GII) and the *Gender Unemployment Gap*. These preliminary regressions aim to show a possible association between the presence of natural resources and fertility rates. However, it is important to also have a causality analysis, in which even the transmission channels through which these effects operate can be identified. This issue will be addressed in the next section. Considering the expressions in logarithms of the models (3) and (4), a 1 percent change in *Total Natural Resources Rents* (expressed in terms of the percentage of a country's GDP) has a positive effect between 0.7 and 0.9 percent on the *Total Fertility Rates*. Therefore, if a country increases its *Total Natural Resources Rents* by 10 percent, its *Total Fertility Rates* would be expected to increase by 9 percent.

Table 4: Main Results, a country-level analysis

	(1)	(2)	(3)	(4)
Outcome: *log Total Fertility Rate*	**OLS**	**Panel**	**OLS**	**Panel**
Total Natural Resources Rents	0.00801***	0.00392***		
	(0.000)	(0.007)		
Log Total Natural Resources Rents			0.00710***	0.00943***
			(0.002)	(0.009)
GDP per capita	0.00002***	0.00004***	8.71e-06***	0.00001***
	(0.000)	(0.000)	(0.000)	(0.000)
Gender Gap in Employment	0.01825***	-0.02502***	0.00512***	-0.00540***
	(0.000)	(0.000)	(0.000)	(0.000)
Gender Inequality (GII)	0.33363*	0.37437**	0.19384***	0.18639***
	(0.095)	(0.018)	(0.000)	(0.007)
Total Unemployment	-0.01963***	-0.00228	-0.00315***	-0.00091
	(0.000)	(0.352)	(0.000)	(0.405)
Uncertainty	-0.30256***	0.10159*	-0.04045***	0.03260***
	(0.002)	(0.051)	(0.117)	(0.032)
Median age	-0.09769***	0.02189***	-0.04620	-0.01286***
	(0.000)	(0.001)	(0.000)	(0.000)
Income class country	-0.24815***	-1.19399***	-0.05693***	-0.24445***
	(0.000)	(0.000)	(0.000)	(0.000)
Labor Force Female	-0.00320	-0.01038*	0.00031	-0.00809***
	(0.190)	(0.075)	(0.542)	(0.000)
Life expectancy	-0.08304***	-0.03779***	-0.01462***	-0.00890***
	(0.000)	(0.000)	(0.000)	(0.000)
Democracy	0.89815***	-0.14134	0.20019***	-0.03124
	(0.000)	(0.183)	(0.000)	(0.271)
Constant	11.25530***	9.47274***	3.07034***	2.84412***
	(0.000)	(0.000)	(0.000)	(0.000)
Countries	142	142	142	142
Observations	2111	2111	2111	2111
R-squared	0.8591		0.9060	
R-sq: within		0.9860		0.9832
R-sq: between		0.7851		0.9300
R-sq: overall		0.9753		0.9810
Year Fixed Effects		*Yes*		*Yes*
Country Fixed Effects		*Yes*		*Yes*

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Robust standard errors in italics

Note: Table 4 reports OLS and Panel regressions (with year and country fixed effects) of Total Fertility Rate (in logarithms) and Total Natural Resources Rents (expressed in both levels and logarithms). Natural Resources Rents is significant and positively associated (the greater the presence of natural resources, the higher the fertility rates). Likewise, additional covariates are added, of which two are relevant for our analysis: GDP per capita and Gender Gap in Employment. The possible transmission channels raised in this paper are development and gender gap in labor market. Table 4 shows that both the GDP per capita and gender gap in employment are significantly solid. Likewise, unemployment levels, uncertainty, the income class country, as well as those variables that reflect the demographic transition of each country, such as median age and life expectancy, are also significant.

The four estimates in Table 4 show that the *Total Natural Resources Rents* have significant effects on the *Total Fertility Rates*, whose relationship is positive. The higher the *Total Natural Resources Rents*, the higher the *Total Fertility Rates*. This positive and significant association is a first approximation of our analysis. However, there could be certain biases related to the phase that countries experience with respect to their demographic transition. Therefore, it is appropriate to carry out in the analysis a division of the countries according to the phase of the demographic transition. The classification of countries developed in Chapter 1 is taken as a reference, in which two sets of countries are taken. On the one hand, there are the countries that in 1960 were advanced or that were starting a late expanding phase in their demographic transition, while on the other hand, there are the countries that were not advanced or were in an early expansion in their demographic transition. Taking into consideration the models used in Table 4, a dummy variable is added which classifies the countries according to their demographic transition ("Demographic Transition").

The results of this new analysis are shown in Table 4 BIS. It is observed that the results provided in Table 4 BIS for the 4 models do not differ significantly from those obtained in Table 4. By adding the variable "Demographic Transition", it is hold that the presence of non-renewable natural resources, expressed through of the indicator "Total Natural Resources Rents", is still significant and positive in terms of its relationship with total fertility rates. Thus, the results given in Table 4 are robust. It is concluded, as a first approach of our analysis at the country level, that non-renewable natural resources have effects on total fertility rates. The presence of natural resources slows down the demographic transition process, generating higher fertility rates.

Table 4 BIS: Main Results, a country-level analysis

	(1)	(2)	(3)	(4)
Outcome: *log Total Fertility Rate*	**OLS**	**Panel**	**OLS**	**Panel**
Total Natural Resources Rents	0.00841***	0.00392***		
	(0.000)	(0.007)		
Log Total Natural Resources Rents			0.00700***	0.00943***
			(0.002)	(0.009)
Demographic Transition	-0.14328***	3.69720***	0.03621***	-0.34564***
	(0.001)	(0.000)	(0.002)	(0.002)
GDP per capita	0.00002***	0.00004***	8.60e-06***	0.00001***
	(0.000)	(0.000)	(0.000)	(0.000)
Gender Gap in Employment	0.01812***	-0.02502***	0.00515***	-0.00540***
	(0.000)	(0.000)	(0.000)	(0.000)
Gender Inequality (GII)	0.31353	0.37437**	0.19830***	0.18639***
	(0.113)	(0.018)	(0.000)	(0.007)
Total Unemployment	-0.01919***	-0.00228	-0.00327***	-0.00091
	(0.000)	(0.352)	(0.000)	(0.405)
Uncertainty	-0.29892***	0.10159*	-0.04124***	0.03260***
	(0.002)	(0.051)	(0.110)	(0.032)
Median age	-0.10280***	0.02189***	-0.04488	-0.01286***
	(0.000)	(0.001)	(0.000)	(0.000)
Income class country	-0.25896***	-1.20764***	-0.05460***	-0.60558***
	(0.000)	(0.000)	(0.000)	(0.000)
Labor Force Female	-0.00390	-0.01038*	0.00049	-0.00809***
	(0.109)	(0.075)	(0.347)	(0.000)
Life expectancy	-0.08327***	-0.03779***	-0.01455***	-0.00890***
	(0.000)	(0.000)	(0.000)	(0.000)
Democracy	0.85115***	-0.14134	0.21399***	-0.03124
	(0.000)	(0.183)	(0.000)	(0.271)
Constant	11.5716***	5.78918***	2.98822***	3.55089 ***
	(0.000)	(0.000)	(0.000)	(0.000)
Countries	142	142	142	142
Observations	2111	2111	2111	2111
R-squared	0.8596		0.9064	
R-sq: within		0.9860		0.9832
R-sq: between		0.7851		0.9300
R-sq: overall		0.9753		0.9810
Year Fixed Effects		*Yes*		*Yes*
Country Fixed Effects		*Yes*		*Yes*

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Robust standard errors in italics

Note: Table 4 BIS reports OLS and Panel regressions (with year and country fixed effects) of Total Fertility Rate (in logarithms) and Total Natural Resources Rents (expressed in both levels and logarithms). It is used a new control variable "Demographic Transition". Natural Resources Rents is significant and positively associated (the greater the presence of natural resources, the higher the fertility rates). Table 4 shows that both the GDP per capita and gender gap in employment are significant. Unemployment levels, uncertainty, the income class country, as well as those variables that reflect the demographic transition of each country are also significant.

3.5. Long-term effects and transmission channels

This work proposes that, although non-renewable natural resources have effects on some social variables related to family change, these effects could also have a significant persistence in the long term. Some recent works have already indicated that these types of resources have very long effects overt time on some outcomes such as economic growth, political preferences, and male higher education levels (Fernihough and O'Rourke 2014; Abramson and Esposito 2020). Therefore, it would not seem strange that these long-term effects also impact the social variables related to family change. If the transmission channels that affect fertility show long-term persistence, for example levels of development, the impacts of natural resources would then also affect demographic and social variables. To address the analysis of persistence in fertility, I use historical information on coal mines, dating back to the Industrial Revolution in Europe. A panel regression is undertaken, at the sub-national level considering the European NUT2 regions. The main independent variables are *Historical Coal Mining* and *Carboniferous Strata*, which represent the abundance of non-renewable natural resources. Both year fixed effects and country fixed effects are used, and some other controls are considered.

Table 5 presents the results, which seem to confirm what is proposed in this paper. Non-renewable natural resources have long-term effects on fertility rates. The higher levels of extraction of natural resources during the period of the Industrial Revolution, the higher current fertility rates.

