Introduction

The well-being of immigrant children is a significant public health issue in countries that experience immigration (Kinge & Kornstad, 2013). It not only serves as a crucial measure of equality and overall welfare (Hemminki, 2014), but also provides insight into potential health disparities among different racial or ethnic groups in the future, during adulthood (Mehta et al., 2013). Inequalities in child health based on migration origins are prevalent in certain immigrant-receiving countries, including France.

France has made remarkable progress in child health, both within Europe and globally. The under-5 mortality rate (U5MR) is below 4‰, which is lower than the European average of 5‰ (UN IGME, 2019). In contrast, the global average stands at 39‰. Despite this overall improvement, disparities persist, especially in infant mortality among immigrant population (Wallace et al., 2020). This is concerning, particularly because France has witnessed a growing number of children born to immigrant parents, accounting for over 30% of births in 2018 and more than a third over the past two decades (Insee, 2023). Moreover, infant mortality has also risen recently in France (Claris, 2022; Trinh et al., 2022), despite a significant decline throughout the previous decades (Insee, 2018). These trends warrant special attention and further investigation.

Numerous studies have examined the health of children based on their migration backgrounds. The outcomes vary depending on the choice of indicators and the countries of origin and destination. For instance, Kinge & Kornstad (2013) found higher infant mortality among children of immigrant women from Africa and Asia in Norway, whereas in the U.S., children born to Mexican women showed lower infant mortality (Hummer et al., 2007). Results may even differ within the same country, depending on the chosen indicators. Previous research highlights a health advantage in terms of birth weight among children of North African immigrants in France and Belgium, as well as among children of Mexican immigrants in the U.S. (Guendelman et al., 1999). However, recent studies in France, based on different data and outcomes, have reignited the discussion on the health of immigrant children. One study documented higher infant mortality among children of Maghreb immigrants (Wallace et al., 2020), while another confirmed the advantage not only in birth weight but also in terms of preterm births and gestational age among children from the same immigrant group (Florian et al., 2021, 2023).

The variations in these findings raise questions about the actual role of migration origin in contributing to inequalities in child health. In other words, can disparities in U5M be attributed to differences in the distribution of confounding variables or to differences inherent in migration origin (Ma, 2008). By adopting a longitudinal approach, this study aims to fill the gaps in cross-sectional approaches (Grosser et al., 2016), as longitudinal research holds immense potential in generating robust estimates and conducting reliable analyses of determinants (Bocquier et al., 2019).

1. Background

1.1. Parental Socio-Economic Status and children's health

Parental socio-economic status (SES), which includes income and education, has been extensively examined in relation to children's health outcomes. Income serves as an indicator of the economic resources available to individuals through capital, employment, or wages. Parents with a decent income are more likely to adequately meet the family's essential needs and provide their children with a higher standard of living through healthy nutrition and adequate healthcare. Additionally, a higher standard of living can act as a protective factor against maternal postpartum depression, the most common postnatal complication in western countries, which likely impacts maternal quality of life, family functioning, and children's development and health (Nakamura et al., 2020). Moreover, income inequality is strongly correlated with infant mortality across all countries, although the causal nature of this association remains to be confirmed in the short term (Avendano, 2012).

Education is one of the most widely used proxy of SES in studies of inequalities in health and mortality. By enabling individuals to understand health promotion messages, improve their medical knowledge(Hoffmann et al., 2018) and access economic and social resources (Green & Hamilton, 2019), parental education, particularly that of mothers, can positively influence children's health at all stages of their development. Revisiting the education-health link using a distributional approach in 153 countries from 1970 to 2016, Shorette & Burroway (2022) reveal that the education advantage is distribution-specific. Specifically, the anticipated advantages of women's education are particularly evident in the middle of the distribution, where infant mortality rates (IMR) range from approximately 11 to 55 deaths per 1,000 live births, but show no significant effect where IMR is either comparatively low or high. This finding is both consistent with and contradictory to previous research, providing a more nuanced picture of how women's access to education relates to global health inequalities.

1.2. Healthy immigrant paradox

The healthy immigrant paradox is attributed to the unexpected health advantages of immigrant groups settled in host countries despite their low SES. Although it has long been discussed in relation to the health of adult immigrants, it can also be observed among children born to immigrant mothers (These native-born children of immigrants are not immigrants themselves but are sometimes called "second-generation immigrants"). Despite their mothers' disadvantaged SES and limited use of prenatal care, the native-born children of Hispanic women exhibit comparable or even better health outcomes compared to those born to non-immigrant mothers in the U.S.(Green & Hamilton, 2019; Mendoza, 2009). A similar advantage is documented in perinatal outcomes for African and Latin American mothers in Spain (Farré, 2016; Stanek et al., 2020, 2021).

The "healthy immigrant" effect suggests that individuals who migrate to host countries are selected by either the host countries themselves, or through self-selection among predominantly healthy individuals (Nørredam, 2015; Agyemang, 2019). In the context of children's health, this implies that there is an intergenerational transfer of health advantages, i.e. an indirect selection whereby healthy immigrant women of childbearing age are more likely to give birth to healthy babies. Evidence supporting this selection has been found in various settings, including France, Belgium, Austria, Spain, U.S. and Canada, with respect to infant mortality or other birth outcomes such as low birth weight, preterm births, and gestational age (Farré, 2016; Guendelman et al., 1999; Hummer et al., 2007; Vang et al., 2015; Sow et al., 2019; Florian et al., 2021, 2023).

1.3. Social capital

The theory of social capital has been proposed to explain the health advantage experienced by immigrants. As described by Putnam (1993), social capital refers to the attributes of a social organisation, including networks, norms, and social trust, which benefit both individuals and society as a whole. Coleman (1988) identified three key components of social capital: obligations and expectations, information channels, and social norms. These elements collectively shape social relationships and contribute to the concept of social capital.

To quantify social capital, various measures have been employed at both the individual and community levels, although most focus on the individual level (Kanas et al., 2012; Allen et al., 2014; Siedlecki et al., 2014; Koelet et al., 2017). Thus, participation in charitable activities, affiliation with a political, apolitical or religious group and any situation that enables social ties to be developed and maintained are individual dimensions of social capital.

