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The Human Sex Ratio at Birth and Late Fetal Mortality: the Italian Case

Abstract

This study explores the short-term relationships between sex ratio at birth and late fetal mortality in Italy from 1910 to 2016. As the leading scholars' attention traditionally focused on long-term trends and variations in the sex ratios at birth among different populations, less interest regarded short-term fluctuations as they were mainly seen as an effect of random variability. We detrended the national series of males proportion among live births and stillbirths by their medium-term component to consider the annual deviations from a normal trend. After controlling for fertility tendencies and wars effects, regression models seem to show the effects of stillbirth on the proportion of male newborns. A sensitivity analysis was also carried out to assess the effects of the perinatal deaths on the proportion of males at birth, combining stillbirths and early neonatal losses to control the possible misspecification between stillborn infants and early neonatal deaths. The significance of late fetal mortality reflects the mortality excess among male fetuses during the intrauterine life, showing evidence for the *in utero* hypothesis selection.

Introduction

In societies where no prenatal sex selection has been observed, male to female ratio at birth (secondary sex ratio, SR onward) is commonly assumed to be relatively stable. It empirically averages around 105 and 106 boys per 100 girls (e.g. Cavalli-Sforza and Bodmer 1971; Pressât 1983; Sieff 1990; Del Panta and Rettaroli 1994, Caselli and Vallin 2001), or around 0,515 when the proportion of males among all births is considered. In areas such as Western Europe, North America, Sub-Saharan Africa and South America, where the choice of a male or a female fetus is not selective by gender (Bongaarts and Guilmoto 2015), these ratios are universally near 105. Moreover, they remain relatively constant over time, varying within narrow boundaries (e.g. Zeng et al. 1993; Gu and Roy 1995; Park and Cho 1995; Das Gupta and Bhat 1997; Dyson 2012).

Following seminal studies on early demographers (Graunt 1662; Sussmilch 1979), Gini (1908) analysed SR variations on a significant amount of population data concluding that the excess of male neonates to females was a universal phenomenon. Many other Authors have later inferred that the SR at birth could have been considered an invariant bio-statistical parameter. Its variations among different populations or short-term fluctuations appeared as random variations from the same level (e.g. Myers, 1947; Colombo 1956).

However, several contributions have directly challenged these conclusions (Chahnazarian 1990; James 1987). Many studies have shown that the ratios fluctuated from time to time, considering countries as a whole and regions or small areas (Møller 1996; Allan et al. 1997; Parazzini et al. 1998; Jacobsen et al. 1999).

Fellman and Eriksson (2011) noted that the secondary SRs progressively increased between the Eighteenth and the Twentieth Century, following the improvements in socioeconomic conditions, and the consequent stillbirth rates in the Nordic countries decreased. According to these Authors, during the demographic transition, SR's trends were associated with both the downward of stillbirth rates and a simultaneous drop in male to female differentials in stillbirth and early mortality rates.

After World War II, the trend changed, and the SR slightly declined in some, but not all, industrialised countries (e.g. Møller 1996; Parazzini et al. 1998; James 2000; Jongbloet et al. 2001). According to Davis and colleagues (1998), a declining trend occurred in Denmark 1950-1994 (Møller 1996), the Netherlands 1950-1994 (van der Pal-de Bruin 1997), Germany (van den Broek 1997), England and Wales (Manning et al. 1997), Canada 1970-1990 (Allan et al. 1997) and the United States 1970-1990 (Allan et al. 1997; Marcus et al. 1998). Even though the reasons for these long-term decreases remain not fully explained, they were connected to the effects of progressive changes in environmental conditions, living standards or population composition (e.g. James 2000), whereas annual short-term oscillations were mainly connected to wars (e.g. Bromen and Jöckel 1997) or other environmental shocks (e.g. Mocarelli et al. 1996; Catalano et al. 2008). Reasons for such changes are difficult to identify and are rooted in speculation about trends and trajectories in assessing primary sex ratios at conception and the process of selection *in utero* (for new insight see Orzak et al. 2015; for further comments, Austad 2015, Catalano et al. 2018), even though the systematic variations in the human sex ratio have still not been thoroughly explained.

Since less attention was focused on the short-term oscillations that were generally assumed to be due to random variability, this study detects the fluctuations of the sex ratios at birth in the short run, directly connecting them with late fetal mortality variations. More specifically, we aim to assess the effects of short-term fluctuations in late fetal mortality on the proportion of males among live births, after controlling for exogenous factors such as changes in reproductive behaviour, and unforeseen shocks due to the two World Wars.

According to the selection *in utero* hypothesis, an adverse effect of late fetal mortality on SR at birth is expected and stillbirth series are used as a proxy of late fetal mortality.

Nevertheless, as a quote of stillbirths could be erroneously misregistered among early neonatal deaths (or vice versa), in a separate sensitivity analysis we also look at the effects of the perinatal deaths on the proportion of males at birth, combining stillbirths and early neonatal losses.

We used Italian birth series by sex from 1910 to nowadays, together with other available series of late fetal and neonatal mortality rates, the proportion of high parity births and maternal age classes. Because of the data availability, we could also include more precise covariates for the time interval 1930-1998, taking into account early neonatal death rates in the first day of life and the late neonatal one from the second to the thirtieth day. Given the country under study, we could exclude that the variations in the sex ratio at birth could be due to direct human intervention, such as selective abortion favouring males as it would be hypothesised for some Asian countries (Bongaarts and Guilmoto 2015).

Assuming a secular perspective and following a traditional statistical approach, we estimate the short-term effect of stillbirth mortality rates on male neonates' proportion at birth through regression techniques.

The outline of this paper is as follows. In the next section, we briefly review the literature on trends and variations in the sex ratio, providing a theoretical background to explain their short-term fluctuations. We also anticipate the hypothetical mechanisms that linked sex ratios to late fetal survivorship. After presenting the data, we describe Italian secular trends in the ratio among neonates from 1910 to 2016, to detect the main historical tendencies and show short-term fluctuations. Then we illustrate an approach combining temporal regressions and medium-term detrended series to measure the short-term impact of late fetal mortality on the proportion of male at birth, controlling for war effects, Spanish flu pandemic, and, when data make it possible (e.g. 1930-1998) also for birth parity and age class of the mother. In the last paragraph, we discuss the results and come to the conclusions.

