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# Years of life lost to revolution and war in Iran

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## Abstract

How was life expectancy in Iran affected by the Islamic Revolution and subsequent war with Iraq? This study examines the joint effect of regime change and the war against Iraq on life expectancy in Iran between 1978 and 1988. If there had been no revolution and war in Iran, how would the life expectancy of Iranians have developed? To answer this question, we use a synthetic control model to construct a counterfactual Iran based on a weighted average of other comparable countries, which reproduces the situation of pre-revolution Iran but does not experience the revolution and war. We then compare the life expectancies of the counterfactual and actual Iran that underwent a regime change and war with Iraq. Our results indicate that an average Iranian's total life expectancy would have been approximately five years longer without the revolution and war. The revolution had a moderate long-term impact on total life expectancy at birth, with the most significant influence being attributed to the war itself, particularly on male life expectancy. Our main findings are robust to a series of tests, including placebo tests. We investigate possible reasons that may explain the impact on longevity.

## KEYWORDS

conflict, human costs, Iran, Iraq, life expectancy, revolution, sanctions, synthetic control method, treatment effect, war

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**JEL CLASSIFICATION**

C23, H56, F51, D74, Q34

**1 | INTRODUCTION**

The increasing trend of violence and conflict worldwide, especially following the Russian invasion of Ukraine, has intensified the discussions on the socioeconomic consequences of such significant violence and instabilities. The detrimental effects of political turmoil and violence extend beyond economic costs and the destruction of infrastructure to also include substantial human losses. Beyond the lives lost to conflict and violence, the younger generation in such cases will experience different types of psychological trauma. Therefore, conflict and violence may exert a persistent effect on people's health and well-being. Against this background, a better understanding of the effects of major political events, such as revolutions, and main types of violence, such as wars, on different aspects of socioeconomic development plays a critical role in designing relevant policies that help mitigate the costly consequences of such events for affected countries, regions, and global community.

This research looks at the Islamic Revolution in Iran at the end of the 1970s, which surprised the global community (see Kurzman, 2005 on the unthinkable revolution in Iran) and ended the long reign of the monarchy.<sup>1</sup> According to Kurzman (2005), the anti-shah protests and general strikes in Iran were a hugely popular uprising in world history, with at least 10% of the population participating. This is a greater proportion than the number of people who took part in the French revolution (less than 2%) and the overthrow of Soviet communism (less than 1%).

Open resistance against the Shah Mohammad Reza Pahlavi, and political system started in February 1977 and worsened in 1978 (Kurzman, 2005 provides a detailed picture of revolution timeline).<sup>2</sup> By February 1979, the Shah fled into exile and the monarchy collapsed. Using the political instability and internal chaos in Iran as an opportunity, the Iraqi army, under leadership of Saddam Hussein, invaded Iran in 1980. An armed conflict started with Iraq and lasted eight years (for a historical review see Zunes, 2009, and Seeberg, 2014). The economic costs of the Islamic revolution and war with Iraq are examined by different studies such as in Amirahmadi (1990), Mofid (1990), Jahan-Parvar (2016), and Farzanegan (2022a).

The Iranian Revolution, according to Kurzman (2005), resulted in significantly fewer casualties compared to other movements. For example, while the South African anti-apartheid movement led to over 7000 revolutionary martyrs, the numbers in Iran were much lower. The Martyr Foundation identified 744 martyrs in Tehran, which was the main center of the Islamic revolution. Kurzman (2005, p. 71) cites figures from the coroner's office and Tehran's main cemetery, Behesht Zahra, which reported 895 and 768 martyrs, respectively. However, as these numbers only focus on Tehran, they may be considered a lower bound for the number of victims from the revolution.

Kurzman also references an original study conducted in 1982 by Sohbatollah Amrai, an employee of the Martyr Foundation, who researched the number of deaths directly related to the revolution. Amrai excluded deaths from accidents and natural causes or those assassinated by revolutionary forces. He then compared his foundation figures against the records of the Tehran coroner's office and the main Tehran cemetery. The comparison showed similar or close figures, indicating that around 700–900 Iranians died in Tehran during the year of the revolution.

The Iraq invasion of Iran in 1980, which materialized because the revolution and change in the balance of power in the Middle East, caused far more human and economic losses. This remains the deadliest war in the history of the Middle East (Razoux, 2015). It was also the longest war of the 20th century. Razoux (2015, p. 471) presents more reliable data on the total casualties of this war, which stood at 680,000 dead and missing. Iran's share of the total death and missing was about 73% (500,000 Iranians), with an additional 1.5 million people wounded and maimed. 85% of those who died were soldiers and the number of Iranian soldier deaths was 3.5 times higher than that of Iraqis. The number of civilians killed by bombings was about 3% of the overall death toll. The remaining 12% of civilian deaths were Kurds who were killed by both Iraqis and Iranians. Around 115,000 soldiers were taken prisoner (70,000 Iraqis and 45,000 Iranians).