Table 5: Fertility and Natural Resources, Subnational-level analysis

	(1)	(2)	(3)
Outcome: *log Total Fertility Rate*			
Log Historical Coal Mining	0.20730***	0.06515	0.19838***
	(0.000)	(0.245)	(0.000)
Log GDP per capita		0.11969**	
		(0.041)	
Log Gap Gender Employment			-0.00361
			(0.510)
Labor force female	-0.02355***	-0.02347***	-0.03062***
	(0.003)	(0.002)	(0.001)
Uncertainty	-0.03474	-0.04132	-0.03093
	(0.180)	(0.155)	(0.274)
Median age	0.05131***	0.04714***	0.05927***
	(0.000)	(0.000)	(0.000)
Democracy	-0.08922	-0.0207	-0.11450
	(0.295)	(0.789)	(0.157)
Income class country	-0.54434***	-0.33778***	-0.53154***
	(0.000)	(0.006)	(0.000)
Life expectancy	0.00191	-0.00731	-0.00555
	(0.864)	(0.567)	(0.620)
Population 15-64 age	0.02475***	0.02240***	0.02912***
	(0.002)	(0.002)	(0.005)
Broadband internet	0.00038	0.00097	0.00098
	(0.698)	(0.563)	(0.415)
Total Unemployment	-0.00716***	-0.00499***	-0.00905***
	(0.001)	(0.020)	(0.000)
Constant	-0.81286	-1.6154**	-0.54213
	(0.238)	(0.047)	(0.470)
Subnational Regions	311	311	311
Observations	2818	2635	2559
R-sq: within	0.9688	0.9678	0.9718
R-sq: between	0.3310	0.5468	0.0520
R-sq: overall	0.9613	0.9590	0.9652
Year Fixed Effects	*Yes*	*Yes*	*Yes*
Country Fixed Effects	*Yes*	*Yes*	*Yes*

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Robust standard errors in italics

Note: The table 5 reports regressions with year and country fixed effects of Total Fertility Rate at subnational level and Historical Coal Mining. Model (1) indicates that the historical presence of natural resources positively impacts current fertility rates. The estimator is significant and positively associated (the greater the presence of historical natural resources, the higher the current fertility rates). Models (2) and (3) consider the GDP per capita and Gap Gender Employment variables, respectively, which are proposed as the transmission channels through which natural resources impact fertility rates (all expressed in logarithms).

In Table 5, model (1), the variables representing both potential transmission channels (Log GDP per capita and Log Gap Gender Employment) are excluded. In this first model, the variable Log Historical Coal Mining has significant and positively associated effects with total fertility rates. However, when the Log GDP per capita variable is added in model (2), the Log Historical Coal Mining variable is no longer significant. This would indicate that the variable Log GDP per capita could represent a solid transmission channel on fertility, since when included in model (2), natural resources no longer have a direct influence on fertility. In model (3) the variable Log Gap Gender Employment is evaluated as a transmission channel. In this case, it is observed that the Log Historical Coal Mining variable continues to be significant, and positively associated. Comparing with model (1), the estimator was just slightly modified. This would indicate that the transmission channel related to gender gaps in the labor market is not strong enough compared to the channel related to development. However, when both transmission channels operate simultaneously, the effects of the Log Historical Coal Mining variable also cease to be significant. In this sense, the combination of both transmission mechanisms could be valid. This evaluation is basically a first approach to analyze the effects of historical non-renewal natural resources on fertility rates.

A more formal analysis uses the source of exogenous variation given by the differences in the underlying geological conditions that generate the exploitation of coal in Europe at the time of the Industrial Revolution, following some works in the literature (Furstenberg and O'Rourke 2014; Scott and Esposito 2019, 2020). Based on this exogenous endowment differentiated between the regions of Europe, the transmission channels on fertility are analyzed. By exploiting this instrumental variable, the problem of endogeneity between the extraction activities of natural resources and the levels of development is addressed, given that the presence of coal mines and industrial agglomerations were not determined randomly. The presence of carboniferous geological deposits could determine the location and exploitation of the coal mines, given the high transportation costs in the exploitation of coal as an energy source, prior to the construction of the railways. Therefore, these carboniferous geological deposits are used as a source of exogenous variation between subsequent economic development and fertility behaviors. On the other hand, gender opportunities in the labor market are proposed as a second driving mechanism through which natural resources can influence fertility rates. The potential relationship between female labor-force participation and fertility is addressed also by the use of historical and instrumental variables. The long-term effects of natural resources on contemporary fertility patterns play a central role in this analysis.

To challenge the potential problem of endogeneity, and through a Two-Stage Least Squares (2SLS) Regression Analysis expressed by equations (2) and (3), "Carboniferous Strata" is used as an instrumental variable, which is obtained from Abramson and Esposito (2019). This indicator is exogenous and considers the underlying geological conditions originated in the carboniferous period (approximately between 270 and 350 million years ago). The results are shown in the Table 6.

Table 6: Total Fertility Rate and Historical Coal Mining, 2SLS estimates

Outcome: *Total Fertility Rate*	**(1)**	**(2)**
Log Historical Coal Mining (predict)	0.5188711***	0.3565752***
	(0.000)	(0.000)
Log GDP per capita	0.1238432*	
	(0.058)	
Uncertainty	-0.0458824	-0.0391089
	(0.136)	(0.155)
Median age	0.0379887***	0.0420899***
	(0.000)	(0.000)
Democracy	0.2164196**	0.1451445
	(0.013)	(0.107)
Income class country	-0.5874335***	-0.7013391***
	(0.000)	(0.000)
Life expectancy	0.0002049	0.0097868
	(0.986)	(0.373)
Population 15-64 age	0.0203119***	0.0229614***
	(0.005)	(0.004)
Broadband internet	0.0014357	0.0008069
	(0.369)	(0.411)
Total Unemployment	-0.0068433***	-0.0090837***
	(0.006)	(0.001)
Constant	-2.63073***	-1.711751**
	(0.004)	(0.016)
Sub-regions	311	311
R-sq: within	0.9664	0.9675
R-sq: between	0.4967	0.2746
R-sq: overall	0.9524	0.9552
Year Fixed Effects	Yes	Yes
Sub-regions Fixed Effects	Yes	Yes
First Stage		
Dependent Variable: Log Historical Coal Mining		
Carboniferous Strata	0.6131472 ***	0.3020626***
	(0.000)	(0.000)
Reduced Form		
Dependent Variable: Total Fertility Rate		
Carboniferous Strata	-1.165396***	0.1452919**
	(0.000)	(0.023)

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Robust standard errors in italics

Note: Table 6 reports the main results of the 2SLS estimates. In the First Stage, it is observed that the instrumental variable *Carboniferous Strata* is significant and has positive effects on Historical Coal Mining. Likewise, in the reduced form, the instrumental variable is significant on the current fertility rates. In the Second Stage, the predicted value of *Historical Coal Mining*, obtained based on the results of the First Stage, is also significant and has positive effects on the *Total Fertility Rate*.

The model (1) in Table 6 indicates that the historical presence of non-renewal natural resources positively impacts current fertility rates, since its estimator is significant and positively associated. This means that the higher levels of extraction of natural resources during the Industrial Revolution, the higher the current fertility rates. In model (2) of Table 6, the impact of the presence of historic coal mines on current total fertility rates is significant and positive, even excluding the GDP per capita variable (in logarithms), so the result is robust. By considering an instrumental variable exogenous to economic development during the times of the Industrial Revolution, the possible endogeneity between economic development and the presence of historic coal mines in those years is controlled, given the possibility that certain initial conditions in some regions of Europe had influenced current economic development. Furthermore, highly developed regions of Europe have also shown higher fertility rates since the 1990s. Therefore, through use of an instrumental variable, as well as controlling by means of the GDP per capita, that possibility of having a spurious relationship is controlled.

To address the identification of possible channels of persistence, through which non-renewable natural resources impact current fertility rates, it is also used the methodology related to instrumental variables. As I mentioned above, there are two transmission channels are proposed. On the one hand, development conditions are considered as the first transmission channel. The resource curse could affect, in a first stage, the economic development of a society, whose impacts would modify family decision-making and alter fertility patterns. On the other hand, the second transmission channel would be the impacts on female participation in the labor force. The presence of fossil fuels and minerals, as well as extractive industries related to natural resources, can alter female participation in the labor force, promoting greater masculinization in job opportunities (Ross 2018; Shepard, Betz and Snyder 2019), and it would lead to a widening of gender gaps, modifying fertility behaviors. Both transmission channels could be operating simultaneously. This idea is tested in the following Table 7:

Table 7: Transmission Channels of the effects of Historical Coal Mining on current Total Fertility Rates, 2SLS estimates

Outcome: *Total Fertility Rate*	**(1)**	**(2)**
Log GDP per capita (predict)	0.0883885*** (0.000)	
Log Gender Gap Employment (Predict)		0.2964715*** (0.000)
Controls: Demographic, Economic, Social, Technological, and political	Yes	Yes
Sub-regions	311	311
Year Fixed Effects	Yes	Yes
Sub-regions Fixed Effects	Yes	Yes
First Stage		
Outcome	*Log GDP per capita*	*Log Gender Gap Employment*
Log Historical Coal Mining	-0.1311142 *** (0.001)	0.6202522 *** (0.000)

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Robust standard errors in italics

Note: Table 7 reports the main results of the 2SLS estimates. In the First Stage, the instrumental variable *Historical Coal Mining* is significant and has positive effects on development and gender gap. In the Second Stage, the predicted value of *GDP per capita* and *Gender Gap Employment* are also significant and has positive effects on the Total Fertility Rate.

Table 7 indicates that the Log Historical Coal Mining and Log Carboniferous Strata variables are relevant, given that they are significant to explain their effects on the Log GDP per capita and Log Gap Gender Employment variables respectively. In this table also is shown the effects of the two transmission channels proposed in this work. In the first stage it is observed that the effects of the Historical Coal Mining on the logarithmic GDP per capita are significant and show a negative relationship. The same occurs with the Carboniferous Strata variable, whose effects on Log Gap Gender Employment are also significant and its relationship is negative. Therefore, it could be anticipated that the presence of non-renewable natural resources could ultimately increase total fertility rates. This, given that a greater endowment of natural resources implies changes in GDP per capita (consistent with the literature on the curse of natural resources). This decrease in GDP per capita ends up increasing total fertility rates. On the other hand, analyzing the second transmission channel, it is observed that natural resources could also have a positive effect on total fertility rates. Considering the results of Table 7, it is confirmed that the greater the gaps in female unemployment and the higher the level of GDP per capita, the higher the levels of total fertility rates. Both transmission channels of the effect of natural resources on fertility are indirect.

In model (1) of the second stage regression, the 1 percent increase in GDP per capita, derived from a variation produced by the increase in the Historical Coal Mining variable, results in an increase of almost 0.09 in total fertility rates, keeping the rest of the variables unchanged. Likewise, model (2) indicates that when there is a 1 percent increase in the Gap Gender Employment, produced by a variation in the Carboniferous Strata variable, it results in an increase in the total fertility rate of 0.29.

3.6. Concluding discussion

This Chapter 3 proposed the existence of a "social curse" derived from the presence of non-renewable natural resources, which affects family change and fertility patterns. The presence of natural resources is highly associated with higher fertility rates . In addition, the long-term effects and persistence of this “social curse” are highlighted in the results provided by this paper, in which the presence of historic coal mines, dating back to the Industrial Revolution in Europe, is associated with current fertility behaviors. In this sense, the effects of natural resources could be transmitted from generation to generation. To analyze this, further studies will be required. However, this paper argues that natural resources could modify job opportunities to the detriment of women, since extractive industries are highly demanding of male labor. Furthermore, the possible market effects derived from the presence of natural resources could also affect those sectors that are intensive in female labor, as is the case of manufacturing.