Background and Hypotheses

In this section, we formulate a hypothetical mechanism to model the effects of short-term fluctuations in late fetal mortality on the proportion of male at birth while controlling for the main exogenous factors. In this theoretical framework, we explicitly assume that short-term fluctuations in the proportion of male neonates could be due to random variability and determined by intrauterine and fetal conditions.

In the following paragraphs of this section, we briefly review previous studies and empirical findings, to provide a theoretical background for our statistical strategy in the Method section.

Postulating as a central hypothesis a higher male fragility than female ones, even before childbirth and after conception (McMillen 1979; James and Banks 200) or even just in the late phase of gestation (Orzak et al. 2015), means that intrauterine mortality should more frequently eliminate the male fetuses. Therefore, we examine the broader literature on sex ratio variation and fetal selection considering that *in utero* selection, and the birth sex ratio varies over time in response to a wide range of ambient shocks (Bruckner and Catalano 2018). As a consequence, this selection mechanism directly impacts on the proportion of male at birth.

Empirically, owing to the lack of information and the difficulty to measure intrauterine mortality, we assume that an indicator related to late fetal survivorship, such as the stillbirth rate, could act as a fair proxy of the fetuses' mortality risk during all or part of the pregnancy. As a matter of fact, in our empirical model, stillbirth rates could capture late fetal mortality as well as at least a part of intrauterine mortality in early fetal life periods. Thus, given the higher fetal male vulnerability, we expect that sudden fluctuations in late intrauterine mortality could affect variations in male proportions among births impacting in the short-term dynamics.

Other possible factors could affect both the sex ratios and the late infant mortality, consequently confounding the stillbirth effect measure in an empirical model. For this reason, our framework also needs to control for the role of concomitant factors.

Since the mother's age and birth order are supposed to be inversely linked to the prevalence of male births, it is important to control for the effects of these two variables on male proportion among neonates.

As pure external agents such as wars, epidemics, or environmental shocks could play a concomitant role in causing sudden fluctuations in the relative number of male newborns, they also need to be under control when the explicative model is defined.

It must also be recalled that a part of the stillbirth registrations may have been mistaken for early neonatal deaths, and *vice versa*, due to varying registration norms and difficulties in distinguishing them in case of premature newborns (Di Comite 1968, Pozzi 2000). Thus, the extent of the effects of late fetal mortality on the sex ratios may be affected by inaccuracies in the official registers. In these terms, it would also be necessary to consider a broader measure of perinatal mortality, based on the sum of the stillbirths and early neonatal deaths, as an alternative proxy for late fetal mortality.

In the next part of this section, we formulate four hypotheses about the effects of late fetal mortality on the sex ratios, and other factors that may affect this outcome. After stating each hypothesis, we elucidate the reasons for our expectation and briefly summarise what previous research has shown. The statistical model in the Method section will include the factors related to each hypothesis.

Hypothesis 1. Stillbirths – An increase in the male proportion among stillbirths reduces the sex ratio at birth

The observation of the long-term trends in most developed countries underlines a contradictory framework without a unified explanation. The analysis of SR calls undoubtedly back the role of bio-demographic and genetic dynamics of the sex ratio from conception to birth, a topic far from being solved. Contemporary studies find that one third and probably many more human conceptions end before live birth. Moreover, those who survive could not represent their conception cohort (Catalano et al. 2008).

As far as the primary sex ratio (PSR) is concerned, the claim that it could be more male-biased than the SR appears often in the scientific literature (e.g. Fisher 1930, Klug et al. 2006; Shettles 1964; Pergament 2002). One of the most referenced theoretical explanations has been the hormonal hypothesis (James 2013), which states that the PSR is tangentially constant and stable as a human physiology product.

After the conception, the intrauterine survival is affected by the embryo's viability and the immunological interactions between the embryo and the mother (Chahnazarian 1988). In these terms, assuming the higher proportion of male embryos at conception and the higher vulnerability of the male fetuses, the PSRs during the fetal life vary as a function of the *intra-utero* mortality. The probability of a male/female newborn should be determined by physiological mechanisms at conception and possibly by sex-specific intrauterine mortality and, therefore, inversely related to the frequency of prenatal losses. However, no universally consistent results testify the associations between sex ratios and stillbirths (Chahnazarian 1988).

New estimates of selection in utero derived from a large amount of data, and referred to the time interval from conception to birth (Orzak et al. 2015) challenged this classical hypothesis, suggesting that the PSR could be unbiased or only slightly male-biased. The sex ratio is supposed to decrease in the first week or so after conception (due to male-biased mortality), it then increases (female-biased mortality *in utero*), levels off after about 20 weeks later, and finally declines slowly from after that (due to excess male mortality roughly in the few months before the end of gestation). The Orzak and colleagues paper originality is that total female mortality during pregnancy would exceed total male mortality, despite the ratio comes up male-biased at birth (Orzak et al. 2015).

Recently, population health researchers have examined pregnancy and selection by means the hypothesis of evolutionary biology. The literature in the field finds that *in utero* selection, and the birth sex ratio, varies over time in response to a wide range of ambient shocks. According to these approaches, pregnancy can be considered an essential part of the mother's life history. Consequentially, selection *in utero* could appear greatest against fetuses likely to yield "the fewest grandchildren per unit of maternal investment" (Bruckner and Catalano 2018).

Other studies that embrace the same approach deepen these concepts underlining that the health composition of live-born males relates to the sex ratio of their birth cohort; and, more specifically, measures of stillbirth, and stillbirth sex ratios, may capture a portion, although minimal, of selection *in utero* against males. Catalano et *al*. (2009) show that high live birth sex ratios precede greater than expected male neonatal death.-Summing up, the stillbirth rates can be adopted as a proxy of the intra-uterine selection process, assuming late fetal deaths could mirror the lost fetuses in earlier pregnancy periods. According to the selection *in utero* hypothesis, stillbirths are expected to have a negative impact on the SR at birth. In these terms, increases in stillbirths' male proportion lead to a reduction in the SR's level.