The war was also associated with significant material losses, which we do not examine here. Apart from material military damages, the financial costs of the war were also significant. The total financial cost of the war to Iran is estimated to be \$645 billion, including loss of oil revenues (\$350 billion), damage to infrastructure (\$180 billion), loss of industrial revenues (\$35 billion), compensation to casualties' families (\$25 billion), purchase of war equipment (\$20 billion), expenses related to war efforts (\$20 billion), importing of refined petroleum products (\$12 billion), and an increase in insurance premiums (oil trade) of \$3 billion. For Iraq, the total costs were \$452 billion.

It is also important to note that during the war period, Iran was under US sanctions after the US embassy hostage crisis following the revolution. However, these estimated figures do not show the opportunity costs of war. Farzanegan (2022a) calculated the income loss for the average Iranian during 1978–1988 resulting from the revolution and war, with an estimated number of an annual loss of about \$3150 per Iranian. These estimations also do not measure the long-term psychological effects of the experience of war conditions (Farzanegan & Gholipour, 2021). Table A1 in Appendix A summarizes the war-related human losses for Iran and Iraq and Table A2 presents the financial costs of the war for Iran and Iraq.

Our focus and contribution are to measure the human costs of a major political event, which was also attached to a destructive war. We aim to understand how Iranian life expectancy could have developed in the absence of the revolution and war and to find the independent effects of revolution and war on the longevity of Iranians. This is a challenging task as one may argue that some of the socioeconomic factors which led to the revolution (e.g., demographic development, economic condition, etc.) were also responsible for subsequent changes in the overall health indicators of Iranians. As mentioned by Holland (1986), one of the main problems of causality analysis is that the unit of intervention cannot be obtained without that specific treatment. In other words, it is impossible to experience our unit of interest with and without of treatment at the same time. Therefore, the challenge of causal analysis is in the estimation of a synthetic unit which best reproduces the factual unit of interest under treatment.

Our approach, based on the synthetic control method (SCM), helps to build a counterfactual Iran which was similar to Iran but does not undergo a revolution and war.<sup>3</sup> Using the SCM approach, we quantify the magnitude of years of life lost due to the revolution and war in Iran. We explore the possible reasons for the estimated effect and thus contribute to our understanding of the mortality impact of war and regime change between the male and female populations.<sup>4</sup>

The study is structured as follows: Section 2 provides a brief review of the literature on life expectancy on growth and the demography of conflict. In Section 3, we explain the data and

methodology used in the study. Section 4 presents and discusses the main results and sensitivity analysis, including an examination of possible factors contributing to the reduction of life expectancy. Finally, we conclude the paper in Section 5.

## 2 | LIFE EXPECTANCY ON GROWTH AND THE DEMOGRAPHY OF CONFLICT LITERATURE

Our outcome of interest in this study is life expectancy. Besides the good quality of data for this indicator across countries and over time, its selection is also well-justified within the literature on economic growth. Oster et al. (2013), Soares (2005), and Kalemli-Ozcan et al. (2000) have shown that lower mortality rates and longer lifespans increase a society's willingness to invest in human capital. This is based on the human capital theory which suggests that a longer life expectancy enhances the incentives to invest in skill acquisition (Becker, 1964; Ben-Porath, 1967). Human capital is shown to have important direct and indirect effects on long-term economic growth across countries (Hanushek, 2013; Hanushek & Woessmann, 2008, 2015). Therefore, understanding the effect of negative shocks such as revolution and war on life expectancy, besides its importance for the human experience of war itself, and the demography of conflict has important implications for human capital formation.<sup>5</sup>

Soares (2005), Kalemli-Ozcan (2002), Kalemli-Ozcan et al. (2000), and de la Croix and Licandro (1999) also provide evidence for a causal effect of life expectancy on growth via the human capital formation mechanism. Among theoretical models which included human capital, specifically health capital in determining economic growth, we can refer to Mankiw et al. (1992), Fogel (1994), Barro and Sala-i-Martin (1995) and Barro (1996). For example, Barro (1996) followed a Ramsey scheme and developed a growth model including physical capital inputs, level of education, health capital, and the quantity of hours worked. He shows that an increase in health indicators enhanced the incentives for investment in education.

Other endogenous growth models developed by (Aghion & Howitt, 1998; Howitt, 2000, 2005; Howitt & Mayer-Foulkes, 2005) also find six different channels through which improvements in the health of a population may increase long-term economic growth (i.e., productive efficiency, life expectancy, learning capacity, creativity, coping skills, and inequality).