A clue to explore in future research could be on the persistence of certain extractive industries, which are generally established for long periods in a region, which may generate patterns of path dependency (Krugman 1991a, 1991b). This could generate new patterns and social norms which could be transmitted over the long term across generations. Some recent works in the literature have already pointed out this cultural persistence on gender roles whose effects have been transmitted over several generations (e.g. Alesina, Giuliano and Nunn 2013).

Family change theories could contribute significantly to explain the heterogeneity in fertility rates derived from the presence of non-renewable natural resources and their persistent effects in the long term. Socioeconomic development stands out as a fundamental determinant of fertility (Becker 1960, 1981; Becker and Barro 1988; Barro and Becker 1989; Becker, Murphy and Tamura 1990; Thornton 2001, 2005; Boldrin and Jones 2002; Myrskylä, Kohler and Billari 2009; Browning, Chiappori and Weiss 2014; Chiappori, Salanié and Weiss 2017; Chiappori, Pierre-André 2020). However, this body of literature shows that fertility trends change because socioeconomic transformations provide new incentives for family change. However, higher levels of development will not necessarily explain an earlier fertility transition. If the highest level of development has been generated by the presence of non-renewable natural resources, we could observe a reversal in gender aspects that could portray the family change and the fertility transition.

Sociodemographic theories point to the diffusion of ideas that influence on fertility linked to high levels of development, such as the second demographic transition (Lesthaeghe and van de Kaa 1986; van de Kaa 1987; Lesthaeghe and Surkyn 1988; Lesthaeghe 2010, 2014, 2020) and development idealism (Thornton 2001, 2005; Thornton, Dorius and Swindle 2015) could also consider the effects of the presence of natural resources. The presence of a social curse could also influence the diffusion of ideational factors that promote change family and fertility

How would non-renewable natural resources, such as the presence of coal mines during the industrial revolution, affect current fertility rates? What would be the mechanisms through which these demographic dynamics emerge and are transmitted across generations? A first channel could be economic development . A second channel could be the labor market, where the presence of non-renewable natural resources could trigger a process of labor masculinization, which could affect the gender gap, as well as certain family domains and fertility rates. Following the Theory of Conjunctural Action, an unexpected endowment of non-renewable natural resources would modify the material aspects in a social structure, in a first stage, so that the equilibrium of the incumbent family behavior would enter a period of disturbance. Job opportunities for women would be significantly reduced by the masculinization process related to natural resources . Subsequently, the schemes on gender roles would be modified, thus transmitting to future generations the new family behaviors (path dependence) that would impact future fertility rates.

The presence of non-renewable natural resources could imply important effects in some family domains, such as gender roles conditions. These effects can be persistent as new schemes emerge and are transmitted across generations. According to the Theory of Conjunctural Action (Johnson-Hanks et al 2011), social structures, given by schemas and materials, can be altered by transformative events, leaving long-term effects on family behaviors. According to this theory, when a new schema or material suddenly becomes available (in this case an exogenous and unexpected endowment of coal resources that would represent a material change), disturbances emerge that lead to altering the equilibrium in the incumbent family behavior. This disturbance opens conjunctures to provide two or more alternative possible futures of family behaviors, which finally are closed when the path forward again becomes unambiguous. The interdependence of the new schemes and materials that derive from these conjunctures provides self-reinforcing mechanisms, resulting in the emergence of a new social structure which generates inertia and continuities in future family behaviors.

The results on these effects of non-renewable natural resources on fertility could contribute to the literature on family change, in three different ways. First, the association of natural resources and family change has not been extensively studied in sociology, demography, and economics. This contrasts with the vast literature in the fields of development and political economics, which highlights the existence of a "natural resource curse" that holds that resource-rich countries tend to grow more slowly than resource-poor countries (Sachs and Warner 1995, 1997, 1999ab, 2001). Therefore, it is proposed the existence of a "Social Curse of Natural Resources" which implies important effects of such resources in current fertility trends. Second, it is proposed that economic development would not necessarily result in a more equal gender transformation. Usually, theories about the transformation of gender relations (McDonald 2000a, 2000b; Esping-Andersen and Billari 2015; Goldscheider et. Al. 2015) have embedded the evolutionary idea that economic development is associated with gender equality. These theories do not support the idea that, in certain situations, there may be a negative association between both variables, nor that there is the possibility of having reversals in terms of gender. Third, the core argument of this paper is that the effects of certain events that occurred in the past can affect current fertility patterns by generating dynamics of path dependence in the long term, which lead to certain family behaviors be more persistent.

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Annex to Chapter 1

Club Fertility Convergence

Division of the countries into two sets

I carry out a division of the countries according to the fertility level in 1960, as well as considering other determinants that indicate the differences in the stages of demographic transition among countries. In particular, I divide the 190 countries analyzed in this chapter into two groups according to their fertility level in 1960, as well as to consider other indicators related to the degree of demographic transition (such as mortality rates and the gap between mortality and fertility rates). On the one hand, there are 71 countries that were in advanced stages of the demographic transition, or were vigorously initiating said transition, which is reflected in low mortality rates and significant drops in fertility. On the other hand, there is a second set of 119 countries, that were still in the very early stages of the demographic transition, characterized by high levels of fertility, high levels of mortality, and whose dynamics of both indicators do not clearly reflect a vigorous decline in 1960 or later.

First, the countries that have shown low mortality rates in 1960 are selected, considering a threshold lower than 13.5 deaths per 1,000 people (Crude Death Rate). This threshold is considered after a review of various countries in that year, which showed that they were in a very advanced stage in the demographic transition, or that their fertility dynamics were clearly downward. For example, Belgium had a Crude Death Rate of 12.4, Luxembourg with 11.8, or France with 11.4. These countries include all those developed in 1960, but also those countries that were part of the Soviet Union or Eastern Europe, such as Russia with 8.3, Estonia with 10.5, or Romania with 8.7. Some developing countries were also included, such as Paraguay with a Crude Death Rate of 8.23, Malaysia with 10.47 or Mexico with 12.27.

Secondly, it is considered as part of the group of countries with an advanced demographic transition or in a late-expanding phase, those that, although they have shown high fertility rates (even those that had a crude birth rate greater than 40 per cent). 1000 people), these countries showed a very clear decline in the years after 1960 and had low rates of Crude Death Rate (below 13.5). For instance, Brazil had high fertility rates in 1960 (42.28 in its crude fertility rate). However, this country had low Mortality rates (13.15 in its Gross Mortality Rate) and observed clear trajectories of decrease in its fertility. , as shown in the following Figures 1A and 2A. Another country in the same case would be Thailand, which had a Crude Mortality Rate of 13.18 and a Crude Fertility Rate of 42.73, but which in subsequent years observed a considerable and sustained drop in this last indicator.

The following Figures 1A and 2A show the behaviors in the falls of the Crude Fertility Rate for both countries.

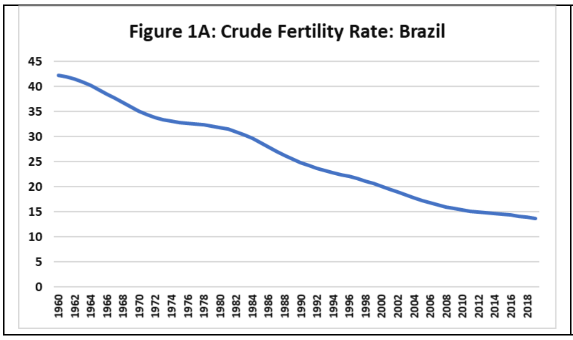


Figure 1A: Crude Fertility Rate: Brazil

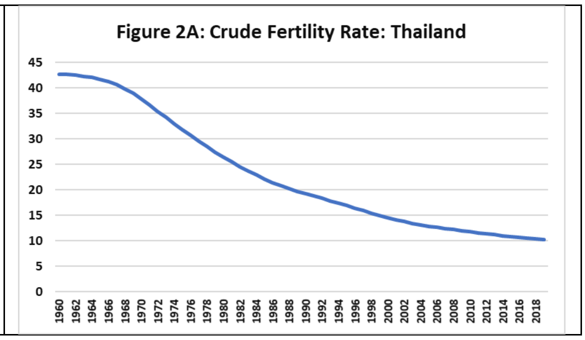


Figure 2A: Crude Fertility Rate: Thailand

This would not be the case of Israel or Iraq, countries where the dynamics of the Crude Fertility Rate is not considerably decreasing in the years after 1960. As observed in the following Figures 3A and 4A, the dynamics of the Crude Rates Fertility rates are ascending in years after 1960 and when these rates are reversed, the falls are not abrupt.

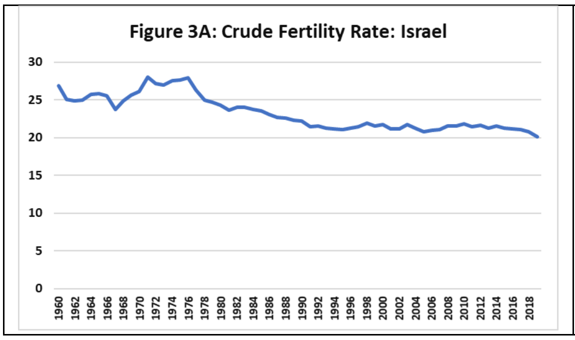


Figure 3A: Crude Fertility Rate: Israel

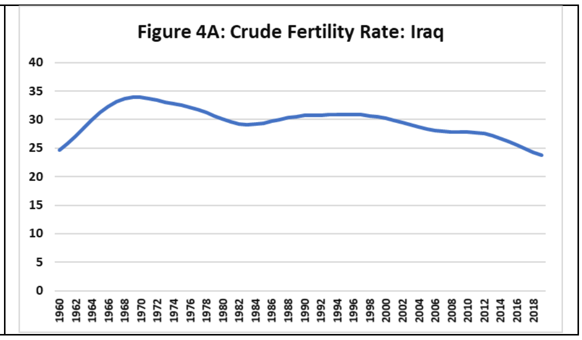


Figure 4A: Crude Fertility Rate: Iraq

Finally, the dynamic that occurs between the difference between the Crude Fertility Rate and the Crude Mortality Rate is considered as an indicator of the demographic transition. When a country observes a trajectory composed only of decreasing rates in this indicator in subsequent years to 1960, we consider that that country has a vigorous demographic transition.