Hypothesis 2. Wars and external shocks – Higher sex ratios at births are expected in the war years.

External events and shocks are supposed to link sudden variations in the sex ratio composition among neonates, since the SR at birth turned out to vary during wars in several European countries, still puzzling the scholars to find a non-contradictory explanation. Upward in the male proportion among births was observed in the twentieth century, during the two World Wars, in several European populations (James 1987; Ulizzi and Zonta 1995). Evident peaks in these proportions were identified during World Wars I and II in Germany (Bromen and Jöckel 1997; Graffelman and Hoekstra 2000). In Finland (Vartiainen et al. 1999; Helle et al. 2009), and the Netherlands, these peaks only occurred during World War II since these countries had remained neutral in World War I or had not directly suffered the cruellest effects of the conflict (Bromen and Jöckel 1997; van den Broek 1997). The reason for the increasing SRs during wartime is not yet well understood. According to the "hormonal explanations" (James 2009), the observed increase of male births is probably due to women and men's prolonged stress status.

Following the Trivers-Willard's (1973) evolutionary hypothesis that selection should appear most significant against those that require the most excellent maternal investment to survive to reproductive age, theorists hypothesise that conception cohorts in gestation during stressful times will exhibit high ratios of males to females among clinical detected fetal deaths and low ratios of male to live female births.

Bruckner et al. (2010) find a sex ratio at birth below 1 in months immediately following 9/11 attack in New York and inferred excess male fetal loss among gestations in weeks 20-24 at the time of the terrorist attack. Similar results are obtained for California (Singh et al. 2017).

Even the economy could play as a stressor (Catalano et al. 2005): in California, a sudden rise in male relative to female fetal deaths in months after raises in the unemployment rate (that accounted for over 3% of overall male fetal deaths).

Similar effects are described for stressors as Earthquakes (Torche and Kleinhaus 2011) and Ramadan (in terms of nutritional disruption) (Almond and Mazumder, 2011). In both cases, they tend to lower the sex ratio among pregnancies with some lags. Other external and environmental agents could also be at work affecting sex ratios at birth both in the long and short run. (Sieff 1990; Fellman and Eriksson 2010). The decline in SRs has also been related to the spread of specific chemical agents (Fellman and Eriksson 2011; Jarrell 2002; Vartiainen, Kartovaara and Tuomisto 1999). For example, these chemical agents could have an evident impact in the short run as in the sudden reduction in the number of male neonates reported in Seveso, an Italian town, after an industrial accident with a large dioxin spillage (Mocarelli et al. 1996).

In the Italian case, during the period under study, the Spanish Flu of 1919 and World I and II are identified as critical and stressing periods for pregnant women.

Hypothesis 3.1 and 3.2. Changes in reproductive behaviour - Sex ratios decrease at the higher parities and the older maternal ages

At the aggregate level, the frequency and composition of births and parents' characteristics could impact the sex ratios. Indeed, literature associates the intra-population variations with some demographic factors such as birth parity and the mother and father's age (James 1987; Chahnazarian 1988, 1990; Biggar et al. 1999). In her comprehensive review, Chahnazarian (1988, 1990) reported that maternal age, paternal age, and birth order are the three demographic factors that have been supposed to affect the SRs. These factors are mutually correlated, and multivariate studies and microdata are generally necessary to control their combined effects. Considering the Italian case, although the association with maternal age in their study was inconclusive, Ulizzi and Zonta (1995) found that as maternal age increased, the sex ratio also increased. Furthermore, Jacobsen et al. (1999) demonstrated for 1983-1994 Denmark that SR decreased with an increased number of children per plural births and with paternal age. In these terms, the male majority seems higher in first births than in subsequent orders, both among live and total births (Colombo 1956; Chahnazarian 1988; James 1987; Teitelbaum 1972; Erickson 1976; Sieff 1990).

Then, possible sex ratio trends could also reflect long-term changes due to the fertility transition process and implying a modification both in parity and in the parents' ages (Wilcox, 2010). Even though this kind of association is not the primary focus in this paper, we will consider it in the statistical models as control factors. More specifically, we expect to observe a decrease in SRs' levels at higher parity (hypothesis 3.1) and the higher maternal ages (hypothesis 3.2).

Hypothesis 4. Perinatal deaths - Because of the misregistration issues, an increase in the male proportion among perinatal deaths decreases the sex ratio at birth

It is well known that historical stillbirths' data are affected by quality issues due to erroneous registrations, as it can occur that early neonatal deaths and stillborn babies are not correctly distinguished. Because of these data quality problems, 'false' neonatal male deaths can impact the levels of the sex ratio at birth. Perinatal deaths will then be used by aggregating stillborn infants and early neonatal deaths. In a further sensitivity analysis, if the misspecification issue is real, a decrease in males' weight on the total number of live births is expected as male perinatal mortality increases.

Methods and Materials

Data sources in Italy

In the present study, we use national births series by sex to handle historical and contemporary official data from the National Italian Institute of Statistics (Istat 2011). Annual series of live birth would be available since 1864 but, as a matter of fact, previous studies already warned about the possible misclassifications of births as either live births or stillbirths in civil national and religious sources (Breschi et al. 2012).

Before the 1910s, the main quality issues are related to the various record procedures of stillbirths/deaths in the first days of life. The neonates who died before the registration (5 days) were considered stillbirths by the law, while the General Direction of Statistics gave specific instructions to compute neonates who died before the notification but gave a sign of life as alive babies. The divergence between the legal and the statistical criteria probably caused a bias in the classification overestimating the stillborns (Pozzi 2000). Then, the increase in the number of stillborn babies before 1910s, and the subsequent reduction were mostly due to changes in the recording procedures (De Vergottini 1965; Di Comite, 1968). Another data issue concerns the possible misclassification of the deaths in the first month of life since before the first decade of the twentieth century some could be erroneously reported in the number of deaths in the subsequent months of post-neonatal period (Pozzi 2000; Del Panta 1997).