At the individual level, social capital can be assessed through both formal support provided by midwives, general practitioners, and other health professionals and informal support offered by partners, family members, or close acquaintances (Nakamura et al., 2020). Formal support is perceived through the lens of the relationships between caregivers and patients, and when these relationships are strong, they can ensure better pregnancy follow-up and improved birth outcomes. Family support also plays a crucial role in pregnancy outcomes (Benza & Liamputtong, 2014) due to its significant influence on the lifestyles and health-related behaviors of its members (Fortin & Le Gall, 2007). Similarly, the support of partners is essential to meet economic needs and strengthen parental involvement or their contribution to maternal and child health (Fiori, 2020; Nakamura et al., 2020). Evidence supporting this notion was provided by Gaudino et al. (1999), who showed that paternal support during childbirth had a protective effect against low birth weight and infant mortality.

At the community level, most measures assess the socio-ethnic and economic characteristics of the neighborhood or area. The most commonly used socio-ethnic dimension is the concentration of immigrants from the same origin in the neighborhood (Muchow & Bozick, 2022). Van Kemenade et al. (2006) referred to a similar concept when discussing social networks based on ethnicity. This entails relying on close-knit networks of individuals from the same cultural background, which promote economic and social integration (Van Kemenade et al., 2006; Gill & Bialski, 2011), as well as a better understanding of the healthcare system (Albertini Früh et al., 2017) and the well-being of immigrants (Van Kemenade et al., 2006; Zhao et al., 2010).The impact of these networks on children’s health has also been documented. As showed by Zeitlin et al. (2011), there is an inverse relationship between the proportion of immigrants in the neighborhood and preterm births among women from Sub-Saharan Africa, and a positive correlation for women born in France. In a cross-sectional ecological study, social capital at a level below the state (trust, association membership) was strongly associated with higher infant mortality rates among Blacks (Kawachi et al., 1997).

Regarding the socio-economic dimension of neighborhoods, its effect on children's health has been the subject of numerous studies. Clausen et al. (2006) showed that residential areas of lower SES had higher risk of pregnancy complications in Oslo East. Spencer et al. (1999) and Bundred et al. (2003) further proved that the most deprived neighborhoods or areas had higher levels of low birth weight in England (in the north). Even more detailed analyses confirm the effects of neighborhood socio-economic level on children's health in the U.S. In a multilevel cross-sectional analysis, Buka et al. (2003) put these effects into perspective by showing a significant decrease in average birth weight as the level of economic disadvantage in the neighborhood increased, and only for African-American mothers. The study of Calling et al. (2011), which reports an increase in infant mortality associated with high levels of neighborhood deprivation in Sweden, supports the hypothesis that neighborhood factors are significantly associated with infant health.

1.4. Discrimination

Several studies have examined the interactions between caregivers and patients, with a specific focus on discrimination and its role in contributing to health disparities.

A recent United Nations analysis of Black women's experiences during pregnancy and childbirth in the Americas concluded that systemic racism in medical systems is one of the main reasons they are more likely to experience serious complications (UNFPA, 2023). Numerous ethnographic studies in France have documented discrimination against women of foreign origin in hospitals at the time of gynecological and prenatal consultations and during or after childbirth (Fassin, 2000; Saurel-Cubizolles et al., 2017; Ouanhnon et al., 2022). This can contribute to inequalities in birth outcomes. Increased preterm births, low birthweight and low gestational age outcomes among women who have experienced discrimination (Rich-Edwards et al., 2001; Rosenberg et al., 2002; Mustillo et al., 2004; Giurgescu et al., 2011; Daalen et al., 2022) are illustrative of the link between (the perception of) discrimination and adverse birth outcomes. Indeed, racial discrimination or discrimination linked to migration origin can act on children health through several mechanisms. It can, via the psychological stress and immunodepression it engenders, stimulate the production of corticotropin-releasing hormone in the placenta, which in turn may increase the risk of preterm delivery (Rich-Edwards et al., 2001). Also, discrimination in hospitals can exacerbate tensions during prenatal or postnatal consultations, lead to the renunciation of care during pregnancy and thus have a negative impact on pregnancy follow-up. Finally, risky behaviors (smoking, alcohol and psychoactive substance use, etc.) during pregnancy may be a response to the chronic stress generated by racial discrimination (Rosenberg et al., 2002; Brondolo et al., 2009). These risk behaviors as well as indicators of child health such as preterm births, low birthweight, and gestational age are important predictors of infant mortality (Evans & Alberman, 1989; Reichman & Teitler, 2006; Farré, 2016; Štípková, 2016; Ballon et al., 2019; Kihal-Talantikite et al., 2019).

1.5. Country of origin context

Few studies in the literature deal with the context of the country of origin. One example is provided by Kinge & Kornstad (2013), whose study focused on infant mortality differentials according to migration origin in Norway. Using the mortality rates prevailing in the mother's country of origin as a proxy for the socio-sanitary characteristics of the country of origin, they found that immigrants from countries with high infant mortality rates have a higher infant mortality rate in Norway. According to them, the attributes of the country of origin are likely to influence the factors associated with infant mortality in the host country.

This finding is consistent with that of Väisänen et al.(2022) that women from the poorest countries have the worst reproductive health. This means that "*the inequalities observed in a global scale in countries' economic outcomes may reproduce themselves as reproductive health inequalities among migrants living in wealthy countries*" (Väisänen et al., 2022). Differences in cultural and environmental factors between the country of origin and the host country, perceptions of healthcare services and a general lack of knowledge about the host country's healthcare system may explain these disparities.

2. Hypotheses

Based on the aforementioned theories, we have formulated the following four hypotheses:

- Considering the effect of migratory origin on children's health and the link between a country's level of development and infant mortality, we posit that disparities in under-5 mortality not only explained by migratory origin but also exhibit a hierarchy based on the level of development of the immigrants' regions of origin (H_1).
- Based on the effect of mixed unions on improving the SES and integration of immigrants, as documented in other studies (Meng & Meurs, 2009; Rodríguez-García, 2015) and the protective effect of parental SES on children's health, we adopt the hypothesis 2 (H_2): children of mixed-origin parents have mortality risks equivalent to those of children born to native parents, attributed to the integration facilitated by mixed unions and the resulting economic and socio-professional advantages.
- Concerning our third hypothesis (H_3), which is based on the positive benefits of social capital, it indicates that: paternal support, which includes the psychological and material support provided to the mother, reduces the risk of under-5 mortality.
- The last hypothesis 4 (H_4) suggests that: a higher percentage of births to immigrant women in the local municipality of birth (assuming positive effect of migrants' social support and social capital) is associated with lower under-5 mortality among immigrant than among native-born.