Empirical studies by Strauss and Thomas (1998) and Schultz (1999) show that enhanced health indicators have positively impacted the learning abilities of children and produced better educational outcomes. Fogel (1994) suggests that approximately one-third of the increase in income in Britain during the 19th and 20th centuries was due to enhancements in health and nutrition. Similar positive effects of higher life expectancy on growth are estimated in the cases of Brazil and Mexico by Mayer (2001). Weil (2007) constructed macroeconomic estimates of the proximate effect of health on GDP per capita. Gyimah-Brempong and Wilson (2004) show that 22% and 30% of the transition growth rate of per capita income in Sub-Saharan African and OECD countries, respectively, can be attributed to improved health human capital.

The magnitude of the impact of longer life expectancy on economic growth is also substantial. For example, Bloom et al. (2004) use a production function model of economic growth and employ a cross-national panel dataset. They show that an increase of life expectancy by one year increases GDP growth rate by 4%.<sup>6</sup>

Longer life expectancy also has a positive impact on savings rates (Kinugasa & Mason, 2007; Zhang & Zhang, 2005). Lee et al. (2000) show that increases in life expectancy are critical to individual saving behavior. Using US household data, Hurd et al. (1998) show that people with

higher subjective survival probabilities save more. Bloom et al. (2003), in their theoretical and empirical study, also find that increases in life expectancy led to higher savings rates at every age, even when retirement is endogenous.

Both higher human capital investment and savings increase labor force productivity (Cervellati & Sunde, 2011). Higher longevity is positively associated with cognitive development (Jamison et al., 1996) and is shown to be a robust determinant of investment and economic growth (Alsan et al., 2006; Bjorvatn & Farzanegan, 2013; Bloom et al., 2004; Mason, 2007). Moreover, the level and development of life expectancy shape fertility behavior, inter-generational transfers, and incentives for claims on pension benefits (Coile et al., 2002; Zhang et al., 2001). Using birth and sibling histories from the Demographic Health Surveys conducted in sub-Saharan Africa, Turan (2020) shows that increases in life expectancy will have a positive impact on growth through fertility, education, and labor supply. From a public finance perspective, increased life expectancy has a positive effect on public funding for education (Gradstein & Kaganovich, 2004). In short, there are many studies which show direct and indirect positive associations between life expectancy and economic development across the world.

In addition to the above-mentioned studies that highlight the relevance of life expectancy for short- and long-run economic growth, another line of literature focuses exclusively on the human experience of war itself and the demography of conflict. For example, in a panel of 84 countries from 1961 to 1998, Li and Wen (2005) study the immediate and lingering effects of interstate and intrastate conflict on adult mortality. They conclude that the immediate effect of civil conflict is stronger than that of the interstate conflict, while the reverse applies to the lingering effect, highlighting the imperative for peace negotiations. Our SCM approach in the case of Iran calculates the average annual years of life lost, showing the magnitude of both the immediate and lingering effects of revolution and war.

Other studies, such as Plümper and Neumayer (2006), and Urdal and Che (2013), examined the effects of war on gender differences in health, including effects on fertility, child mortality, and maternal mortality. Plümper and Neumayer (2006), in particular, argue that during periods of conflict, interstate and civil wars, on average, have more adverse effects on women than men. During peacetime, women, on average, live longer than men. Thus, they suggest that armed conflict tends to reduce the gap between female and male life expectancy.<sup>7</sup> Based on a global time-series cross-national study from 1970 to 2005, Urdal and Che (2013) show that war negatively affects reproductive health. Armed conflicts contribute to high fertility levels through increased social insecurity, loss of reproductive health services, and lower female education.

### 3 | DATA AND METHODOLOGY

#### 3.1 | Data

##### 3.1.1 | Outcome variable: Life expectancy

For our main outcome variable, we use an indicator of longevity from the World Bank (2022). Life expectancy at birth refers to “the average number of years a newborn is expected to live if mortality patterns at the time of its birth remain constant in the future.” In other words, it looks at a number of people of different ages who died in a year and provides a snapshot of overall “mortality characteristics” that year for the population.”<sup>8</sup> Increasing child and/or adult mortality is an important driver of decreasing life expectancy. Life expectancy at birth is derived from

life tables and is based on gender- and age-specific death rates. For more details on estimations of life expectancy, see Ortiz-Ospina (2017).<sup>9</sup>

For example, the total life expectancy (average over male and female population) in 1979 was 58.6 years in Iran. This means that a hypothetical cohort of infants living through the age-specific mortality of Iran in 1979 could expect to live for 58.6 years, assuming that the mortality patterns observed in 1979 remain constant throughout their lifetime. In 1981, after the revolution and during the war with Iraq, for example, we see that the total life expectancy is reduced to 56.7 years (with a more significant reduction in male life expectancy). This reduction in the estimated index is because mortality patterns in Iran worsened during the period of 1979–1981. In short, the effect of the revolution (internal violence, civil disorder, civil war, assassinations, terrorism, etc.) and the war with Iraq, along with increasing poverty during the war, resulted in the deterioration of mortality patterns, leading to a decline in life expectancy.