Because of this data problems, we limited the first part of our analysis to the time interval from 1910 to 2016 for which long series of sex ratios at birth, stillbirth rates and neonatal death rates in the first month are available.

Nevertheless, although changing definitions of stillbirth over time and cultural shifts complicate direct comparisons of overall counts and rates of stillbirth, we know of no report which suggests that these changing definitions and cultural norms apply disproportionately to one sex in the historical period considered. For this reason, the annual proportions of male births and stillbirth may offer a valid and consistent estimate of the potential disproportionate male representation. However, as already said, in a further sensitivity analysis, we assess this possible data issues by measuring the impact on the SRs of the perinatal mortality series.

We refined the second part of our analysis, including the national series of the deaths in the first day of life that, unfortunately, are available in Italy only starting from 1930. Then, the perinatal deaths for the sensitivity analysis were based on stillbirths and early neonatal deaths aggregation on the first day of life. Furthermore, this second analysis controls the effects of other indicators related to the fertility change, such as live births by parity and age class of the mother, the first one not published anymore after 1997.

Because of the lacking in data, we have constructed the perinatal mortality series considering the deaths in the first month of life from 1910 to 2016. On the contrary, we can focus on perinatal mortality data related to the first day of life and fertility indicators only for the shorter interval from 1931 to 1997. We must recall that from 1980, the Italian National Institute of Statistics (ISTAT) changes the definition criteria of the birth's parity classification, which counts births for the woman's live births instead of to the marriage (Bonarini 2018). However, this variation does not seem having left signs in births trends by parity.

A regression approach

To measure the impact of the late fetal variations on the composition by sex among the neonates in the short term, we estimated a set of regression models using annual time-series.

Given the time-series nature of our data, we have chosen a classical approach which comes from historical demographic studies where regression techniques were combined to a detrending series method to measure the short-term shock of prices on vital rates, by using residuals from the 11-terms moving average series (e.g. Lee 1981; Galloway 1988). Thus, both the dependent and independent variables have been preliminarily detrended of their medium-term component using a proper filter. While several methods can filter time series data, including the most known Hodrick-Prescott (1997) filter, we rely on the Hamilton filter, as prior literature has suggested that it produces more robust results (2017).

Dependent variable

We decided to assume as dependent variable the annual proportion of male neonates (PM) at birth instead of the sex ratio (SR). The PM's denominator that refers to the total amount of live births is larger than in sex ratios and, consequently, less affected by random variability.

Nevertheless, we obtained similar results, not reported here for the sake of brevity, when we estimated the regression models assuming the classical sex ratios as a dependent variable.

To detect the dependent variable's autocorrelation order, we preliminary explored the autocorrelation and the partial autocorrelation functions (respectively, ACF and PACF) related to the male proportion of live births. When a significant autocorrelation at 97.5% was found, the model's regressors also included the dependent variable lagged according to its autocorrelation order.

Detrended series

As already said, since we are interested in how stillbirth levels could impact on the proportion of male neonates in the short-term, the residuals from a medium-term trend for each series were preliminary calculated by using the Hamilton filter (Hamilton 2016). These residuals represent the deviations from "normal years" for both the dependent and the independent variables. Therefore, positive and negative residuals indicate higher or lower values than the average trend in the medium run. The regression measures the effect of the deviations in late fetal mortality on the variations of the proportion of male neonates through the estimated parameters.

Main analysis

The first model refers to the period from 1910 to 2016. We include the proportion of males among stillbirths as main covariates (PSB).

In this first equation, the PSB is considered a proxy for intrauterine mortality. Referring to Hypothesis 1 on the selection *in utero* process, it is supposed to have a negative effect on the proportion of males among live births, assuming that a sudden increase in the PSB variable could produce a decrease in the PM series.

The verification of Hypothesis 2 needs an additional dummy variable that controls for the First and the Second World War (1915-1918; 1940-1945), the post War period (1946) and the epidemics of 1919 Spanish Flu.

The equation in 1.1 shows the form of the first estimated model.

Since a second autocorrelation order has been detected in the PM's serial structure employing ACF and PACF, the independent variables also comprise a one and two years lagged proportions of males, respectively indicated as PM_{t-1} and PM_{t-2}.

The β_0 and β_1 parameters in (1.1) refer to the lagged dependent variable effects, whereas the β_2 coefficient measures the effect of the short-term fluctuations in the proportion of male stillbirths (PSB) trends on the PMs, and the β_3 coefficient is related to the dichotomous controls. The subscription *t* refers to the current year.

$$PM_t = \beta_0 PM_{t-1} + \beta_1 PM_{t-2} + \beta_2 PSB_t + \beta_3 year_{war} + \alpha_t \qquad (1.1)$$

After the OLS model estimations, we calculate ACF and the PAC of the residuals to verify the existence of autocorrelation among errors. As some presences of residual autocorrelation of the fourth-order were detected, we estimated a further model using the Newey–West correction to provide consistent estimators of the coefficients' variances (Stock and Watson 2011).

We also estimate a second model for the shorter time interval of 1931-1997. As already recalled, for this period, fertility variables on birth parity and maternal age distributions are present in the Istat database.

To control fluctuations in the fertility trends, we included the Hamilton detrended series of birth parity in the analysis measured as the percentage of live births equal or greater than 3 (PAR3) and birth proportion from mother aged 35 and more (AGE35). No statistically significant autocorrelation of the dependent variable existed, and thus no lagged dependent variables have been furtherly included. Therefore, equation (1.2) is as follows:

$$PM_t = \beta_0 PSB_t + \beta_1 PAR3_t + \beta_2 \text{AGE35}_t + \beta_3 year_{war} + \alpha_t \quad (1.2)$$

According to our central Hypothesis 1 on the effect of intrauterine mortality, we expected that PSB has negative linear effects on PMs. As Hypothesis 3.1 and 3.2 assume that sex ratios are reduced at higher parities and the older maternal ages, negative linear effects are also supposed for PAR3 and AGE35 proportions. In World War I and II years, a positive linear relationship is possibly expected as already seen in some other countries (Hypothesis 2).