3. Methodology

3.1. Data

This study uses data from the permanent demographic sample (EDP). The EDP is France's largest socio-demographic panel. It contains individual-level anonymized records on life events from civil register and census data. Eligibility for the sample is based on date of birth. Prior to 2004, the sample consists of individuals born between 1 and 4 October, and from 2004 onwards, of births occurring in the first four days of the first month of each quarter. Our sample contains 687,535 births from 1990 to 2020, representative of all births in France. The number of deaths under age 5 is 3,024. The implementation of the longitudinal analysis was strongly based on the tools developed by Bocquier et al. (2019) for longitudinal data management and analysis within the framework of the Event History Analysis method in Stata.

3.2. Regression analysis

Prior to presenting the multivariate analysis, we will provide a description of the steps involved in the propensity score method. This methodology allowed us to create a weight variable, which will be used to properly balance the dataset across the variables used in the subsequent multivariate analysis.

3.3. Propensity score method

The propensity score method is used to balance or make similar the characteristics of two groups in order to compare them on a given dimension. It involves synthesizing all these characteristics or conditioning variables into a single variable known as the propensity score. Introduced by Rosenbaum & Rubin (1983), the propensity score defines the probability of receiving treatment based on the observed variables between two groups, with one designated as the treatment group and the other as the control group. Through this method, a hypothetical group of study participants is created. In our study, the group of interest (i.e., children of immigrants) is similar to the reference group (i.e., children of natives) in terms of some observed characteristics other than migration origin (Ma, 2008).

Mathematically, the propensity score noted e(x_i) is such that e($\boldsymbol{x_i}$)=P($\boldsymbol{z_i}$=1|$\boldsymbol{x_i}$). Given our two distinct groups, children of immigrants and children of natives, with the latter being the treated group, we estimate the propensity score using the available data *(z_i,x_i)(i=1, 2,...,N),* where:

$$\begin{cases} z_i = 1 \ \ for\ children\ of\ natives \\ z_i = 0 \ \ for\ \ children\ of\ immigrants \\ x_i = set\ of\ covariates\ for\ individual\ \ i \end{cases} \qquad (1)$$

This estimation is carried out in several steps. Selecting the covariates required for estimating the propensity score is the initial step. For more details see appendix.

The propensity score is then estimated using an appropriate estimation method. The final step is to analyse the balancing properties of the propensity score, re-running the first two steps if necessary. Analyses were carried out in R (version 3.0.2) in particular using the cobalt and MatchIt packages (Greifer, 2022a, 2022b).

The choice of covariates was based on the results of the Oaxaca-Blinder decomposition carried out in a previous analysis. These results showed that the most significant disparities in U5M were associated with the age of the mother or father at the child's birth and the father's socio-professional category (SPC). In addition to these variables, we also considered the marital status of parents and other variables relating to the child's characteristics such as infant sex, plural birth and region of birth of the infant in France to estimate the propensity score.

Following a logistic regression to examine the probability of being born to a native mother based on these explanatory variables, we estimated the propensity score using the weighting method. It involves assigning each unit a weight w_i corresponding to the inverse of its probability of belonging to one of the two groups to which it belongs: the inverse of the propensity score, $e(x_i)$ for the native-born group and $1-e(x_i)$ for immigrant-born group. Thus,

$$\boldsymbol{w_i} = \frac{z_i}{e(x_i)} + \frac{1-z_i}{1-e(x_i)} \qquad (2)$$

This method ensures a robust balance of covariates, similar to that of a full matching (Austin, 2013; Austin & Stuart, 2015, 2017). These balances were assessed through several tools, some of which are presented in the appendix and results section. Once equilibrium was achieved, making the two groups almost similar, we used the propensity score obtained to generate a weight variable, which then be applied to the database (longitudinal section).

3.4. Survival Analysis

In order to assess the impact of migration origin on under-five mortality (U5M), the Weibull model was used. This model was chosen because of the similarity of the curve of the hazard function (of U5M) to that of a probability density function of a Weibull distribution (Fig A.1, Appendix). The Weibull distribution, belonging to the family of parametric probability distributions along with the normal and exponential distributions, offers some distinct advantages. As a properly specified parametric model, it helps address statistical challenges that arise from limited event occurrences (Scholey, 2019) such as the deaths occurring before one year.

- Model specification

Weibull regression modelling involves estimating the parameters of the covariates, assuming that they exert a multiplicative influence on the hazard function. This relationship can be mathematically expressed as follows:

$$\lambda(t|Z) = \lambda_0(t)*exp\ (\beta'Z)\ ,\ t\geq 0 \qquad (3)$$

where $$\lambda_0(t|\rho) = \rho t^{\rho-1}\ ,\ \rho > 0\ and\ t \geq 0 \qquad (4)$$

λ_0(t) denotes the baseline hazard function or baseline risk, independent of covariables in the model. A higher baseline hazard reduces the proportion of children surviving to a given age.

The Weibull distribution is characterized by several parameters, with ρ representing the shape parameter in the model. This parameter is assumed to be constant and not dependent on any covariate (Wagstaff & Nguyen, 2002). If ρ > 1 it means that the hazard function increases over time. In practical terms, this indicates that the risk of under-5 mortality (U5M) increases as time progresses. In other words, children are at a higher risk of dying as they grow older within the age range under study**.** If ρ = 1, the hazard function is constant over time, which would indicate that the risk of mortality remains constant over the period studied. If ρ < 1, the hazard function decreases over time, implying that the risk of mortality decreases as time progresses. It is worth noting that in a broader context of the Weibull model, two additional parameters, namely the scale (θ) and position (δ) parameters, can be considered. The Weibull model described above represents a special case in which θ=1 and δ=0.

β' is the vector of parameters or regression coefficients and Z is a vector of covariates or determinants of child survival? Differences in U5M probability between children born to native mothers and other groups are measured by the Hazard Ratio (HR) mathematically expressed as follows:

$$HR = e^{\beta_i} \qquad (5)$$

where *i* represents each category of categorical variables.

- Variables

The outcome variable is death occurring before the child's fifth birthday. The independent variable is the parental origin measured by the country of birth of the parent (father or mother). Six categories of origin are identified: Sub-Saharan Africa, North Africa, Eastern Europe, other European regions, Asia and other group including America-Oceania or others. These categories are compared with French-born as natives.

The mixed parenting variable allows for the distinction of four categories of children: those born to two immigrant parents, those born to two native parents, those born to an immigrant mother and a native father, and a final category of children born to an immigrant father and a native mother. These last two categories are considered as belonging to mixed parenting for simplicity, given the methodological ambiguity surrounding the measurement of mixed parenthood or mixed union (Rodríguez-García, 2015). For greater precision on this variable, we have combined it with migratory origins.