### 3.1.2 | Predictor variables

The following predictors of life expectancy are used to produce a counterfactual Iran before applying the joint treatment of the Islamic Revolution and war. The selection of predictors is based on earlier literature regarding determinants of longevity, the availability of data from all countries in the donor group from 1965 to 1977 and their contribution in generating a counterfactual Iran before the treatment year with high preciseness. The following are used as predictors and correlates of the outcome in SCM: per capita expenditure-side real GDP at chained PPPs (in 2017 US\$), share of government spending in GDP (Pritchett & Summers, 1996), population growth rate (Acemoglu & Johnson, 2007), and age dependency ratio (Ediev et al., 2019; Sanderson & Scherbov, 2015). An increase in income per capita may also correlate with the improvement of education, increasing cognitive ability to manage health risk factors (Hamidi et al., 2018; Lleras-Muney, 2005). Data on real income per capita and government spending in GDP are from the Penn World Table (version 10) (Feenstra et al., 2015). Population growth rate and age dependency ratio data are from the World Bank (2022). Finally, we control for previous records of life expectancy in the years 1976, 1974, 1972, 1970, 1968 and 1966 to help increase the goodness of fit of the counterfactual Iran with the factual Iran during the pre-revolution and war periods. In Appendix D, following the suggestion of Kaul et al. (2015), we re-examined our estimations with 1–3 lags of the outcome variable. The key results remain robust.

## 3.2 | Methodology

We use the synthetic control method to study the trajectory of longevity in Iran before and after the Islamic Revolution. This method employs a weighted average set of control units, presenting a synthetic control unit that reflects the treated unit (i.e., Iran) in terms of predictors of the outcome (i.e., life expectancy) before the shock. The SCM minimizes the gap between the vector of characteristics of Iran and its synthetic counterpart before the revolution. Moreover, in the SCM approach, an outcome variable such as life expectancy should be comparable between the treated country (Iran) and its synthetic counterpart before the event (revolution and war with Iraq), provided that the synthetic Iran is successfully generated. In the latter case, if there is a divergence between the factual Iran and its counterfactual counterpart after the treatment year, it indicates the causal impact of the revolution and war on the life expectancy of Iranians.

Abadie et al. (2010) present several distinct advantages of SCM over regression-based methods. The method employs a transparent weighting framework and controls for time-varied unobserved country characteristics to reduce concerns from simply comparing countries, which may arise in more descriptive studies. Such descriptive studies usually lack an explicit counterfactual. In their survey study, Athey and Imbens (2017) present SCM as “*Arguably the most important innovation in the evaluation literature in the last 15 years ... This method builds on difference-in-differences estimation, but uses arguably more attractive comparisons to get causal effects.*”. SCM relies on pretreatment outcome matching (Imbens & Wooldridge, 2009). It employs preintervention trends in outcomes and supplementary predictors to simulate a counterfactual outcome scenario reflective of the hypothetical lack of the intervention itself. For a recent survey of this method see Gilchrist et al. (2023) and Abadie (2021).

We use a panel of data from 1965 to 1988 for a donor sample which originate from the Middle East & North Africa (MENA) region<sup>10</sup> or are members of Organization of the Petroleum Exporting Countries (OPEC)<sup>11</sup> and/or are located around the area of Iran (e.g., Turkey). We exclude countries which have had significant experiences of conflict, war, revolution, or similar events during the pre- and/or post-treatment years. These are Algeria (instabilities following Algerian War of Independence in 1960s, a new constitution, commitment to socialism and introduction of Islam as state religion in 1970s), Iraq (war with Iran), Israel (different quality of institutions in the MENA region, Suez Crisis, Six Day War, Camp David Accord, Invasion of Lebanon, First Intifada uprising), Lebanon (civil war), Libya (the Gaddafi era and confrontation with the US), Morocco (Polisario movement and war with Algeria in Western Sahara), Syria (rise of Assad, war with Israel, rise of the Muslim Brotherhood, uprising in Hama), Venezuela (democratic rule), and Yemen (civil war, formation of South Yemen).<sup>12</sup> In the case of total life expectancy as an outcome of interest, we use 16 countries for generating the counterfactual Iran. The ceasefire between Iran and Iraq was reached in 1988, ending a war that started in 1980. The treatment year is determined to be 1977 (start of open resistance against the Shah when exiled opposition leader Ayatollah Khomeini ordered the masses to strike, boycott, tax resistance, and other forms of civil disobedience) (Kurzman, 2005; Zunes, 2009).<sup>13</sup>