For instance, this would be the case of Brazil, where it is observed that the difference between the Crude Fertility Rate and the Crude Mortality Rate has a persistent fall in the years after 1960 (see Figure 5A). On the contrary, when a country observes that in subsequent years of 1960, the difference between the Gross Fertility Rate and the Gross Mortality Rate maintains a non-decreasing dynamic, it is considered that this country is just beginning its demographic transition process. This would the case of Iran (see Figure 6A), where this indicator has a non-decreasing dynamic after 1960.

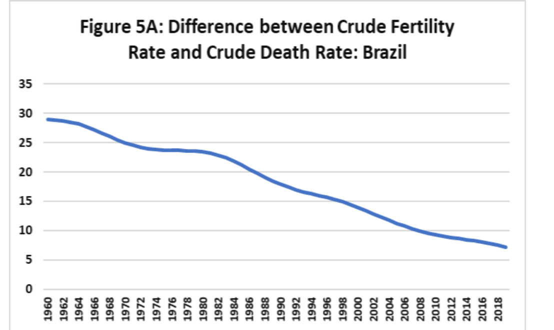


Figure 5A: Difference between Crude Fertility Rate and Crude Death Rate: Brazil

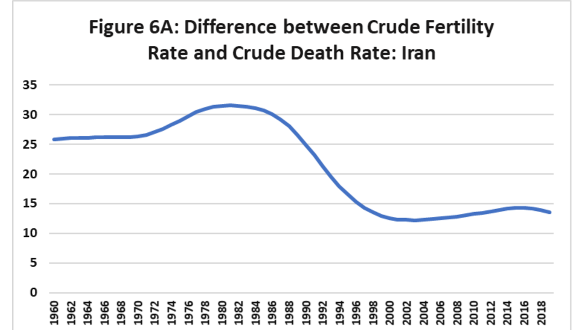


Figure 6A: Difference between Crude Fertility Rate and Crude Death Rate: Iran

When a country that meets low mortality rates in 1960 (less than 13.5 in its crude mortality rates), or has a decreasing and sustained dynamics in its crude fertility rates in the years immediately after 1960, or the difference between the crude fertility rate and crude mortality rate is decreasing, we would consider this country within the set of "countries with late-expanding or advanced demographic transitions in 1960". Otherwise, when a country does not meet any of the 3 aforementioned assumptions, that is, if said country has either high mortality rates in 1960, or non-decreasing crude fertility rates in the years immediately after 1960, or the difference between the crude fertility rate and the crude mortality rate is not decreasing in years after 1960, we consider that this country must be found in the set of "countries with early-expanding or not-advanced demographic transitions in 1960".

The following Table 1A lists the countries according to their stage of the demographic transition in which they were in 1960.

Countries with late-expanding or advanced demographic transitions in 1960			
Country	Crude Death rate (per 1,000 people) in 1960	Trend of the Crude Birth rate (per 1,000 people) in the years after 1960	Trend of the Difference between Crude Birth rate and Crude Death rate in the years after 1960
Aruba	6,388	Decreasing	Decreasing
Albania	11,326	Decreasing	Decreasing
Argentina	8,567	Decreasing	Decreasing
Armenia	9,646	Decreasing	Decreasing
Australia	8,6	Decreasing	Decreasing
Austria	12,7	Decreasing	Decreasing
Azerbaijan	12,83	Decreasing	Decreasing
Belgium	12,4	Decreasing	Decreasing
Bulgaria	8,1	Decreasing	Decreasing
Bahamas, The	7,274	Decreasing	Decreasing
Bosnia and Herzegovina	9,656	Decreasing	Decreasing
Belarus	9,918	Decreasing	Decreasing
Brazil	13,353	Decreasing	Decreasing
Barbados	10,826	Decreasing	Decreasing
Canada	7,8	Decreasing	Decreasing
Switzerland	9,8	Decreasing	Decreasing
Channel Islands	12,157	Decreasing	Decreasing
Chile	11,498	Decreasing	Decreasing
Colombia	11,666	Decreasing	Decreasing
Costa Rica	10,229	Decreasing	Decreasing
Cyprus	7,506	Decreasing	Decreasing
Czech Republic	9,8	Decreasing	Decreasing
Germany	12	Decreasing	Decreasing
Denmark	9,5	Decreasing	Decreasing
Spain	8,6	Decreasing	Decreasing
Estonia	10,5	Decreasing	Decreasing
Finland	9	Decreasing	Decreasing
France	11,4	Decreasing	Decreasing
United Kingdom	11,5	Decreasing	Decreasing
Georgia	12,402	Decreasing	Decreasing
Greece	7,3	Decreasing	Decreasing
Hong Kong SAR, China	5,966	Decreasing	Decreasing
Croatia	10	Decreasing	Decreasing
Hungary	10,2	Decreasing	Decreasing
Ireland	11,5	Decreasing	Decreasing
Iceland	6,6	Decreasing	Decreasing
Italy	9,6	Decreasing	Decreasing
Japan	7,6	Decreasing	Decreasing
Korea, Rep.	12,622	Decreasing	Decreasing

Lebanon	10,467	Decreasing	Decreasing
Lithuania	7,8	Decreasing	Decreasing
Luxembourg	11,8	Decreasing	Decreasing
Latvia	10	Decreasing	Decreasing
Macao SAR, China	8,65	Decreasing	Decreasing
Moldova	11,646	Decreasing	Decreasing
Mexico	12,27	Decreasing	Decreasing
North Macedonia	10,58	Decreasing	Decreasing
Malta	8,6	Decreasing	Decreasing
Montenegro	9,9	Decreasing	Decreasing
Malaysia	10,477	Decreasing	Decreasing
Netherlands	7,6	Decreasing	Decreasing
Norway	9,1	Decreasing	Decreasing
New Zealand	8,8	Decreasing	Decreasing
Philippines	9,692	Decreasing	Decreasing
Poland	7,6	Decreasing	Decreasing
Puerto Rico	6,7	Decreasing	Decreasing
Korea, Dem. People's Rep.	13,165	Decreasing	Decreasing
Portugal	10,7	Decreasing	Decreasing
Paraguay	8,23	Decreasing	Decreasing
French Polynesia	11,001	Decreasing	Decreasing
Romania	8,7	Decreasing	Decreasing
Russian Federation	8,304	Decreasing	Decreasing
Singapore	6,2	Decreasing	Decreasing
Slovak Republic	7,8	Decreasing	Decreasing
Slovenia	9,6	Decreasing	Decreasing
Sweden	10	Decreasing	Decreasing
Thailand	13,18	Decreasing	Decreasing
Ukraine	8,675	Decreasing	Decreasing
Uruguay	9,735	Decreasing	Decreasing
United States	9,5	Decreasing	Decreasing
Venezuela, RB	9,481	Decreasing	Decreasing

Countries with early-expanding or not-advanced demographic transitions in 1960

Country	Crude Death rate (per 1,000 people) in 1960	Trend of the Crude Birth rate (per 1,000 people) in the years after 1960	Trend of the Difference between Crude Birth rate and Crude Death rate in the years after 1960
Afghanistan	32,219	Not declining	Not declining
Angola	27,097	Not declining	Not declining
United Arab Emirates	15,714	Decreasing	Not declining
Antigua and Barbuda	9,643	Not declining	Not declining
Burundi	23,226	Not declining	Not declining
Benin	28,847	Not declining	Not declining
Burkina Faso	28,562	Not declining	Not declining

Bangladesh	20,324	Not declining	Not declining
Bahrain	14,694	Decreasing	Not declining
Belize	11,181	Not declining	Not declining
Bolivia	23,584	Not declining	Not declining
Brunei Darussalam	13,857	Decreasing	Not declining
Bhutan	28,811	Not declining	Not declining
Botswana	17,687	Not declining	Not declining
Central African Republic	28,161	Not declining	Not declining
China	25,43	Decreasing	Not declining
Cote d'Ivoire	28,627	Not declining	Not declining
Cameroon	22,243	Not declining	Not declining
Congo, Dem. Rep.	22,794	Not declining	Not declining
Congo, Rep.	18,924	Not declining	Not declining
Comoros	23,413	Not declining	Not declining
Cabo Verde	20,396	Not declining	Not declining
Cuba	8,834	Not declining	Not declining
Djibouti	18,24	Not declining	Not declining
Dominican Republic	16,112	Decreasing	Decreasing
Algeria	20,355	Not declining	Not declining
Ecuador	15,676	Decreasing	Not declining
Egypt, Arab Rep.	19,358	Decreasing	Not declining
Eritrea	25,11	Not declining	Not declining
Ethiopia	25	Not declining	Not declining
Fiji	8,449	Not declining	Not declining
Micronesia, Fed. Sts.	13,705	Not declining	Not declining
Gabon	25,486	Not declining	Not declining
Ghana	18,464	Not declining	Not declining
Guinea	29,661	Not declining	Not declining
Gambia, The	31,123	Not declining	Not declining
Guinea-Bissau	25,761	Not declining	Not declining
Equatorial Guinea	28,015	Not declining	Not declining
Grenada	11,065	Not declining	Not declining
Guatemala	18,695	Not declining	Not declining
Guam	8,019	Decreasing	Not declining
Guyana	10,066	Decreasing	Not declining
Honduras	19,928	Not declining	Not declining
Haiti	22,612	Not declining	Not declining
Indonesia	19,177	Not declining	Not declining
India	22,184	Not declining	Not declining
Iran, Islamic Rep.	21,933	Not declining	Not declining
Iraq	17,534	Not declining	Not declining
Israel	5,7	Not declining	Not declining
Jamaica	8,877	Not declining	Not declining
Jordan	15,8	Not declining	Not declining
Kazakhstan	12,299	Decreasing	Not declining
Kenya	19,952	Not declining	Not declining
Kyrgyz Republic	15,658	Not declining	Not declining
Cambodia	21,77	Not declining	Not declining
Kiribati	19,221	Not declining	Not declining