By focusing on the variable associated with the support of the father during the child's birth, we can use the availability of the father's date of birth in the birth certificate. In other contexts, this has been used as a proxy for measuring paternal recognition (Castro-Martin, 2010). While this variable may capture a certain level of support, we think it is insufficient to encompass all dimensions, albeit indirectly. Hence, we combined it with another variable indicating whether the child's name includes only the father's name, only the mother's name or both parents' names. This enabled us to construct a comprehensive variable representing the father's support. We assumed that if the father's name and date of birth were listed on the birth certificate, it indicated that the father provided some level of support to the child at the time of birth. Consequently, we derived a binary variable indicating whether or not the father was providing support to the child.

In regards to determining the proportion of immigrant children born within the municipality (PICM), our methodology was based on the approach used by Muchow & Bozick (2022) to quantify social capital through co-ethnic proximity. Indeed, immigration patterns and the distribution of immigrant populations can vary significantly across municipalities. Certain municipalities may have higher concentrations of immigrants, potentially creating distinct community dynamics, including stronger or weaker social support systems. By using the municipality as the spatial unit, the analysis is sensitive to these local variations in immigrant population density and the associated effects on social capital and access to resources. Similarly, to this indicator, our index (PICM) is obtained as follows:

$$PICM = \frac{n_{Imh}}{N_h} \tag{6}$$

Where n_{Imh} is the number of births to immigrant women in municipality h and N_h is the total number of births in the same municipality. We ran M1 and M2 models with continuous variable of PICM, by multiplied it by 10 to get the effect of a 10% increase in the proportion of children of immigrant women. We estimated the third model (M3) by including the interaction terms between PICM and migratory origins while using PICM as a categorical variable allowing us to distinguish a low proportion (PICM-) when PICM is less than 0.5 and a high proportion (PICM+) when PICM is equal to or greater than 0.5.

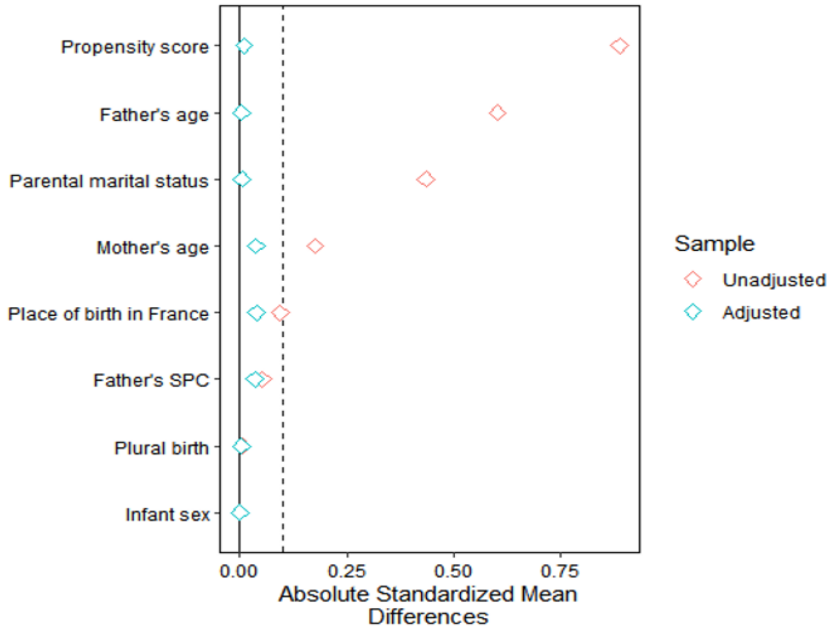
Alongside these variables, we adjusted for several other infant and parental characteristics using propensity score. These include infant sex, plural birth, place of birth in France, father's SPC, marital status of parents and the age of the father and mother at the child's birth.

4. Results

4.1. Propensity score

Fig 1 provides a concise overview of the mean or standardized proportional differences across all covariates. Each point on the plot represents the equilibrium statistic for a specific covariate, color-coded to indicate whether it was calculated before (unadjusted) or after weighting (adjusted). The dotted lines depict the threshold set to visualize equilibrium.

Fig *1:* Equilibrium statistics before and after weighting

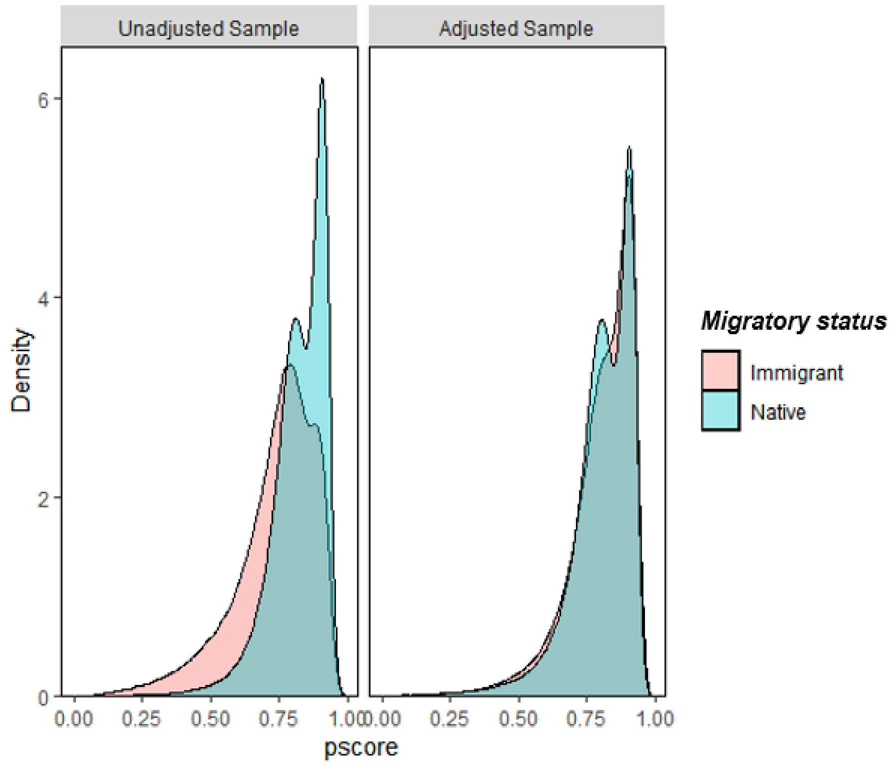


Source: Author's calculations based upon Permanent Demographic Sample (EDP), 1990–2020.