The synthetic control method employs countries in the donor pool which have not been exposed to the treatment (the Islamic Revolution and war with Iraq) to build the counterfactual development of life expectancy for Iran in the post-treatment period.<sup>14</sup> This method considers that different countries from the donor pool share different degrees of similarities with Iran by using country weights  $\omega_d$  for each country  $d$  in donor pool, assuming that these weights are between 0 and 1, that is,  $0 \leq \omega_d \leq 1$  and  $\sum_{d=1}^D \omega_d = 1$ . To identify and generate the best possible counterfactual Iran from all possible combination of countries in the donor sample, the SCM uses the pretreatment information of the outcome variable (life expectancy in this study)  $Y_t$  and additional predictor variables  $Z_t$  which have shown to be relevant explanatory variables for life expectancy (as explained earlier). Formally, the synthetic Iran is generated by selecting weights  $\omega_d$  such that  $Y_t - \sum_{d=1}^D \omega_d^* Y_{dt}$  and  $Z_t - \sum_{d=1}^D \omega_d^* Z_{dt}$  are minimized for the years prior to the treatment, that is, Iran's revolutionary period and the war with Iraq for  $t < 1977$ .



In simple terms, the optimal synthetic Iran should not only have the same (or similar) life expectancy as Iran during the pre-revolution and war periods, but it should also have the same (or similar) values of the covariates. The treatment effect  $\alpha_t$  is calculated as  $\alpha_t = Y_t - \sum_{d=1}^D \omega_d^* Y_{dt}$  for  $t > 1977$ .

The impact of the revolution and war on life expectancy is equal to the difference between the factual Iranian life expectancy and the estimated counterfactual life expectancy over the period of 1978–1988 had the Iranian Revolution and war not happened.

## 4 | RESULTS

In the case of total life expectancy, the final donor pool includes the following sample of 16 countries, after excluding above-mentioned cases and countries with missing observations: Angola, Bahrain, Djibouti, Ecuador, Egypt, Gabon, Jordan, Kuwait, Malta, Nigeria, Oman, Qatar, Saudi Arabia, Tunisia, Turkey, and United Arab Emirates. For the outcome of total life expectancy, the counterfactual Iran is generated by the following countries, ordered by their respective weights: Saudi Arabia (61.5%), Nigeria (25.2%), Malta (6.8%), and Egypt (6.8%).<sup>15</sup>

Table 1 shows the average pre-revolution values of the covariates for the factual and synthetic versions of Iran. The synthetic Iran is substantially similar to the factual Iran in terms of pre-revolution life expectancy. As column 5 in Table 1 shows, the gap between the total life expectancy of the factual Iran and its estimated counterfactual is insignificant. In addition, there is a close match between predictors of life expectancy between the factual and counterfactual Iran. As shown by Botosaru and Ferman (2019), an accurate balance on covariates may not be required for the synthetic control method as long as there is a good match on outcomes prior to the treatment. In our case, there is a good match between the covariates and a significant closeness of the outcome (life expectancy) in selected pre-revolution years between the factual Iran and its synthetic. Moreover, the optimization process in SCM assigns variable weights based on the predictive power of each covariate. Therefore, poor predictors of the outcome will receive less importance in the matching process (Bonander, 2018).

In addition to the data on the differences between the factual Iran and its synthetic, Table 1 also shows the unweighted averages of variables for countries with weights greater than 0, excluding Iran, during the pretreatment period. This is to highlight that there would be significant differences if one does not construct the correct weights. The differences are shown in column 6. As we can see, there are significant differences, especially in terms of the predicted outcomes, between the factual Iran and its counterfactual (without considering the optimum weights). This increases our confidence in the application of the SCM approach in generating the counterfactual Iran before the beginning of the open resistance against the Shah. This shows that the *unweighted* donor pool shows a weak counterfactual, in terms of preintervention outcomes.

Moreover, to examine whether the comparison unit created using SCM is a good counterfactual, we need to measure how well it resembles the treated unit (i.e., Iran) before the revolution. The root mean square prediction error (RMSPE) of the outcome variable is used by Abadie et al. (2010) to measure the fit or lack of fit between the trend of the outcome variable for the treated unit and its synthetic version. If RMSPE is 0 then the counterfactual unit is perfectly reproducing the trajectory of the factual unit before treatment. If RMSPE differs from 0, then it

**TABLE 1** The means of predictors during the pre-revolution period (1965–1976) for life expectancy at birth, total (years).