Kuwait	9,544	Not declining	Not declining
Lao PDR	20,321	Not declining	Not declining
Liberia	29,444	Not declining	Not declining
Libya	23,974	Not declining	Not declining
St. Lucia	13,588	Decreasing	Not declining
Sri Lanka	11,827	Decreasing	Not declining
Lesotho	18,548	Not declining	Not declining
Morocco	18,464	Not declining	Not declining
Madagascar	24,851	Not declining	Not declining
Maldives	28,044	Not declining	Not declining
Mali	36,838	Not declining	Not declining
Myanmar	21,953	Not declining	Not declining
Mongolia	19,855	Not declining	Not declining
Mozambique	24,27	Not declining	Not declining
Mauritania	19,87	Not declining	Not declining
Mauritius	9,813	Decreasing	Not declining
Malawi	27,937	Not declining	Not declining
Namibia	18,925	Not declining	Not declining
New Caledonia	10,1	Not declining	Not declining
Niger	28,885	Not declining	Not declining
Nigeria	26,381	Not declining	Not declining
Nicaragua	18,737	Not declining	Not declining
Nepal	27,248	Not declining	Not declining
Oman	22,457	Not declining	Not declining
Pakistan	20,675	Not declining	Not declining
Panama	9,873	Not declining	Not declining
Peru	18,439	Not declining	Not declining
Papua New Guinea	25,101	Not declining	Not declining
Qatar	9,398	Decreasing	Not declining
Rwanda	22,734	Not declining	Not declining
Saudi Arabia	20,319	Not declining	Not declining
Sudan	17,551	Not declining	Not declining
Senegal	26,023	Not declining	Not declining
Solomon Islands	16,184	Not declining	Not declining
Sierra Leone	32,3	Not declining	Not declining
El Salvador	17,066	Not declining	Not declining
Somalia	26,748	Not declining	Not declining
South Sudan	32,512	Not declining	Not declining
Sao Tome and Principe	17,807	Not declining	Not declining
Suriname	11,358	Not declining	Not declining
Eswatini	20,743	Not declining	Not declining
Syrian Arab Republic	16,102	Not declining	Not declining
Chad	26,537	Not declining	Not declining
Togo	24,13	Not declining	Not declining
Tajikistan	18,235	Not declining	Not declining
Turkmenistan	15,946	Not declining	Not declining
Timor-Leste	29,006	Not declining	Not declining
Tonga	9,951	Not declining	Not declining

Trinidad and Tobago	9,026	Decreasing	Not declining
Tunisia	23,264	Not declining	Not declining
Turkey	20,281	Not declining	Not declining
Tanzania	20,626	Not declining	Not declining
Uganda	20,385	Not declining	Not declining
Uzbekistan	13,599	Not declining	Not declining
St. Vincent and the Grenadines	12,541	Decreasing	Not declining
Virgin Islands (U.S.)	10	Decreasing	Not declining
Vietnam	12,045	Decreasing	Not declining
Vanuatu	16,007	Not declining	Not declining
Samoa	10,822	Not declining	Not declining
Yemen, Rep.	36,234	Not declining	Not declining
South Africa	17,398	Not declining	Not declining
Zambia	18,471	Not declining	Not declining
Zimbabwe	14,441	Not declining	Not declining

Annex to Chapter 2

Supplementary Information

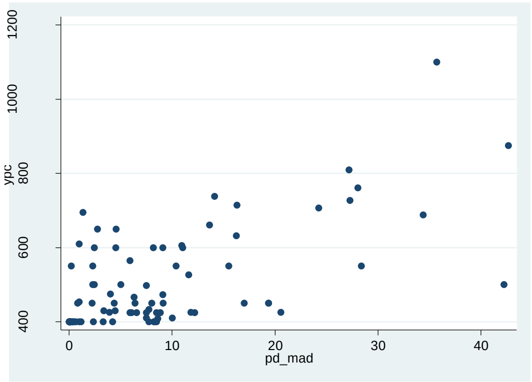
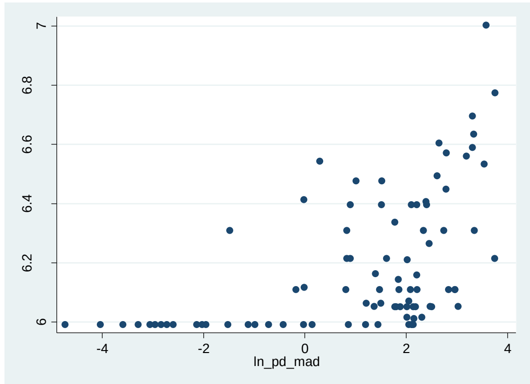
Income Level and Inequality in the Aztec Empire on the Eve of the Spanish Conquest

A2. Estimates of average income in the Aztec Empire and its provinces

A2.1.1 Relationship between income and population density

To produce our estimates of average income in the Aztec Empire, we exploit the variation in population density among different societies. In a pre-industrial context, population density is strongly correlated with average income, as shown by studies that have used population density as a proxy for relative levels of development (1). Based on information provided by Ashraf and Galor (2), we exploit the positive relationship between population density and average income level. We use a sample of 66 pre-industrial societies in different years (1, 1000 and 1500 CE), building upon previous studies that have estimated per capita income levels (See Figures 1A and 2A).

Fig. A1. Relationship between population density and average income for preindustrial societies

<table>
<tr><th>Panel A: Relationship between population density (pd_mad) and average income (ypc, $PPP 1990)</th><th>Panel B: Relationship between natural logarithm of population density (ln_pd_mad) andand natural logarithm of average income (ln_ypc)</th></tr>
<tr><td>
</td><td>
</td></tr>
</table>

Notes: Both graphs confirm that in preindustrial societies there exists a relationship between population density and average income. This relationship is positive, both for absolute values and for their natural logarithmic transformation.

We estimate two models, using (M1) Ordinary Least Squares (OLS) and (M2) Two-Stage Least Squares Regression Analysis (2SLS) with an instrument to control for the possible endogeneity between population density and average income. We use information in natural logarithms for both variables. Other geographical controls are used. The logarithmic population density variable is restricted (greater than zero) for better functional form.

File "1 Data 66 preindustrial societies.XLSX" contains the information used to estimate average income. The variables used in both models are the following:

ypc	= GDP per capita (in column G),
ln_ypc	= natural logarithm of GDP per capita (in column E),
pd_mad	= population density (in column F)
ln_ pd_mad	= natural logarithm of population density (in column D),
ln_abslat	= natural logarithm of absolute latitude (in column S),
distcr1000	= mean distance to nearest coast or river (in column W),
land100cr	= percentage of land within 100 km of coast river (in column X),
animal	= number of domesticated animal species, which is our instrumental variable to control for endogeneity in model (2).

The results of the two models are presented in Table A1, whose estimators are very similar (0.1895 of the OLS vs 0.1977 of the 2SLS). We take the 2SLS model as it presents advantages in the face of a possible endogeneity bias.

Table A1: Estimating the relationship between population density and average income (<u>GDP per capita $PPP 1990)</u>

Dependent Variable:	**Ln GDP per capita $PPP 1990**	
VARIABLES	Model (1) OLS	Model (2): 2SLS IV: Animal domestication
Ln population density	**0.1895*** **	**0.1977 *** **
	(0.000)	(0.000)
Ln land productivity	-0.0716**	-0. 0404 *
	(0.014)	(0.085)
Ln absolute latitude	0.0856	0.0227
	(0.469)	(0.594)
mean distance to nearest coast or river	-0.0633 (0.743)	-0.1477 (0,452)
percentage of land within 100 km of coast river	-0.2404 (0.106)	-0. 1218 (0.444)
Constant	5.7275	5.8293***
	(0.000)	(0.000)
Observations	66	66

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

A.2.1.2 Estimation of the average income in the Aztec Empire and its 38 provinces

We first use the coefficient from model (2) in Table A1 to estimate the average income for the Aztec empire, considering a population density of 42 inhabitants per square kilometer. This density comes from assuming a population of 7 million people within the Empire, with an area of 170,000 square kilometers in 1519, which is coherent with recent historical and archaeological literature (3; 4; 5).

Based on the above, we estimate that the average income across the Aztec Empire was 712.4 $PPP 1990. This figure is obtained based on Model M2, through the following equation (1):

$$\text{ln\_ypc } i = 5.8293 + 0.1977\ (3.7376) \qquad (1)$$

Where yi is the natural logarithm of GDP per capita, 5.8293 and 0.1977 are the estimators obtained for the constant and the natural logarithm of population density, respectively, shown in Table A1. 3.7376 is the natural logarithm for a population density of 42. The result from equation (1), ln_ypc i = 6.5686, is in natural logarithm. By applying the proper exponential transformation in this result we obtain a GDP per capita of 712.4 $PPP 1990. Note that this estimate for the Empire as a whole constitutes just a first approximation, as indeed we produced a more precise estimate directly from the detailed income distribution obtained with the procedure described in Section 2. This being said, our more refined estimate of 690.1 $PPP 1990 differs only slightly from the 712.4 $PPP 1990 obtained with the simpler procedure described above.

In order to estimate the average income in the 38 provinces of the Aztec Empire, we use available information about the population density in 1492 from (5). However, this information refers to the territorial division of the current subnational administrative entities of Mexico and Guatemala (states and departments). Therefore, we first select the current administrative entities where the Aztec Empire was located and we take the population density in 1942 for these territorial entities.

As a second step, we weight these population density estimates to reflect the conditions of the 38 provinces of the Aztec Empire. First, we collect information on the number of towns and locations in each Aztec Imperial province in 1519 from Barlow (6). Second, we weight the population density information of each state or department in 1492 according to the proportion of towns identified by Barlow which could be attributed to each current state or department.

For instance, the province of Tlatelolco included 11 towns, of which 9 have been identified by archaeologists. These 9 identified towns were located in two different current states: 3 in what is now Mexico City (or Federal District) and 6 in what is now Estado de Mexico. Consequently, we estimated the population density of the Aztec province of Tlatelolco (157.6 people per sq. km) as a weighted average of the population density reported for these two modern administrative areas, giving a weight of 3/9 to Mexico City ([3/9]x392.3369 = 130.8 people per sq. km.) and of 6/9 to the Estado de Mexico ([6/9]x40.3 = 26.8 people per sq. km). The sum of both figures gives as a result of 157.6 people per sq. km (130.8 + 26.8 = 157.6).