After applying the weighting, all data points now fall within the acceptable threshold, indicating that equilibrium has been reached. Additionally, the noticeable leftward shift in both the average age difference (between immigrant and native-born) of the father and the proportion of married parents suggests that these two variables have achieved the best balance in the dataset.

The univariate visual graphic of the propensity score is an additional tool for assessing its balancing characteristic, as shown in figure 2. This graph displays a non-parametric estimate of the density of the propensity score in the two groups. The distributional balance for propensity score serves as a benchmark to assess the comparability of the groups, ensuring that immigrant and native-born have sufficient similarities to allow meaningful comparisons (Lecocq et al., 2016). In particular, the graph shows a significant similarity in the distribution between the two groups after weighting (adjusted sample). In summary, the propensity score method successfully achieved a balance in the characteristics between the two groups, albeit with some minor residual imbalances.

Fig *2:* Distributional balance for propensity score



Source: Author's calculation based upon Permanent Demographic Sample (EDP), 1990–2020

4.2. Multivariate analysis

Tab 1 describes the sample according to migratory origins and mixed parenting, the main independent variables of interest. The sample covers 3073831 person-years, with 3024 deaths in the first five years.

Tab *1:* Description of the sample

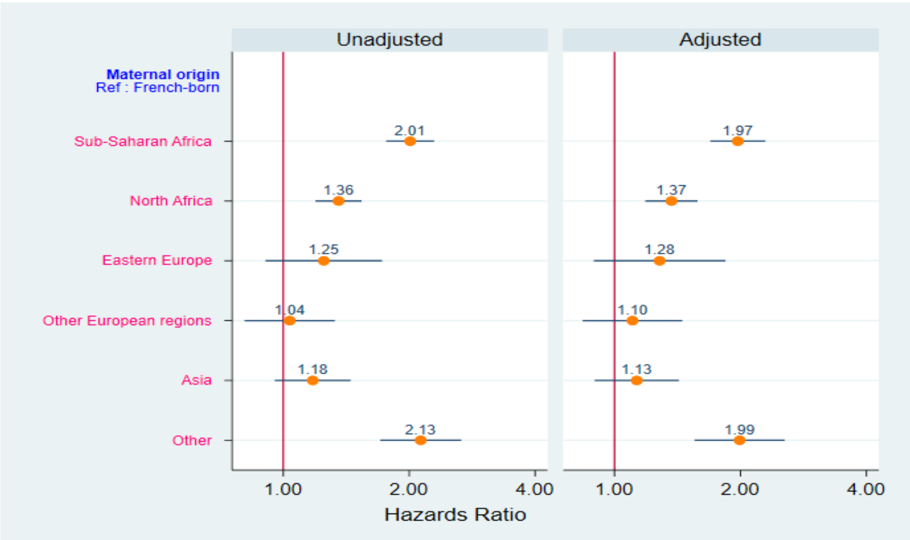
Parents' region of origin		Person-years	%	Deaths
Maternal origin				
French-born		2458879.96	79.99	2,203
Sub-Saharan Africa		129518.04	4.21	246
North Africa		215500.61	7.01	267
Eastern Europe		32056.78	1.04	38
Other European regions		68183.80	2.22	64
Asia		86741.43	2.82	92
Other		82950.04	2.70	114
Mixed parenting				
Mother	*Father*			
Immigrant	Immigrant	363742.33	11.83	511
Native-born	Native-born	2122483.47	69.05	1747
Native-born	Immigrant	311736.34	10.14	399
Immigrant	Native-born	275868.52	8.98	367
Mixed parenting by region of origin				
Both parents are natives		2122483.5	69.05	1747

Both parents are from Sub-Saharan Africa	84349.37	2.74	167
Sub-Saharan African and native parents	74827.46	2.43	114
Both parents are from North Africa	142862.88	4.65	184
North African and native parents	169037.82	5.50	190
Both parents are from eastern Europe	16018.58	0.52	26
Eastern European and native parents	15106.86	0.49	11
Both parents are from other European regions	25880.86	0.84	19
Other European and native parents	75371.81	2.45	68
Both parents are from Asia	59109.50	1.92	67
Asian and native parents	45880.32	1.49	44
Other	242901.70	7.90	387
Total	**3073830.66**	**100.00**	**3024**

Source: Author's calculation based upon Permanent Demographic Sample (EDP), 1990–2020

Fig 3 presents results of the unadjusted (before weighting) and adjusted (after weighting) models

Fig *3:* Hazard Ratio of U5M before and after weighting



Source**:** Author's calculation based upon Permanent Demographic Sample (EDP), 1990–2020

When the Hazards Ratio is compared before and after weighting, mortality inequalities persist between immigrant and native-born. The results with the adjustment for covariates reveal a higher U5M among children born to immigrant mothers, except for those from Europe and Asia. Specifically, children of Sub-Saharan African mothers are twice as exposed to the risk of U5M than children of natives. For children of North-African mothers, the risk is 1.18 to 1.57 higher while for those of group including America, Oceania and others, it is 1.55 to 2.55 higher. These persistent disparities, despite the adjustment of covariates, are likely attributed to migratory origin (Ma, 2008), indicating its central role in the shaping of U5M inequalities independently of other characteristics, and thus confirming our first hypothesis (H_1).

Tab 2 displays the results of three weighted Weibull models (M1, M2 and M3) in which child and parent characteristics were used as control variables.

Tab *2:* Weibull models of under-5 mortality weighted through optimal matching

Variables	M1		M2		M3	
	HR	95% CI	HR	95%CI	HR	95% CI
Mixed parenting						
Both parents are immigrants	1.50***	(1.32-1.72)				
Immigrant mother and native father	1.27**	(1.11-1.46)				
Immigrant father and native mother	1.24**	(1.05-1.45)				
Both parents are natives		Ref				
Mixed parenting by region of origin						
Both parents are from Sub-Saharan Africa			1.97***	(1.60-2.41)		
Sub-Saharan African and native parents			1.63***	(1.26-2.10)		
Both parents are from North Africa			1.52***	(1.27-1.82)		
North African and native parents			1.33**	(1.09-1.62)		
Both parents are from eastern Europe			1.72*	(1.11-2.65)		
Eastern European and native parents			0.53	(0.26-1.09)		
Both parents are from other European regions			0.94	(0.57-1.55)		
Other European and native parents			0.98	(0.71-1.35)		
Both parents are from Asia			1.32	(0.99-1.75)		
Asian and native parents			0.99	(0.67-1.45)		
Both parents are natives			Ref			
Proxy for paternal support			0.57***	(0.47-0.68)		
Yes	0.54***	(0.45-0.65)			0.58***	(0.48-0.70)
No	Ref		Ref			Ref
Proportion of immigrant children in municipality (PICM)	1.06***	(1.02-1.10)	1.04*	(1.02-1.08)		
PICM x Migratory origins						
French-born x PICM+					1.98***	(1.62-2.43)