By performing the ACF and PACF, no autocorrelation emerged among the OLS residuals, and thus no Newey estimators were calculated.

Sensitivity analysis

As Hypothesis 4 assumed, another dimension affecting SR fluctuations relates to the misspecification between still and alive births. Consequently, a quote of the events could plausibly fluctuate from one categorisation to the other due to changes in the normative and statistical rules as time goes by. Considering both fetal and early mortality together can easily keep this type of problem under control. Therefore, our sensitivity analysis considers the broader male proportion among the perinatal deaths (stillbirths plus neonatal deaths) (PPD) as the main regressor. Following Hypothesis 4, the male proportion among perinatal deaths (PPD) should be negatively related to males' weight on the total number of live births (PM).

For the first period under study from 1910 to 2016, perinatal deaths are the sum of stillbirths and neonatal deaths in the first month of life (eq. 2.1):

$$PM_t = \beta_0 PM_{t-1} + \beta_1 PM_{t-2} + \beta_2 PPD_t + \beta_3 year_{war} + \alpha_t \quad (2.1)$$

As in the previous equation 1.1, it was necessary to include the two lagged PM_{t-1} and PM_{t-2} variables due to the dependent variable's second-order autocorrelation. Since the residuals showed a significant fourth-order autocorrelation, we presented the estimates based on the Newey-West estimators.

For the shorter period from 1931 to 1997, we obtained the perinatal death events by adding stillborn infants and early neonatal deaths within the first day of life (eq. 2.2).

$$PM_t = \beta_0 PPD_t + \beta_1 PAR3_t + \beta_2 \mathrm{AGE35}_t + \beta_3 year_{war} + \alpha_t \quad (2.2)$$

In (2.2), the regressors do not include the lagged dependent variable as no significant PM autocorrelation was preliminary detected. We also presented the original OLS estimates since the residuals were not significantly autocorrelated.

Results

Sex Ratios Trends in Italy

This section focuses on the long-term trend of the proportion of male neonates in Italy from 1910 to 2016, reporting the confidence interval for each year (figure 1, left panel) and following the recent literature (Fellman and Erikson 2011; Fellman 2018).

It is worth to recall that analysing for Italy the 1926-1995 SRs trends, Parazzini and colleagues (1998) found no evident evolutions, whereas Astolfi and Zonta (1999) reported that during the 1970-1997 time interval the proportion of male births has significantly declined in the four most populated Italian provinces.

In figure 1 (left panel), it is possible to detect different phases in the observed trends. First, the interval, including the two World Wars from 1915 to 1945, does not show a well-defined trend, and is affected by noticeable fluctuations. As stated by literature, we register an evident increase at the end of World War I, whereas the rise in 1946, one year after the end of World War II appears less intense. If we consider the maximum value reached in 1916 the increase in the proportion at birth was 0.6% in World War I for the average values of the five-years interval 1910-14, and 0.3% in World War II comparing the maximum value in 1946 with the average in the period 1935-40. After World War II, Italy shows an upward trend in SR from 1950 to around 1995. According to previous studies, this tendency could relate to variations in fetal mortality levels (stillbirth rates), when the general living standards and prenatal and natal care progressively increased in quality.

Looking at the more recent tendencies, PMs at birth slightly declined in the last two decades, revealing a delay of some twenty years to other developed and industrialised countries.

Still, at figure 1, the right panel shows the deviations from the Hamilton trend. Having removed the medium-term trends, short-term fluctuations in males' proportions are evident with high and frequent positive peaks until the third decade of the Twentieth century. Afterwards, we can notice that the variations persist but within narrower boundaries.

Figure 1 - Here

Late fetal and neonatal mortality trends in Italy

Assuming late fetal and more generally perinatal mortality rates as proxies of intrauterine mortality, we preliminary explore the stillbirth rates and the main early mortality measures in Italy from 1910 to 2016. We then take into account early deaths soon after birth on the first day of life. Two main features of figure 2 are worth considering (see the left panel). The first is the persistent and robust decline of stillbirth rates worldwide; the second relates to the differentials in male to female mortality levels that close only after 1980. From figure 2 (still at the left panel), an evident decline starts after World War I, and from the end of World War II, two simultaneous downwards can be detected both in stillbirth rates and in sex ratios in stillbirths as the gap between male and female curves progressively decreased until the end of the 1960s.

In the right panel of figure 2, we also reported the deviations from the Hamilton filter for both the male and the female stillbirth rates. Variations in short-term trends reflect the changes in the magnitude of the original series presented on the left panel, with large fluctuations in the first half of the period and a progressive and robust magnitude reduction in the second one. Interestingly, male and female residuals remain on similar values along the entire period.

Figure 2 – Here

Then we consider the neonatal death rates separately in the first day and month (figure 3, left panel). After the Wars, neonatal mortality started to decrease rapidly when the first month of life was taken into account, showing almost the same declining pace of stillbirth rates. Males always registered higher mortality rates than females.

Interestingly, first-day mortality shows a lower change than first-month mortality. The first and most substantial decrease in neonatal mortality in the first month is due to exogenous factors, whereas first-day mortality is related to risky endogenous conditions in antenatal or early natal life. Although male mortality is higher than female until 1990, the differential progressively reduced in the following years.

Figure 3 also shows the residuals from the Hamilton filters for the first day and month death rates by sex on the right panel. Even in this case, oscillations' amplitude follows the decrease in the absolute correspondent series's magnitude. The mortality rates in the first day and month for both sexes reflect the Wars' effects, while the oscillations for all the series converge toward zero in the last decades under study.

Figure 3 – Here

Regression results

The model regression results in tables 1 and 2 refer to different time intervals from 1910 to 2016 and from 1931 to 1997.