Finally, as a third step, this population density obtained for each province of the Aztec Empire is taken and the regression model M2 is applied. For example, following the case of the province of Tlatelolco, we consider the value 157.6 people per km2 in the estimation of average income. To do this, we apply the natural logarithm to this value, obtaining the figure of 5.06. This last value is applied to equation (1), which results in 6.83 (5.829303+ [0.1977978]*[5.06] = 6.83). This last figure expressed in natural logarithms becomes 925.4 $PPP 1990.

The information about the estimated average income by Aztec province is in the sheet "income per Aztec province", in the file:

"NEW VERSION 4 Estimates GINI in Provinces and Empire and Extraction Levels.XLSX"

The results about the estimated average income for each province of the Aztec Empire, expressed in $PPP 1990, are in Table 1, Column B, of the main text. We also estimate the average income for each province in terms of Minimum of Subsistence, which is in Table 1, Columns C. Note that by assigning the level "1" to minimum subsistence as defined above, higher or lower income levels can be expressed as a multiple of 1: for example, across the Empire the imperial ruling class had an average income equal to 905.19 times subsistence (see Table 44A).

A.2.1.3 Estimate of Minimum Subsistence in $PPP 1990.

In order to express the average income in terms of subsistence minimums, we consider an amount of 400 $PPP 1990, which is the level usually assumed in the literature for similar purposes (7; 8). We divide each term in column B, Table 1, by $PPP 400. For instance, the average income in Tlatelolco is 925.4 $PPP 1990. In order to express this in terms of subsistence minimums, we divide 925.4 by 400, obtaining 2.30: an income of more than double that needed for pure subsistence. It is important to note that our subsistence minimum, equivalent to 400 $PPP 1990, is higher than the level for mere physical survival, which would be 300 $PPP 1990 based on the literature (7; 8).

In the file "NEW VERSION 4 Estimates GINI in Provinces and Empire and Extraction Levels.XLSX", in the sheet "income per Aztec province" we include estimates of the average income for each province expressed in terms of $PPP 1990 (column V) and Minimum of Subsistence (column W).

A.2.1.4. Equivalences

The following Table A2 shows the equivalences used to develop our estimates. Equivalences between cocoa beans, mantas and $PPP 1990/subsistence minimums are needed because part of the literature provides useful quantitative information expressed in the former units of measurement.

Table A2: Equivalences used to develop the estimates

Physical survival level: 300 $PPP = 0.75 Minimum Subsistence	We assume a minimum daily caloric intake of 2,370 for an adult and 1,820 daily calories for the non-working population (children and elderly), as suggested by the literature for the Indian population (9; 10). Given these caloric intakes, we use a minimum diet expressed in grams of corn, assuming an equivalence of 182,400 calories per bushel of corn. Thus, the minimum amount of corn to achieve the 2,370 daily calories needed by an adult is 963 grams, and 722 grams of corn for the children and the elderly. To obtain the average consumption per inhabitant, the proportion between the adult population, children and elderly estimated by Rojas (11) is used to weight the two figures, thus obtaining an average daily amount of 866.6 grams of corn. Therefore, the amount of 866.6 grams of corn is equivalent to 300 dollars, which corresponds to the level of physical survival indicated by the literature (7; 8).
Minimum subsistence: 400 $PPP = 1 Minimum Subsistence	We assume the Minimum Subsistence level indicated by the literature (7; 8).
1 $PPP = 2.29 cocoa beans	1 bushel of corn had the price of 1 Real or 100 cocoa beans (12). We can then set the subsistence minimum at 1.88 cocoa beans per person per day and 686 cocoa beans per person per year (considering 365 days a year). The amount of 686 cocoa beans per person per year is also the

	equivalent of an income of $PPP 300 at 1990, given that this is required to survive with the minimum nutrition. As we set our subsistence income at the higher level of 400 $PPP 1990, our subsistence minimum equals 916 cocoa beans per capita per year. With either of these two estimates we reach the equivalence of 1 $PPP = 2.29 cocoa beans.
1 *manta* = 800 cocoa beans	The equivalence is provided by the literature (13)

A.2.2. Estimation of social tables

Social tables providing information about the population size and the average income of distinct categories are often used to roughly estimate inequality levels in historical societies, particularly when detailed information about the complete income distribution is lacking (7; 14). In the following we elaborate a full set of social tables for different areas of the Aztec Empire, based on the information provided by archeological and historical sources.

A.2.2.1 Social Classes

For the 38 single provinces of the Aztec Empire we develop social tables composed of 9 distinct categories. Also for the city-states that formed the Triple Alliance (Tenochtitlan, Texcoco and Tlacopan) we develop social tables with 9 categories. The categories are the same between provinces and Triple Alliance city-states, bar the highest ranking one: in the city-states this was the imperial ruling class, while in the provinces it was the provincial ruling class. As these two categories had different characteristics and income sources, they are kept separate. We also develop a social class for the whole of the Aztec Empire, which has 10 categories as it includes both the imperial ruling class and the provincial ruling class.

Our starting point is the work by Smith and Hicks (15) on inequality and social class in the Aztec society, but we improve our social tables using additional information from the literature when needed. The main social distinction in the Aztec Empire was between those who owned the land (the nobility), those who did not (the commoners), and slaves.

The top of the social structure of the Aztec Empire was formed by the nobility, which can be further divided into 3 categories:

- **Imperial ruling class**. This social category was not considered in Smith and Hicks (15), since their study focused on the imperial provinces only. The Imperial Ruling Class lived in Tenochtitlan and in the other two city-states that were part of the Triple Alliance (Texcoco and Tlacopan). This category had representatives in the provinces for the collection of taxes, the *Calpixque*. Even though they were very few in number, considering the members of the imperial ruling is relevant since they received a very sizeable part of the income generated locally, through taxes.

- **Provincial ruling class**. This social category includes the kings and the governing councils, formed by important nobles, of the provinces that had been conquered by the Triple Alliance and had become part of the Aztec Empire. The Aztec Empire used to keep the same conquered ruling group at the head of the provinces. However, the provincial ruling class had a duty to collect taxes within the province and hand them over to the Empire.

- **Non-ruling nobles**. This category includes the other nobles who owned land and who exploited it directly or indirectly through the commoners. Members of this social class also supported the ruling class in the administrative tasks of government.

The middle of the Aztec social-economic structure was occupied by the commoners, who did not own land. Importantly, there were no significant differences between commoners living in the countryside or in urban areas. The majority of commoners were farmers (including most urban commoners) and the source of much of the inequality within the commoner class was the varying mechanisms by which they obtained land to cultivate. However some, specialized in more profitable activities, had a social status above the other commoners (15). Therefore, the commoners can be classified into two groups: one including people with specialized occupations (further divided into 3 special categories), and a much larger one whose members, the *macehualtin*, were characterized by seasonal pluriactivity (further divided into three subgroups, with different levels of income).

Special Categories 1, 2 and 3: These are the special categories for commoners with specialized occupations identified by the literature (15):

- **Special Category (3):** guild merchants (*pochteca*) and luxury artisans. This category refers to wealthy commoners who took advantage of the commercial economy and could accumulate considerable fortunes. People in this category worked directly for kings or high nobles, and also sold their products on the marketplace.

- **Special Category (2):** high priests and top warriors. This category includes those who occupied the top positions in hierarchical organizations closely linked to the state administration. Although they were not part of the nobility, they enjoyed great prestige and social influence. Note that among "top warriors" we do not only find professional soldiers, but also conscripts (all males were required to serve as soldiers) who had risen in rank and prestige by capturing enemy prisoners or by performing other battlefield feats.

- **Special Category (1):** non-nobles *calpixque* or city officials, in charge of collecting taxes in the neighborhoods (*calpolli*).

Commoners (*macehualtin*) Levels 1, 2 and 3: Includes the rest of commoners. The differentiation into 3 sub-categories, with different levels of average income, is based on a range of factors, among which particularly prominent is the way in which they gained access to the lands (15):

- **Commoners Level (3):** this category includes commoners who had direct access to farmland, through institutions associated with their neighborhood or village (*calpulli* and *teccalli*). These commoners were generally ancient settlers, who had to pay a tax (not a rent) to the local ruler, who in turn sent part of the tax revenues to the Triple Alliance. Although there are geographical and institutional differences between *calpulli* and *teccalli*, in both institutional arrangements the commoners had access to land and were characterized by having lived on their land for many years.

- **Commoners Level (2):** this category includes construction workers, loaders (*tamemes*), unskilled craftsmen and other workers earning temporary salaries. Although it would be improper to think of these as salaried workers entirely analogous to their Western counterparts, their income came from specific payments for their services which were structurally similar to a temporary salary.

- **Commoners Level (1):** this includes *mayeques,* whose access to land was through direct dependence on a noble rather than through the institutions of *calpulli* or *teccalli*. The *mayeques* did not pay tribute to the supreme lord, but paid rent to the noble (16). Historians frequently compare this to European serfdom since they lacked freedom and self-determination. This group is generally identified with new settlers, who had immigrated into a community after fleeing from other places ravaged by wars or famines. For Tenochtitlan, this category also includes the servants of both the nobility and the Great Temple (*Templo Mayor*).

Finally, at the bottom of the social scale were the **slaves** (*tlacohtin*): the tenth and lowest category in our social table.

A.2.2.2 Population for each social class:

The late Aztec Empire had a population of about 7 million people, distributed as follows: 250,000 in the city of Tenochtitlan; 35,575 in the city of Texcoco; 30,000 in the city of Tlacopan; and on average 176,315 people in each of the 38 provinces.

For Tenochtitlan, we obtain our estimate as the mid-point in the range of 200,000-300,000 proposed by Rojas (17; 18). For Texcoco, we obtain our estimates of 35,575 as an average between the population levels proposed by the literature (4, 19)[17]. For Tlacopan, we assume a population of 30,000, considering the upper bound of the range provided by Denevan (4) of 10,000 to 30,000. Excluding the population

[17] One study proposes a range of 43,200-51,000 (4) and another proposes an estimate of 24,100 (19). We first average 24,100 with the higher and upper bounds of the alternative range, obtaining 33,600 and 37,550. We then further average these two values, obtaining our estimate of 35,575.

of the three city-states that formed the Triple Alliance, we are left with 6,684,425 inhabitants. Dividing them evenly among the 38 provinces we obtain an estimated average of 175,905.9 inhabitants per province.