Variables	M1		M2		M3	
	HR	95% CI	HR	95%CI	HR	95% CI
French-born x PICM-					Ref	
Sub-Saharan Africa x PICM+					2.05***	(1.51-2.78)
Sub-Saharan Africa x PICM-					1.98***	(1.65-2.37)
North Africa x PICM+					1.27	(0.84-1.91)
North Africa x PICM-					1.53***	(1.31-1.78)
Eastern Europe x PICM+					1.73	(0.65-4.61)
Eastern Europe x PICM-					1.33	(0.90-1.97)
Other European regions x PICM+					1.58	(0.60-4.12)
Other European regions x PICM-					1.03	(0.76-1.40)
Asia x PICM+					0.90	(0.45-1.81)
Asia x PICM-					1.26	(0.98-1.61)
Intercept	0.02***	(0.01-0.03)	0.02***	(0.01-0.03)	0.02***	(0.01-0.03)
ρ	0.22	(0.21-0.23)	0.22	(0.21-0.23)	0.22	(0.21-0.23)

Note: Analyses are weighted through optimal matching (propensity score computed with following covariates: infant sex, plural birth, place of birth in France, father's socio-professional category, mother's marital status, and age of the father and mother at the child's birth; see fig 1).
PICM+ indicate high (>=0.5) proportion while PICM- indicate a low proportion. ***p<0.001; **p<0.01; *p<0.05.
Source**:** Author's calculations based upon Permanent Demographic Sample (EDP), 1990–2020.

In terms of the impact of mixed parenting on U5M, its protective effect hasn't been shown. The risk of U5M for children born to mixed parents remains high compared to children born to two native parents. Even when distinguishing the regions of origin, the mortality risk remains higher, although it decreases for children born to mixed parents, as shown in model M2. This result, which does not prove the protective effect of being born to mixed parents, allows us to reject the second hypothesis (H_2).

Our results provide support for the effects of paternal support and the proportion of immigrant children in municipality (PICM), both independently and with potential interactions with migratory origins. These models reveal that paternal support during childbirth plays an essential role in reducing under-five mortality. This result, which corroborates the third hypothesis (H_3) further underlines the importance of paternal involvement in child health.

In terms of the impact of the PICM, the results reveal a remarkably significant effect. Specifically, being born in a municipality with a high (vs. low) proportion of immigrant children, significantly increases under-five mortality (U5M). Through the interaction effect between the proportion of immigrant children and migratory origins in model M3 it is evident that children of French natives born in a municipality with a high proportion of immigrant children exhibit a higher U5M. The results indicate that the excess mortality among children of women from Sub-Saharan Africa persists regardless of the type of municipality of birth, whereas that of children of women from North Africa is only observed among those born in municipality with a low proportion of immigrant children.

5. Discussion

The persistence of disparities, even after adjusting for covariates, highlights the significant impact of migratory origin on inequalities in child health. Our results are in line with previous studies that have already documented excess mortality among infant born to mothers from Sub-Saharan Africa and North Africa (Niel, 2011; Wallace et al., 2020). The latter most often experience pregnancy-related hypertension, exhibit lower rates of pregnancy declaration or delayed declaration compared to French women (Deneux-Tharaux et al., 2009), and receive inadequate prenatal care and follow-up (Niel, 2011). In addition, these women often have a lower SES than women born in France (Zeitlin et al., 2011) and face a disproportionate burden of discrimination (Défenseur des droits, 2019). Simultaneously, these findings could potentially reflect the impact of the origin context, given that African countries exhibit the highest rates of infant mortality globally.

Although migration of women from Eastern Europe are as recent as those from Sub-Saharan Africa, our findings did not reveal any significant excess under-5 mortality (U5M) among these groups. A similar pattern emerges for Asian mothers, consistent with the research conducted by Mehta et al. (2013), which documented favourable health outcomes across seventeen health indicators compared to other ethnic groups in U.S. This finding is also supported by research showing that Chinese newborns had satisfactory birth weights that were not statistically different from those of children born in France and Spain (Rovillé-Sausse & Prado Martinez, 2009). In addition, some Asian groups have relatively favourable health behaviours (Wallace & Kulu, 2014). Finally, it is important to note that our findings present a contrast to the concept of a healthy immigrant paradox. The infant health advantages documented for North African-born (Florian et al., 2021, 2023) seem to be more associated with sample bias rather than an intergenerational transfer of health advantages. As several studies have pointed out, the ELFE[1] cohort, which is the database used in these previous studies, suffers from selective attrition, excluding more immigrant women (Bournez et al., 2018; Nakamura et al., 2020; Kadawathagedara et al., 2021). Bournez et al. (2018) reported a refusal rate of around 51%, a particularly high rate among people of low SES, including immigrant women.

In terms of the impact of mixed parenting on U5M, the result is surprising insofar as mixed unions, and therefore mixed parenting, are considered to facilitate social (Kalmijn, 1998; Kulu & González-Ferrer, 2014) and economic (Meng & Meurs, 2009), enabling parents to have adequate resources to care for their children. Such a result can be viewed from the perspective of the fragility of mixed unions, as shown in some studies (Goldstein & Harknett, 2006; Rodríguez García & Miguel Luken, 2015). This can, through the deprivation of resources, impact both the health of the mother and the child.

The positive effect of paternal support on mortality is in line with those of Gaudino et al.(1999) who propose that paternal involvement, as indicated by the inclusion of the father's name on the birth certificate, offers protection against low births weight and infant mortality in Georgia (U.S.). Furthermore, they are consistent with studies showing significantly higher adverse outcomes among mothers with limited or no partner information in their child's birth certificate in the U.S. (Tan et al., 2004; DeSisto et al., 2018).