Predictors	Factual Iran (1)	Synthetic Iran (2)	Unweighted average of variables for countries with weight >0 (3)	Difference (1–2)	Difference (1–3)
Life expectancy (1976), years	55.74	55.93	57.68	–0.18	–1.94
Life expectancy (1974), years	54.46	54.29	56.48	0.18	–2.02
Life expectancy (1972), years	52.56	52.60	55.33	–0.04	–2.77
Life expectancy (1970), years	50.86	50.98	54.28	–0.12	–3.43
Life expectancy (1968), years	49.50	49.51	53.35	–0.01	–3.84
Life expectancy (1966), years	48.30	48.24	52.48	0.06	–4.19
log real GDP per capita	8.49	9.38	8.18	–0.89	0.31
Population growth (annual %)	2.73	3.35	1.98	–0.62	0.75
Age dependency ratio (% of working-age population)	90.21	86.39	78.56	3.82	11.65
Share of government consumption at current PPPs	0.12	0.12	0.21	0.00	–0.09

becomes challenging to measure the synthetic unit's goodness of fit. To facilitate the assessment of the quality of the pretreatment fit, Adhikari and Alm (2016) developed a “pretreatment fit index”. A pretreatment fit index of 0 indicates a perfect fit. In our case, the pretreatment fit index is 0.002 which indicates a very good match before the revolution between Iran and its synthetic control with reference to the life expectancy rate.<sup>16</sup>

Figure 1 displays the total life expectancy trajectory of factual Iran and its synthetic counterpart between 1965 and 1988. The synthetic Iran closely replicates the life expectancy of the factual Iran during the entire pre-revolution period, but the two lines diverge significantly starting in 1977. While life expectancy slows down in the factual Iran, the overall level of life expectancy in its synthetic counterpart keeps ascending at a similar pace as the pre-revolution period. The average annual decline in total life expectancy from 1978 to 1988 is estimated to be five years. In other words, in the absence of revolution and war, the total life expectancy of an average Iranian would have been five years longer. The gap between the two lines continues to widen until the middle of the war with Iraq (1983–84) and then narrows by the end of the war (1988). In other words, while the revolution had a moderate long-term impact on total life expectancy at birth, the most significant impact was attributed to the war itself. It is

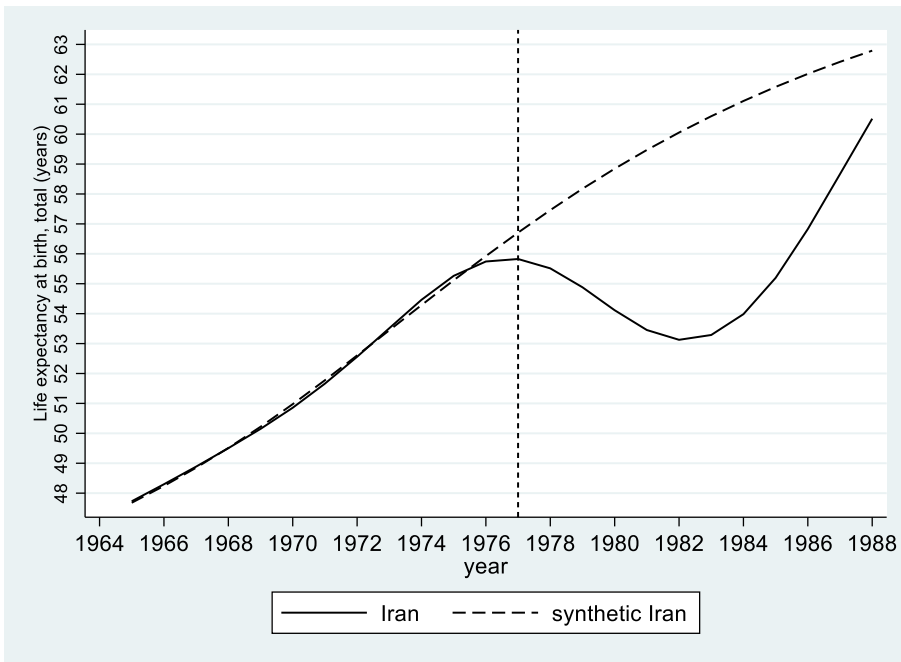


FIGURE 1 Life expectancy at birth, total (years): Iran versus synthetic Iran. [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

worth noting that the revolution played a crucial role in reshaping regional power dynamics and increasing the risk of contagion effects in neighboring autocratic Arab countries. Consequently, these factors (among others) motivated the Iraqi government to initiate the war against Iran. In our study, we refer to the joint effect of the revolution and the war on the life expectancy of Iranians.