Looking at model 1.1 in table 1 that refers to the 1910-2016 period, the proportion of males among the stillbirths (PSB) has no significant effects on the PMs deviations from their medium-term trend, without offering any support for the Hypothesis 1. This lack of significance is probably due to a data quality issue since some stillborn infants could have been erroneously registered among neonatal deaths. The misregistration of the stillbirths could be more severe in the first years of the period under study. Interestingly, from model 2.1 still in table 1, the proportion of males among the perinatal deaths in the first month of life has a negative effect on the dependent variable PM with a 0.06 probability significance, confirming the expected Hypothesis 4. From this result, it is relatively straightforward that a quote of the neonatal deaths could be stillborn babies erroneously registered as live births.

Table 1 - Here

From 1931 to 1997 (table 2), the PSB effects estimate improves probably because of the better registrations and the additional control variables (model 1.2). In these terms, the PSB effect's magnitude increases to -0.02 with a 0.05 significance level, confirming Hypothesis 1 and the *in utero* theory selection. However, even for this latter period, it seems that a certain degree of misspecification between still and alive births still exists since the PPD series have a more substantial 0.034 negative impact on the PM with a fully statistical significance (model 2.2), supporting again Hypothesis 4.

Turning to consider the control variables, the magnitude and statistical significance of the war years seem to have a feeble effect and only for the period from 1910 to 2016. Indeed, this long time interval includes both the War World I and II (table 1, models 1.1 and 2.1). The positive effect sign is in the expected direction, partially confirming the increase in the male proportion at birth due to external shocks (Hypothesis 2). Nevertheless, no significant war effect is found in models 1.2 and 2.2 in table 2, which refers to the shorter period from 1930 to 1998, including only the War World II.

Finally, the effects of changes in the reproductive behaviour find only a partial confirmation regarding Hypothesis 3.1 on the higher parity effects. Indeed, only the proportion of birth equal or greater than parity 3 (PAR3) exerts an expected negative effect in both models 1.2 and 2.2 presented at table 2, respectively with a 0.05 and 0.07 significant levels.

Table 2 – Here

Focusing on the R-squared, we can note a decline from about 0.25 in models 1.1 and 2.1 (period 1910-2016) to 0.12 and 0.17 respectively in models 1.2 and 2.2 (period 1931-1997). We recall that in models 1.2 and 2.2. the significant birth parity effect is also present. However, as already said, a fourth-order autocorrelation significantly affects the residuals from models 1.1 and 2.1 for the period from 1910 to 2016. In these terms, the higher explained variation of the PMs could be partially due to the residuals' autocorrelation structure.

Final Notes

In this paper, we analyse short term fluctuations of the proportion of males in Italy considering two different periods according to the available data. Our central hypothesis is that the fluctuations in late fetal mortality could impact sex ratio variations because of a selection process involving the most fragile male fetuses during the intrauterine life (Hypothesis 1). We controlled for exogenous variables as war or epidemic shocks (Hypothesis 2) or parity of births and maternal ages (Hypotheses 3.1 and 3.2). In a further sensitivity analysis, we also checked the possible misspecification between stillborn babies and early neonatal deaths that could confound the estimated effect of male late fetal mortality on sex ratios.

The analysis shows that short variations in the male proportion of stillbirths had no significant effect for the first period from 1910-2016 (table 1). However, the proportion of males among perinatal death in the first month shows an effect in the expected direction bordering the statistical significance. This second result could explain the not statistically significant effect of the male stillbirths' since it was probably due to the possible "flowing" of some events from antenatal to postnatal phases depending on the changing norms of statistical classifications (Hypothesis 4). Unfortunately, the perinatal deaths from 1910 were derived summing stillbirths and deaths in the first month of life as the more precise data on earlier neonatal deaths are not available for the first decades of the Twentieth century. In these terms, this variable is an imprecise measure as it also considers the neonatal deaths after the first day of life, which are not a good proxy of late fetal mortality.

Looking at the analysis on the period from 1910 to 2016, wars and epidemic shock impact the sex ratios as expected, though with a very small coefficient and significance, supporting Hypotheses 2 related to a higher proportion of male births stressing exogenous events.

When the second and shorter interval from 1931 to 1997 is considered (table 2), it has been possible to calculate the perinatal mortality series considering the early deaths in the first day of life. Furthermore, we could control other types of variables underlined by the literature, such as birth parity and maternal ages. In this last set of models, the significant effects of stillbirths' male proportions confirm Hypothesis 1. Early perinatal deaths' male proportion has a higher magnitude and a statistically significant impact since it could capture the incorrect number of births, thus supporting Hypothesis 4.

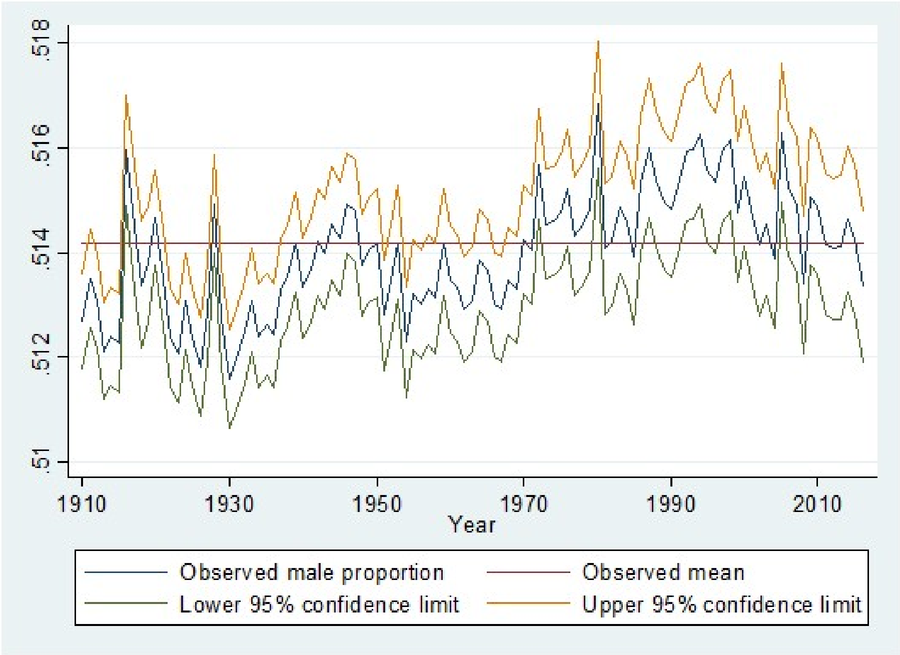
These results strengthen the primary hypothetical mechanism we already anticipated in Hypothesis 1, according to which the higher male fragility combined with sudden late fetal mortality variations could explain short-term fluctuations in sex ratios at birth. Our results support the hypothesis that short-term fluctuations in sex ratios are not exclusively due to random variability since variations in the male proportion of stillbirths or perinatal deaths could explain at least around 25% and 17% of the sex ratios variability in the short-term for the periods 1910 to 2016 and 1931 to 1997, respectively.