As for our result on the effect of the proportion of immigrant children in municipality , it seems to diverge from the findings of Zeitlin et al (2011) who describe in France, specifically in the Seine-Saint-Denis district, an inverse association between the proportion of immigrants in the neighborhood and preterm births among Sub-Saharan African women. This difference between our results and those of the above-mentioned study can be explained in several ways. In this study, the methodological approach accounted for the hierarchical structure of the data using a multi-level logistic model. Additionally, the analyses were limited to the Seine-Saint-Denis district, so the conclusions cannot be generalized to the whole of France. Moreover, several studies

[1] ELFE is French Longitudinal Study of Childhood, the first national longitudinal study of children, addressing the many aspects of their lives from the angles of social science, health and the environment. It follows more than 18,000 children born in mainland France in 2011.

have reported contradictory results, depending on the immigrant groups considered, regarding the effect of this variable on children's health (Fang et al., 1999; Kaufman et al., 2003; Pearl et al., 2001; Reagan & Salsberry, 2005), suggesting caution when interpreting such a variable.

The higher proportion of immigrant children associated with a significant risk of U5M for native-born and some immigrants, shows its profound influence on child health outcomes. The aggregation of immigrants in a specific area or the clustering of births to children of immigrants could be a catalyst for social cohesion and the promotion of various forms of solidarity and mutual assistance, which can have a positive impact on health outcomes. This is not consistent with our result, allowing us to reject the hypothesis H_4. Does it reflect the adverse effects of ghettoization on child survival? Providing a definitive answer to this question is challenging. Nevertheless, this result may overshadow the influence of other factors including the insufficient availability of social and healthcare service and infrastructure within these areas. One possible interpretation may be the spread of risky health behaviours in these segregated areas. Adverse health behaviours such as refusing to have an abortion in the event of a high-risk pregnancy, non-compliance with the vaccination schedule, and late detection of abnormalities, particularly in the case of maternity or perinatal care (Fortin & Le Gall, 2007), may be influenced or even reinforced by the community through cultural norms (Mendoza, 2009). In addition, segregated areas are often plagued by insecurity and high unemployment (van San, 2004; Bolt et al., 2010; Balascio et al., 2023), which can expose their inhabitants to stress and risky health behaviors, the effects of which on preterm births and pregnancy complications have been demonstrated (Misra et al., 2001).

Conclusion

The aim of this study was to clarify the role of migratory origin on under-5 mortality, while examining other factors such as the mixed parenting, the proportion of immigrant children born in the municipality and the paternal support. Using the propensity score instead of directly including socioeconomic covariates in the regression, we are able to address bias in the measure of immigrant-native gap arising from differences in observable characteristics (Rosenbaum & Rubin, 1983). This methodology which effectively unveils disparities between immigrant and native-born while mitigating socioeconomic disparities' effect through the weighting technique, allows us to confirm the importance of migratory origin on inequalities in under-5 mortality. This undoubtedly removes any doubt about the existence of the epidemiological paradox raised by certain recent studies on children's health in France, i.e. the excess infant mortality among North African women despite better perinatal health outcomes. Our research also sheds light on the effects of the high proportion of immigrant children born in the municipality and emphasizes the crucial role of the paternal support on child survival and allows us to enrich the literature on children's health based on migratory origin.

The use of a longitudinal approach, which enabled us to consider the person-years at risk in different birth cohorts and the events associated with them in order to obtain reliable regression estimates, as well as the richness and quality of the data, are the main strengths of this research.

This research is not without limitations. Indeed, the propensity score method, although a valuable tool in our study, is sensitive to the choice of variables. It focuses primarily on selection based on observable characteristics, neglecting unobservable factors (Lecocq et al., 2016). Another limitation is the operationalization of paternal support. In France, despite a 2005 Law allowing parents to freely choose their child's surname, the tradition of giving the father's surname remains prevalent. Thus, in 2018, around 91% of children had the father's surname, either alone or in combination with the mother's surname (Breton et al., 2020). While our results indicate that paternal support, as measured by the inclusion of the father's name and age on the birth certificate, is associated with protection against U5M, we lack information on why this information has been omitted from some birth certificates or whether it really reflects involvement or support during pregnancy. Further study of this variable is therefore suggested.

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Appendix

A. Weibull model

Fig *A.1*: U5M, hazard function

Source: Author's calculations based upon Permanent Demographic Sample (EDP), 1990–2020.

B. Propensity score method

Choice of covariates

The initial stage of propensity score estimation presents the first challenge. There is no universally accepted rule for selecting appropriate variables. Some authors suggest incorporating into the estimation procedure all variables correlated with both the treatment and the variable of interest (Quantin, 2018). Conversely, others stress the delicate balance between statistical and theoretical considerations. While the inclusion of a large number of variables may improve the precision of propensity score estimation, it also leads to an increase in the variance of the estimators. On the other hand, omitting crucial variables could introduce bias into the estimates (Lecocq et al., 2016).

The results of the Oaxaca-Blinder (O-B) decomposition, as discussed in a previous analysis, along with the existing theory on immigrant health, guided our selection of variables. Factors such as infant sex, plural birth, place of birth in France, father's SPC, marital status and the age of the father and mother at the child's birth were considered. In the decomposition analysis (Tab A.1), under-5 mortality differences between immigrant and native-born are substantially accounted for by these variables, with the exception of the infant sex and plural birth. However, we have incorporated all of these variables into the construction of the propensity score. It is important to note that these two groups are not directly comparable on average, and the propensity score method will therefore be used to address and correct for these differences.

Tab A.1: O-B Twofold decomposition of U5M (per 10,000 births) gap between children born to immigrant and those born to native-born

	Coef	low95	high95	
Immigrant-native gap	19.77	14.98	24.56	
Endowment effect	2.31	0.51	4.12	
Unexplained factors	17.46	12.44	22.47	
	Coef	low95	high95	Variables
	0.00292	-0.0711	0.0769	Sex (Female)
	0.202	0.0258	0.379	Plural birth
	1.229	0.659	1.8	Place of birth (Overseas France)
	0.0719	0.0443	0.0897	Father's SPC+
	-0.719	-2.519	1.082	Married parent
	-2.216	-3.314	-1.118	Father's age
	3.739	1.763	5.715	Mother's age

Source: Author's calculation based upon Permanent Demographic Sample (EDP), 1990–2020.

Choice of method

Once the variables have been selected, they are incorporated into a model, typically a logistic regression model, with a few exceptions such as the use of generalized boosted models—a non-parametric multivariate regression technique (McCaffrey et al., 2003). Following estimation, the obtained propensity score facilitates the formation of two groups, namely a treatment group and a control group, employing various methods. The most commonly employed methods include matching, Stratification, and weighting. However, choosing the most appropriate method can be challenging, as each approach possesses its own advantages and limitations. As highlighted by (Lecocq et al., 2016), no single method supersedes the others, and the selection of the appropriate method depends on the specific characteristics of the dataset at hand (Lecocq et al., 2016; Quantin, 2018).