The top of the social structure of the Aztec Empire, formed by the imperial ruling class, the provincial ruling class and the non-ruling nobles, accounted for 2% of the overall population (15). We divide it as follows:

- **Imperial ruling class**. For this category we assume a population of approximately 600 people who resided entirely in the cities of the Triple Alliance. We base our estimate on the number of provincial lords who used to be close to the emperor in the *Templo Mayor* (11). This category includes the emperor (*huey tlatoani*) and his direct family who had extensive military, civil and religious powers. It also includes the *cihuacóatl* (a kind of "co-emperor" who was in charge of tax administration, religious affairs and judicial appeals); the *tlacochcálcatl* and the *tlacatécatl* (army chiefs); the *huitzncahuatlailótlac* and the *tizociahuácatl* (main judges); the *tlatoque* (representatives of the Empire in the provinces); the *tecutli* (judge and supervisor of the payment of taxes in the provinces). For Tenochtitlan, we assume that this category represented 0.2% of the population, which would correspond to 500 people. For Texcoco and Tlacopan, we assume that this category represented 0.16% of the population, which would correspond to 60 people in Texcoco, and 40 in Tlacopan.

- **The provincial ruling class.** For this category we assume a population of 491.7 people per province, corresponding to an estimated 18,685 people across the Empire. This means that in the 38 provinces, we have 0.28% of the total population in this social category; its prevalence will be marginally lower in the Empire as a whole as this category is absent from the cities of the Triple Alliance (see later, table 44A). This estimate is coherent with the assumption made by (20) for the ancient Mexican communities.

- **The non-ruling nobles**. We assume a population of 1.72% of the population in each province (approximately 3,025 non-ruling nobles in each province and 114,972 in the 38 provinces of the Empire). This estimate is obtained by subtracting the 0.28% population in the provincial ruling class from the 2% that corresponds to the overall nobility of each province of the Empire. The case of Tenochtitlan is particular. Since it was the imperial capital, the noble class represented a larger population than in the rest of the provinces: an estimated 5% of the total population of the metropolis (11). Thus, subtracting the 0.2% that represented the Imperial Ruling Class residing in Tenochtitlan, non-ruling nobles amount to 4.8% of the city population (12,000 people). For both Texcoco and Tlacopan, we estimate that non-ruling nobles were 1.84% of the population. This figure is obtained by subtracting from the 2% of the nobility the 0.16% that represents the imperial ruling class in these two cities. This amounts to 655 non-ruling nobles in Texcoco and 552 in Tlacopan.

In the special categories, we assume a population equivalent to 2% in the 38 provinces, Texcoco and Tlacopan, and 6% in Tenochtitlan. In other words, the size of the population belonging to these groups was similar to that of the nobility. Based on the available literature (11), we assume the following percentage distribution of the population for each special category:

- **Special Category (3):** 0.4% of the total population in the Empire, the provinces and the city-states of Texcoco and Tlacopan. For Tenochtitlan, 1% of the total population in the city.

- **Special Category (2):** 0.6% of the total population in the Empire, the provinces and the city-states of Texcoco and Tlacopan. For Tenochtitlan, 2% of the total population in the city.

- **Special Category (1):** 1% of the total population in the Empire, the provinces and the city-states of Texcoco and Tlacopan. For Tenochtitlan, 3% of the total population in the city.

In the categories of commoners, we assume that there was around 93% of the total imperial population. This estimate is obtained as a residual category, given the estimated 2% nobility, 2% commoners in special categories and 3% slaves. We take the information in the *Matrícula de Huexotzinco* according to Herrera and Thouvenot (21).

- **Commoners Level (3):** 43.6% of total population in the provinces and the city-states of Texcoco and Tlacopan. For Tenochtitlan, we assume a figure of 36% of the population based on the available information (11).

- **Commoners Level (2):** 10% of total population in the provinces and the city-states of Texcoco and Tlacopan. For Tenochtitlan, we assume a figure of 17% of the population based on the available information (11).

- **Commoners Level (1):** 39.4% of total population in the provinces and the city-states of Texcoco and Tlacopan. For Tenochtitlan, we assume a figure of 30% of the population based on the available information (11).

The final category is that of slaves, which we can be estimated based on (11):

- **Slaves:** 3% of the total population for the 38 provinces, Texcoco and Tlacopan. For Tenochtitlan, we assume 6% of the total population.

A.2.2.3 Social Classes and Income Level

At the provincial level there are two sources of income variation:

1. The average income level, which is estimated according to the procedure described in Section 1 of this Supplementary Information.
2. The payments that each province had to make to the Aztec Empire (according to the Mendoza Codex and the *Matricula de Tributos*).

For simplicity, we measure different income levels in terms of multiples of the minimum subsistence level.

The amount related to Imperial extraction (which represents the income of the imperial ruling class) is subtracted from the estimated income generated by each province. This amount was different across provinces. We assume a fixed income level for all categories of commoners and for the slaves. Subsequently, we subtract the income of these categories from the post-tax provincial income. The obtained residual is then distributed among the non-ruling nobles and the provincial ruling class, in a proportion of 25% for the non-ruling nobles and 75% for the provincial ruling class.

This proportion is coherent with the available estimates of wealth differences between social categories (15).

Income of the Imperial ruling class:

The income of this social category comes from the taxes paid by the 38 provinces. Tax payments by provinces are estimated based on the literature (13; 22) and reflect the value of tax paid in *mantas* (blankets). The distribution of *cargas* (loads) can be used as a proxy for the tax burden paid in each province and is reported by the Mendoza Codex (22). Overall, these tax payments correspond to the annual income of the Imperial Ruling Class that resided in Tenochtitlan, Texcoco and Tlacopan. Payments were made from the provinces to Tenochtitlan, and later a part was transferred to the cities of Texcoco and Tlacopan. The information on tax payment by province can be found in the sheet "ImperialTaxation" of the document:

"NEW VERSION 4 Estimates GINI in Provinces and Empire and Extraction Levels.XLSX"

For instance, the Triple Alliance received 3,280 *cargas* ("loads") from Tlatelolco out of a total of 332,165 *cargas* paid by the 38 provinces (22): 0.99% of the total (see cells C3, C2 and E3). We use this percentage as a proxy for the proportion of imperial taxation contributed by this province. We convert the number of *cargas* into *mantas*, taking into consideration the equivalence "*cargas-mantas*" of the province of Tlauhpan (13). We can then estimate that Tlatelolco had to transfer annually 6,191 *mantas* to the three cities of the Triple Alliance (see cell F3). This amount would be equivalent to 4,952,800 cocoa beans (which is obtained by multiplying 6,191 by 800 since each *manta* was equivalent to 800 cocoa beans) or 2,162,795 $PPP 1990, obtained by dividing the cocoa beans by 2.29 (see cells G3 and H3). These estimates are in the document "NEW VERSION 4 Estimates GINI in Provinces and Empire and Extraction Levels.XLSX", sheet "ImperialTaxation".

We assume that the income of the imperial ruling class, coming from the tax payments made by the provinces, was distributed among the 3 cities as follows: 88% for Tenochtitlan, 6% for Texcoco, and 6% for Tlacopan. The literature (23) has highlighted that when the Triple Alliance was formed in 1426, the distribution of taxes would be 2/5 for Tenochtitlan, 2/5 for Texcoco and 1/5 for Tlacopan (originally, the Alliance was formed to defeat the Tepaneca Empire, which was ultimately accomplished in 1430). However, during the rule of Moctezuma II (1502 to 1520, when Hernán Cortés arrived) the distribution of taxes was no longer proportional at all, as almost all the tax revenues went to Tenochtitlan (24; 25).

Income of slaves: We assume that the slaves income corresponds to the minimum caloric intake of 866 grams of corn, which corresponds to 300 $PPP 1990 and 0.75 in terms of multiples of the subsistence minimum (as explained in Section 1.3, 300 $PPP 1990 is the minimum necessary for mere physical survival). Note that on some occasions people gave themselves as slaves to nobles or wealthy commoners just to gain access to the minimum subsistence and avoid death by starvation.

Income for Commoner 1: We estimate an income level for this category of 0.8 in terms of minimum of subsistence, slightly higher than what a slave received. The *mayeques* or "dependent commoners" have often been compared to the European serfs, as they lacked freedom and self-determination. Therefore, it seems logical to assume that members of this category were close to the minimum subsistence level:

above slaves, but below salaried workers who enjoyed a degree of freedom and self-determination.

Income for Commoner 2: We estimate an income level for this category of 0.85 in terms of minimum of subsistence.

Average income for this category is derived from a reported salary of 12.5 cocoa beans per day in 1530 (26). We assume that the salary increased by around 30% between the period prior to 1519 and the year 1525 as a consequence of the imbalances generated by the demographic crisis and the collapse of the Aztec Empire. This 30% figure is similar to the increase in wages observed in Europe a few years after the demographic crisis caused by the Black Death of 1347-52. Therefore, the daily wage before 1519 would be around 9.62 cocoa beans per day[18]. We assume that a family had 7 people on average and that the economically active population was 31.6% of the total population based on the available estimates (11). Therefore, for each day worked a family would have received 21.14 cocoa beans (obtained by multiplying 9.62 by 2.198 - which in its turn is obtained by multiplying 7, the size of a representative family, by 0.314, which is the share of the economically active population).

We also assume that a year had 256 working days, considering the festivities included in the two calendars used by the Aztecs. In this way, a family would receive an average of 5,450 cocoa beans annually. Dividing this figure by 7 (the average size of a family)

[18] This salary is consistent with some observations provided by the literature (12), as in the markets there were unskilled workers who were hired for similar amounts, and those in charge of the steam baths and prostitutes charged between 8 and 10 cocoa beans.

we obtain a total 778.5 cocoa beans per year per person. This is equal to 85% of the minimum subsistence level.

Regarding the number of working days per year, note that the Aztecs, following other Mesoamerican cultures, used two calendars. The first was the solar calendar (*Xiuhpohualli*), which had 365 days and was organized in 18 months, each with 20 days; each month with four weeks of 5 days each, giving a total of 360 days. They also had 5 days called *Nemontemi*. The second was the religious calendar (*Tonalpohualli*) which had 260 days, divided into 20 weeks of 13 days each. We consider the following to be non-working days: i) the 5 days of *Nemontemi*, in which people had to stay at home; ii) 73 days of the solar calendar dedicated to the market (they used to work 4 days a week and the fifth was to the market); iii) 20 days known as *Panquetzaliztli*; iv) 11 days in other festivities (27; 28).