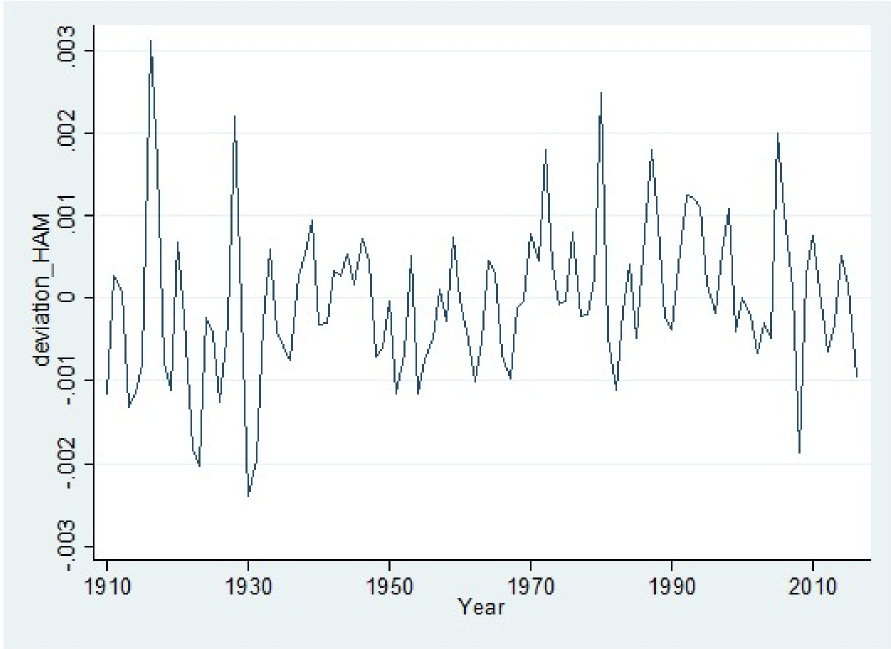
Pure external shocks such as the two World Wars or the Spanish Flu pandemic showed only weak significant effects.

We also controlled for the role of other demographic factors related to fertility trends (see table 2), as we stated formulating Hypothesis 3.1 and 3.2 respectively on the effects of higher birth parities and older maternal ages.

Variations in the proportion of births by mothers aged 35+ do not show statistically significant effects on male neonates' proportion. On the contrary, the proportion of newborns with parity equal or greater than three was found statistically significant and in the expected directions, confirming that higher parity births tend to produce less male neonates. However, since our objective is to study the PMs' short-term fluctuations, a higher proportion of high parity births in a given year could be probably due to a sudden change in the reproductive behaviour mainly implying postponements of first marriages and first childbirths. This kind of postponements could more frequently affect younger or new couples, still not set down and therefore more exposed to an unexpected economic crisis or other adverse conjunctures.

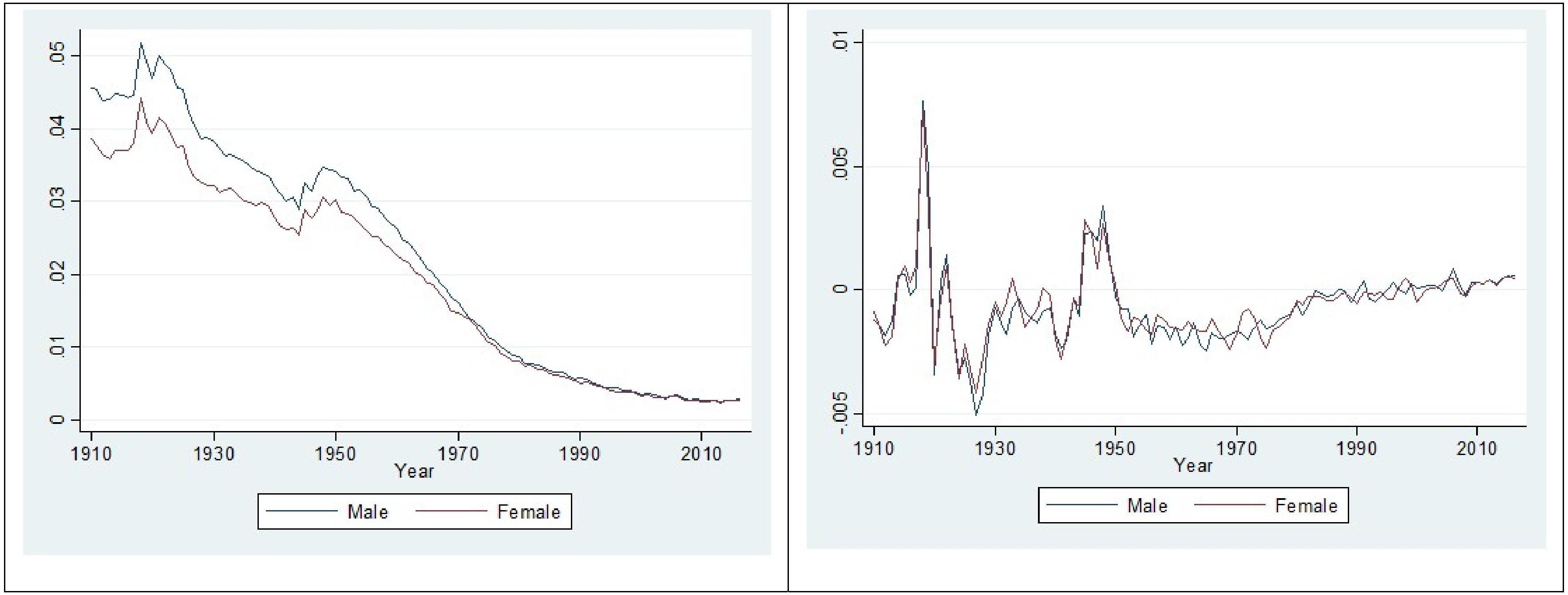
Figure 1 Proportion of males (left panel) and deviations from the Hamilton trend (right panel) in Italy, 1910-2016