The method we have chosen is weighting for several reasons. Undoubtedly, the full (with replacement) matching method could have been selected as the optimal choice. Indeed, as Austin (Austin, 2013) and Austin & Stuart (Austin & Stuart, 2015, 2017) have shown using Monte Carlos simulation, this method is the most optimal compared with the others, in particular weighting and partial (without replacement) matching methods. However, considering the limitations of partial matching when applied to our dataset, the substantial sample size, and the memory constraints associated with full matching, weighting emerges as a viable alternative. Furthermore, as demonstrated by Austin and Stuart (2015), the weighting method can perform as well as the full matching method.

Weighting method is similar to the re-weighting procedures used in survey sampling to take account of observations with varying probabilities of inclusion in the sample (McCaffrey et al., 2003). It involves the creation of a new variable incorporated into a regression model. By assigning higher scores to the immigrant-born, inverse weighting reduces the weight assigned to native-born and immigrant-born with similar observable characteristics, while increasing the weight assigned to immigrant-born. This approach offers the advantage of preserving the entire sample for analysis and can produce almost unbiased estimates, particularly for large samples under specific conditions (Austin, 2016; McCaffrey et al., 2003). However, it may encounter challenges stemming from excessively high weights, particularly when certain units exhibit very low propensity scores (Austin & Stuart, 2017). To overcome this issue, truncation can be used. By setting a threshold, this technique addresses the problem of assigning extremely high weights to certain observations. In our analysis, for example, we observed a weight exceeding 30. Consequently, we applied truncation at the 99th percentile, resulting in a maximum weight of approximately 13.

In the weighting method, each unit is assigned a weight, noted w_i,which is inversely proportional to its probability of belonging to one of the two groups. More specifically, for the native-born group, the weight is determined by the inverse of the propensity score, $e(x_i)$, while for immigrant-born, it is determined by $1 - e(x_i)$.

Thus, $\boldsymbol{w_i} = \frac{\boldsymbol{z_i}}{\mathbf{e}(\boldsymbol{x_i})} + \frac{\mathbf{1}-\boldsymbol{z_i}}{\mathbf{1}-\mathbf{e}(\boldsymbol{x_i})}$

Balancing properties

This section focuses on presenting indicators commonly employed to assess the balancing property of the propensity score. The quality of the propensity score is usually assessed and reported using statistical measures and graphs. The main indicators are mean or standardized proportion differences and variance ratios.

The standardized difference in means is the difference in the means of a (continuous) variable in the immigrant-born and native-born groups, divided by the sum of the variance of the two groups.

Thus, $\boldsymbol{Diff_1} = \frac{\bar{X}_{Na} - \bar{X}_{Im}}{\sqrt{\frac{s_{Na}^2 + s_{Im}^2}{2}}}$

where $\bar{X}_{Na}$ and $\bar{X}_{Im}$ are the empirical means of the covariates X in the native-born and immigrant-born groups respectively and s_{Na}^2 and s_{Im}^2 the corresponding empirical variances.

When dealing with categorical variables, this refers to the difference in the proportion of a specific category between the two groups under investigation, as demonstrated by the following equation:

$$\boldsymbol{Diff_2} = \frac{\hat{p}_{Na} - \hat{p}_{Im}}{\sqrt{\frac{\hat{p}_{Na}(1 - \hat{p}_{Na}) + \hat{p}_{Im}(1 - \hat{p}_{Im})}{2}}}$$

where $\hat{p}_{Na}$ et $\hat{p}_{Im}$ are the proportions for a given category.

The standardized difference approach has the advantage of not being affected by sample size, which makes it particularly relevant for matched data (Quantin, 2018). It plays a significant role in comparing differences in observable characteristics before and after adjustment, thereby ensuring the accuracy of the propensity score. To evaluate the balancing property, a visualization of the distribution of each covariate is employed (not presented here). Covariates are considered unbalanced when the standardized difference or proportion difference is minimal. However, there is no universally recognized threshold for determining the significance of these differences. The choice of a threshold for comparison is ultimately left to the discretion of the analyst (Lecocq et al., 2016).

As previously mentioned, the balancing property of the propensity score extends beyond the mean or proportion alone. It encompasses the entire distribution of covariates. Therefore, it is suggested to consider additional indicators, such as variance ratios (Tab A.2). These ratios are employed to assess the distributional shape of covariates beyond their central tendencies. The variance decreases as the average difference in the variable between the two groups decreases. Variance ratios close to 1 mean that the variances are (almost) equal in the two groups and therefore indicate a balance in these groups (Rosenbaum & Rubin, 1983). It is worth noting that significant differences in shape may indicate suboptimal balance even if mean differences and variance ratios are below certain thresholds (Greifer, 2022a).

Tab A.2 summarizes some key indicators before and after adjustment (weighting). These indicators include the standardized difference in means or proportions (Diff) and the variance ratios (V.ratio). The terms "Un" and "Adj" represent abbreviated forms of "Unadjusted" and "Adjusted," respectively, denoting the corresponding values. It is clear from this table that the application of weighting has led to an enhancement in the balance across all variables. This improvement is reflected by bringing all variables below the threshold of 0.1 for standardized mean differences or proportions, although some minor imbalances remain. In particular, a more substantial balance is achieved for the father's age and the parent's marital status, which exhibits a much higher degree of balance.

Tab *A.2:* Some balancing indicators

		Before adjustment		After adjustment (weighting)	
Socioeconomic characteristics	Type	Diff	V. Ratio	Diff	V. Ratio
Infant sex	Binary	-0.00001	NA	-0.001	NA
Plural birth	Binary	-0.00522	NA	-0.00466	NA
Place of birth of the infant in France	Binary	-0.09486	NA	-0.03910	NA
Mother's age	Continuous	-0.17657	0.83819	-0.03851	0.81105
Father's age	Continuous	0.463925	0.60387	0.00473	0.93160
Matrimonial status of parent	Binary	-0.43487	NA	-0.00514	NA
Father's SPC	Binary	0.05330	NA	0.03619	NA
Propensity score	Continuous	0.88730	0.43416	0.01119	0.94219

Note: Variance Ratio is only computed for continuous variables
Source: Author's calculations based upon Permanent Demographic Sample (EDP), 1990–2020.