In summary, the results indicate a substantial negative impact of both internal and external violence on the life expectancy of Iranians. Comparatively, the estimated negative effect of the revolution and war in Iran is significantly larger than the average negative impact of UN sanctions on life expectancy, which is approximately 1.2–1.4 years in a global sample. Furthermore, the negative impact of US sanctions on life expectancy is more limited, estimated to be around 0.4–0.5 years (Gutmann et al., 2021).<sup>17</sup>

The difference in life expectancy between the factual and counterfactual Iran is illustrated in Figure 2, while Table 2 provides summary statistics for the estimated gap in life expectancy between Iran and its synthetic counterpart.

## 4.1 | Inference procedures, sensitivity analysis, and possible explanations

### 4.1.1 | In-space placebo test

To test the robustness of our main estimations, we use placebo or falsification tests. These are also known as randomization inference tests in statistical fields (Bertrand et al., 2004). Placebo

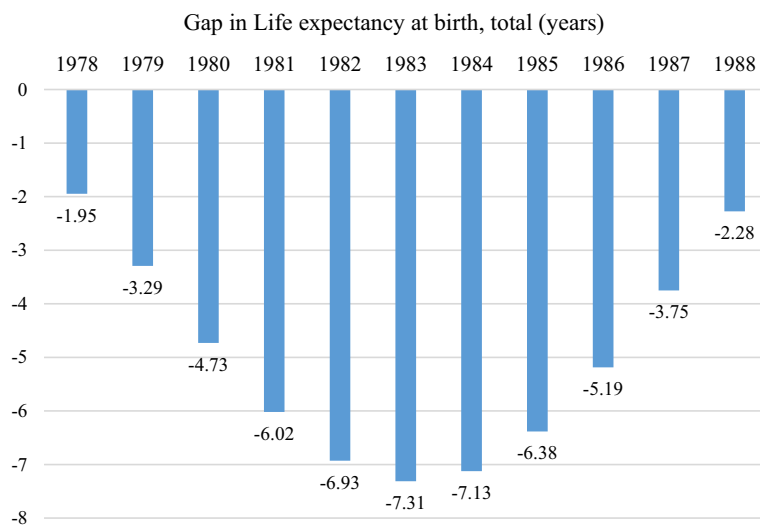


FIGURE 2 Estimated lost years of life for Iran under revolution and war. [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

TABLE 2 Summary statistics for the life expectancy gap between Iran and synthetic Iran (1978–1988).

Mean of loss	–5 years
Median of loss	–5.19 years
Minimum loss	–1.95 years
Maximum loss	–7.31 years
<i>SD</i>	1.94 years
Post-treatment period (1978–1988)	11 years

tests have a simple framework: if SCM is applied to other countries that were not under the treatment (revolution and war), then logically, a similar significant negative health outcome should not be observed, as in the case of Iran. If a similar trajectory for other countries is observed, then the estimated effect for Iran cannot be associated with the post-revolution shock. The placebo tests are shown in Figure 3.

The tests were applied to the other 16 countries in the donor sample in 1977. The thick black line shows the earlier estimated health effect for the factual Iran. The other lines represent the gap between the life expectancy of each of the other countries and their related synthetic counterparts produced by SCM. From Figure 3, it is clear that the factual Iran shows a significant drop after 1977. There is no other country in this sample which shows a similar negative health effect when subjected to the treatment.

In addition to this visual check, we calculate a pseudo *p* value based on the rank of the treatment unit's post-/pre-root mean square prediction error ("RMSPE") ratio compared to the untreated placebo units' post-/pre-RMSPE ratios (as in Abadie et al., 2010). As the results in Figure 4 show, the largest ratio of post-treatment RMSPE to pretreatment RMSPE belongs to Iran (49.20). The inference procedures show a pseudo *p* value of  $1/17 \approx 0.058$ , giving a *p* value of approximately 94%, meaning that there are no other placebo runs that outperform or match