Income for Commoner 3: We assume that this category had an income level of 1 in terms of minimum of subsistence. Note that the members of this category did not own their land, which explains why their income remained somewhat constrained. For example, Henry Hawks, an English traveler of the 16th century, pointed out that "The Indian lives the whole week with less than one *real*, which the Spaniard or anyone else cannot do" (12). While this testimony refers to the post-Conquest period, it seems probable that in the decades immediately following the fall of the Aztec Empire the conditions of farming commoners were no worse than before it, also considering the relative abundance of resources determined by the demographic collapse.

Special Category 1: For this category we estimate an income level of 2 in terms of minimum of subsistence. Based on the literature (15: Table 29.2) the *calpixque* (neighborhood tax collectors) had an income which was between 2 and 17 times that of commoners. We assume a conservative income level of twice that of the richest commoners, considering as a reference the size (in square meters) of houses in Yautepec, as reported by archaeological studies.

Special Categories 2 and 3: Based on the literature, these categories had relatively high incomes. Considering the income levels estimated for Special Category 1 and in the absence of additional information, we make the reasonable assumption that category 2 (high priests and top warriors) had an income level of 3 in terms of multiples of the subsistence minimum, while category 3 (luxury artisans) had an income level of 4. For Tenochtitlan we assume a higher income level of 6 (for category 2) and 8 (for category 3). For the other two cities that were part of the Triple Alliance, Texcoco and Tlacopan, we assume an intermediate level of income between that of Tenochtitlan and the provinces: 4.5 and 6 for categories 2 and 3 respectively.

Provincial ruling class and non-ruling nobles: The income of these categories varies according to the province depending on two factors: the level of extraction made by the imperial ruling elite and the average income level of each province. Based on the literature (15) we assume that 75% of this income went to the provincial ruling class and 25% to the other non-ruling nobles. The original information relates to a sample of six landholding communities in Morelos (15: 31).

A.2.2.4 Social Tables and calculation of the Gini index of income inequality across the Aztec Empire

Based on the information collected from the various sources mentioned above, we build a full set of Social Tables: i) For Tenochtitlan; ii) For city-states associated with the Triple Alliance; iii) for the 38 provinces. Each single table is detailed below. Based on these tables, calculating the Gini index (or any other inequality measure) for the three cities of the Triple Alliance or for each province is immediate (see sheet "Income&Gini_Provinces&CityState"). These tables can also be used to obtain the overall distribution across the whole of the Aztec Empire, as well as the related synthetic social table (see sheet "IncomeDistr&Gini_AztecEmpire"). These estimates are in the document "NEW VERSION 4 Estimates GINI in Provinces and Empire and Extraction Levels.XLSX". The synthetic social table is done in Section 2.5.

Note that the incomes that we report as multiples of minimum subsistence could also be roughly converted to 1990 $PPP by using the equivalence which has been established in Section 1.2 (income level 1 = 400 $PPP 1990).

Table 3A: Tenochtitlan (capital city)

Income Social Group	**Average Income (in terms of subsistence)**	**Estimated population share (in %)**
Imperial ruling class	963.7	0.2
Non-ruling Nobles	39.9	4.8
Special Category 3	8.00	1
Special Category 2	6.00	2
Special Category 1	4.00	3
Commoners Level 3	1.05	36
Commoners Level 2	0.85	17
Commoners Level 1	0.80	30
Slaves	0.75	6

Table 4A: City-States associated with the Triple Alliance: Texcoco

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Imperial ruling class	577.2	0.16
Non-ruling Nobles	33.2	1.84
Special Category 3	6.00	0.4
Special Category 2	4.50	0.6
Special Category 1	3.00	1
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10
Commoners Level 1	0.80	39.4
Slaves	0.75	3

Table 5A: City-States associated with the Triple Alliance: Tlacopan

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Imperial ruling class	684.5	0.16
Non-ruling Nobles	23.9	1.84
Special Category 3	6.00	0.4
Special Category 2	4.50	0.6
Special Category 1	3.00	1
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10
Commoners Level 1	0.80	39.4
Slaves	0.75	3

Table 6A: Tlatelolco (province 1)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	366,98	0.28
Non-ruling Nobles	19,91	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 7A: Petlacalco (province 2)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	395,05	0.28
Non-ruling Nobles	21,44	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 8A: Acolhuacan (province 3)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	181,98	0.28
Non-ruling Nobles	9,87	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 9A: Cuauhnahuac (province 4)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	364,48	0.28
Non-ruling Nobles	19,78	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 10A: Huaxtepec (province 5)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	371,76	0.28
Non-ruling Nobles	20.17	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 11A: Quauhtitlan (province 6)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	216,63	0.28
Non-ruling Nobles	11.76	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 12A: Axocopan (province 7)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	184,62	0.28
Non-ruling Nobles	10.02	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 13A: Atotonilco de Pedraza (province 8)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	192,65	0.28
Non-ruling Nobles	10.45	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 14A: Hueypochtlan (province 9)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	198,68	0.28
Non-ruling Nobles	10,78	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 15A: Atotonilco el Grande (province 10)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	185,62	0.28
Non-ruling Nobles	10.07	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 16A: Xilotepec (province 11)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	188,28	0.28
Non-ruling Nobles	10,22	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 17A: Quahuacan (province 12)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	260,24	0.28
Non-ruling Nobles	14,12	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 18A: Tollocan (province 13)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	208,60	0.28
Non-ruling Nobles	11.32	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 19A: Ocuillan (province 14)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	212,62	0.28
Non-ruling Nobles	11.54	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 20A: Malinalco (province 15.a)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	216,63	0.28
Non-ruling Nobles	11.76	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 21A: Xocotitlan (province 15.b)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	224,67	0.28
Non-ruling Nobles	12.19	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 22A: Tlachco (province 16)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	132,13	0.28
Non-ruling Nobles	7,17	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 23A: Tepequacuilco (province 17)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	103,06	0.28
Non-ruling Nobles	5.59	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 24A: Cihuatlan (province 18)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	99,34	0.28
Non-ruling Nobles	5.39	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 25A: Tlauhpan (province 19)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	124,64	0.28
Non-ruling Nobles	6.76	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 26A: Tlalcozauhtitlan (province 20a)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	136,19	0.28
Non-ruling Nobles	7.39	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 27A: Quiauhteopan (province 20b)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	136,44	0.28
Non-ruling Nobles	7.40	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 28A: Youaltepec (province 20c)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	148,73	0.28
Non-ruling Nobles	8,07	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 29A: Chalco (province 21)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	310,61	0.28
Non-ruling Nobles	16,85	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 30A: Tepeyacac (province 22)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	126,71	0.28
Non-ruling Nobles	6.88	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 31A: Coaixtlahuacan (province 23)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	126,54	0.28
Non-ruling Nobles	6,87	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 32A: Coyolapan (province 24)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	128,61	0.28
Non-ruling Nobles	6.98	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 33A: Tlachquiauhco (province 25)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	136,68	0.28
Non-ruling Nobles	7.42	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 34A: Tochtepec (province 26)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	115,86	0.28
Non-ruling Nobles	6.29	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 35A: Xoconochco (province 27)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	87,31	0.28
Non-ruling nobles	4,74	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 36A: Quauhtochco (province 28)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	132,63	0.28
Non-ruling Nobles	7.20	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 37A: Cuetlaxtlan (province 29)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	106,47	0.28
Non-ruling Nobles	5.78	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 38A: Tlapacoyan (province 30)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	174,91	0.28
Non-ruling Nobles	9.49	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 39A: Tlatlauhquitepec (province 31)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	141,07	0.28
Non-ruling Nobles	7,65	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 40A: Tochpan (province 32)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	96.08	0.28
Non-ruling Nobles	5.21	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 41A: Atlan (province 33)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	163.87	0.28
Non-ruling Nobles	8.89	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 42A: Tziuhcoac (province 34)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	152,89	0.28
Non-ruling Nobles	8,30	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

Table 43A: Oxitipan (province 35)

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Provincial ruling class	111.59	0.28
Non-ruling Nobles	6.06	1.72
Special Category 3	4.00	0.4
Special Category 2	3.00	0.6
Special Category 1	2.00	1.0
Commoners Level 3	1.00	43.6
Commoners Level 2	0.85	10.0
Commoners Level 1	0.80	39.4
Slaves	0.75	3.0

A.2.2.5. Income distribution and social table for the Aztec Empire as a whole

The information coming from the 41 distinct social tables presented in Section 2.4 can be used to produce a relatively detailed distribution of the income across the whole of the Aztec Empire. This is done by taking into account the population share of each city or province compared to the whole of the Empire, re-scaling accordingly the population shares presented in each "local" social table, and finally using all the entries to build a distribution representative of the whole of the Empire. This is done in file "NEW VERSION 4 Estimates GINI in Provinces and Empire and Extraction Levels.XLSX" XLSX", sheet "IncomeDistr&Gini_AztecEmpire") . This distribution can then be used to calculate directly any possible inequality measure, for example the Gini indexes and the top income percentiles.

It is also useful to present this information more synthetically, by collapsing the information from the complete distribution into a social table having the same characteristics as those introduced earlier. This is done in Table 44A. Note that as slaves and commoners are given the same income across cities and provinces, their estimated income will be the same across all social tables. The income of the specialized categories, which has been assumed to be higher in Texcoco and Tlacopan compared to the provinces, and much higher in Tenochtitlan, will be a population-weighted average. The same is true for the three categories of nobility (Imperial ruling class; provincial ruling class; non-ruling nobles) whose income has been allowed to vary across each city and province.

Table 44A: Social Table for the Aztec empire as a whole

Income Social Group	Average Income (in terms of subsistence)	Estimated population share (in %)
Imperial ruling class	905.19	0.0086
Provincial ruling class	183,21	0.2674
Non-ruling Nobles	12,92	1.8311
Special Category 3	4.36	0.4214
Special Category 2	3.34	0.6500
Special Category 1	2.21	1.0714
Commoners Level 3	1.00	43.3286
Commoners Level 2	0.85	10.2500
Commoners Level 1	0.80	39.0643
Slaves	0.75	3.1071

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