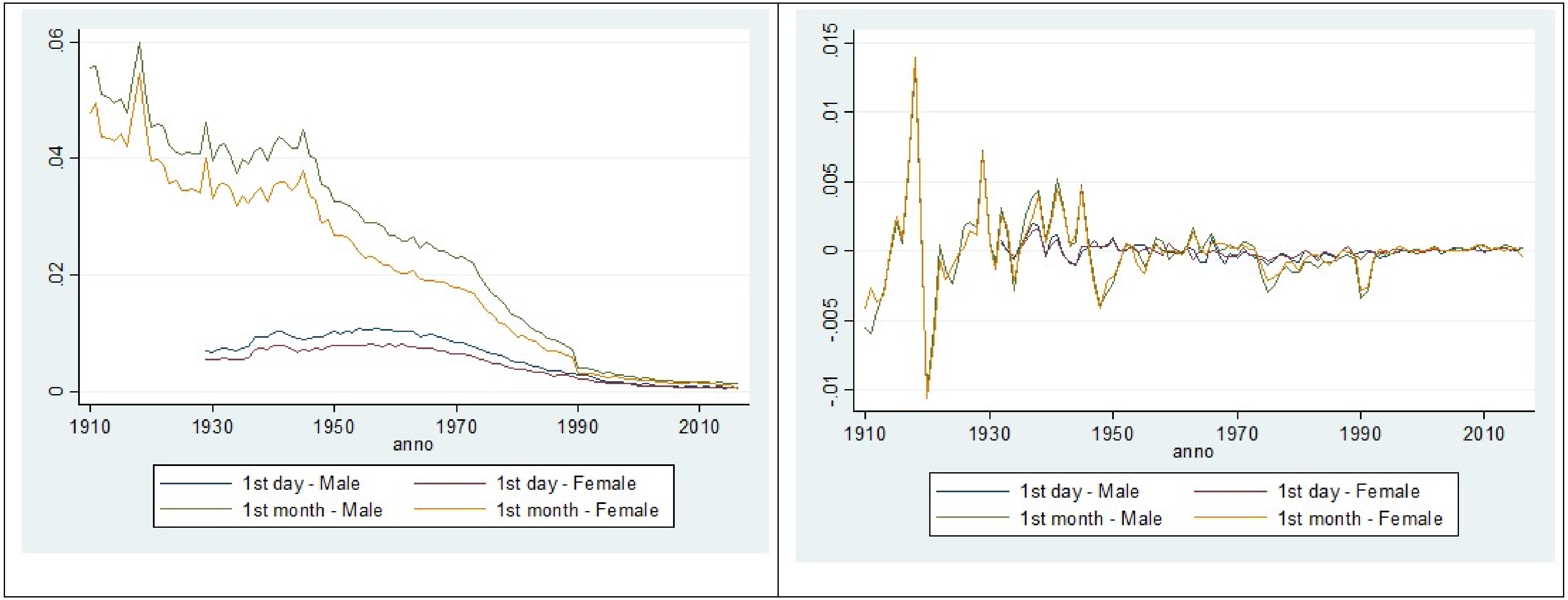
Source: ISTAT

Figure 2 Stillbirth rates by sex (left panel) and deviations from the Hamilton trend (right panel) in Italy, 1910-2016



Source: ISTAT

Figure 3 Neonatal mortality rates by sex (left panel) and deviations from the Hamilton trend (right panel) in the first day and month (0-30 days) of life in Italy, 1910-2016



Source: ISTAT

Table 1 - Regression models (OLS) for Proportion of Males among Live Births in Italy, 1910-2016

	Model 1.1		Model 2.1	
Dep. Var. = Proportion of males among live births	Coef.	P>t	Coef.	P>t
Proportion of males among live births – lag 1	0.3789	0.000	0.3831	0.000
Proportion of males among live births – lag 2	-0.3860	0.000	-0.3910	0.000
Proportion of males among stillbirths	-0.0084	0.155		
Proportion of males among perinatal deaths - 1st month			-0.0142	0.060
War Years	0.0004	0.069	0.0003	0.091
Constant	-0.0001	0.484	-0.0001	0.531
F	15.11	0.000	16.38	0.000
	0.245		0.251	
Number of obs	107		107	

Note: time-series preliminary detrended through Hamilton filter (2016)

Table 2 - Regression models (with Newey-West standard errors) for Proportion of Males among Live Births in Italy, 1931-1997

	Model 1.2		Model 2.2	
Dep. Var. = Proportion of males among live births	Coef.	P>t	Coef.	P>t
Proportion of males among stillbirths	-0.0202	0.053		
Proportion of males among perinatal deaths - 1st day			-0.0345	0.007
Proportion of births => 3 parity	-0.0153	0.055	-0.0136	0.076
Proportion of births => 35 years - maternal ages	0.0085	0.505	0.0056	0.650
War Years	0.0001	0.632	0.0002	0.475
Constant	0.0001	0.367	0.0001	0.132
F	2.09	0.093	3.13	0.021
R-squared	0.122		0.173	
Number of obs.	65		65	

Note: time-series preliminary detrended through Hamilton filter (2016)

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