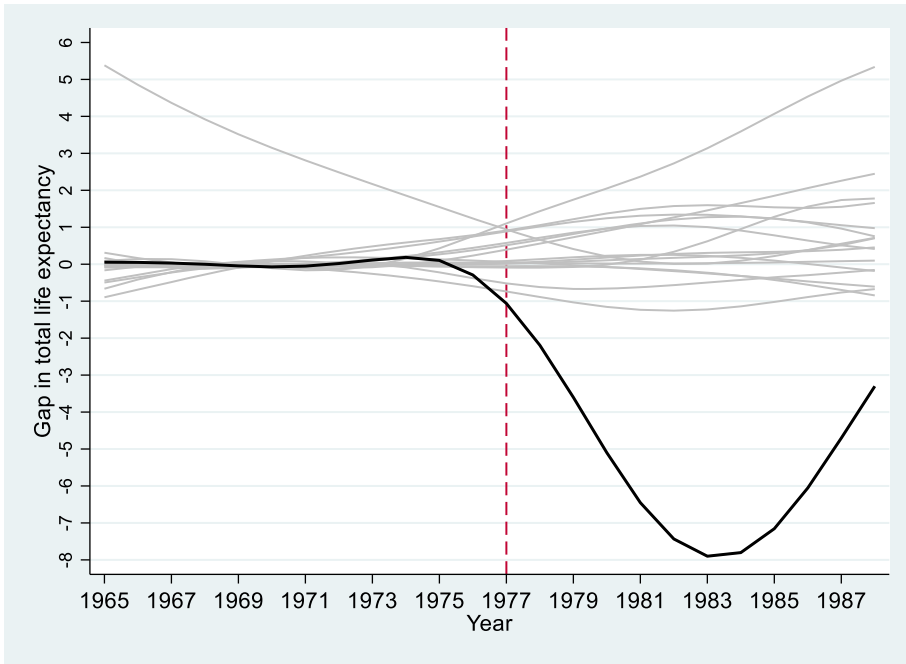


FIGURE 3 (In-space) Placebo test. [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

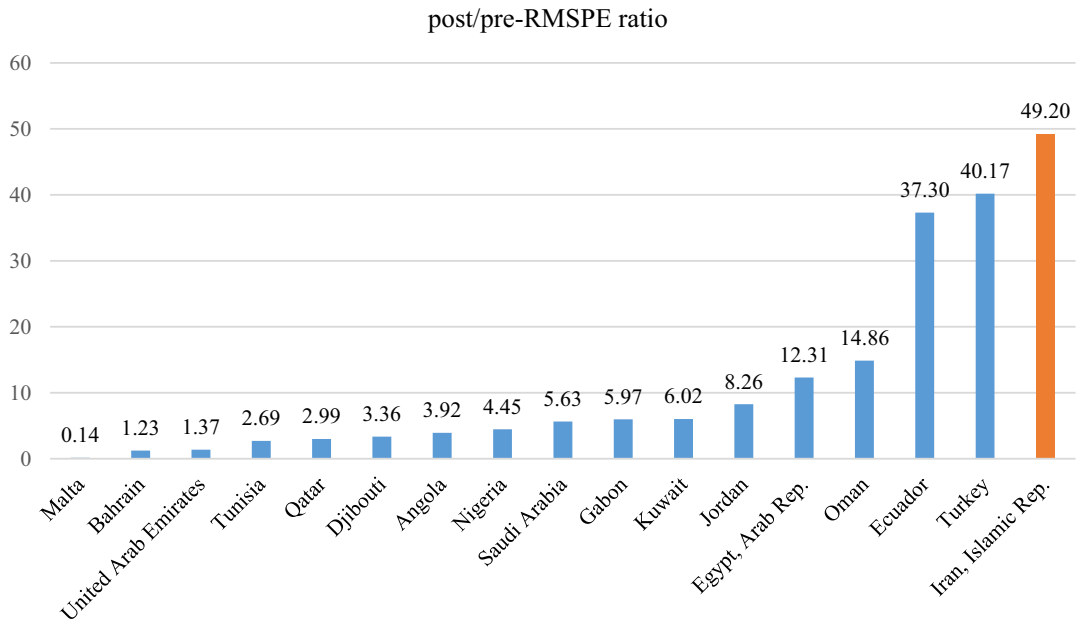


FIGURE 4 Ratio between the post- and pre-intervention root mean squared prediction error (RMSPE). [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

the effect of Iran's estimate when preintervention fit (RMSPE) is accounted for. We can interpret this as having 94% confidence in the main findings. The evidence for a causal health effect of the Iranian revolution and war is strong.

4.1.2 | Change in time dimension (in-time placebo)

What happens to the results produced by the synthetic control method if other years are selected as treatment shocks? To evaluate the reliability of the results, and in addition to “in-space placebo” test, we follow Abadie et al. (2015) and conduct an “in-time placebo” examination. We re-estimate the SCM model but change the treatment year from the beginning of the revolution in 1977–1974, which was associated with sudden significant increase of petroleum export revenues. Is there a similar divergence between the life expectancy of the factual Iran and its synthetic even if another non-revolutionary period is used? Figure 5 displays the results of the “in-time placebo” study.

In Figure 5, there is no divergence between the actual life expectancy of the factual Iran and its synthetic and there is no effect estimated for 1974. This shows that the random selection of a year with a major positive oil price shock before revolution does not generate the effect which was observed from the real shock (i.e., revolution). Similar results are also found when we changed the treatment year to 1973. This also supports the validity of the “no anticipation effects”. Revolution was an unthinkable event (see Kurzman, 2005). Note that in these estimations, the matching procedure between Iran and synthetic Iran is conducted by taking the average of the covariates before the placebo dates (1965–1973 for the placebo treatment year of 1974 and 1965–1972 for the placebo treatment year of 1973).

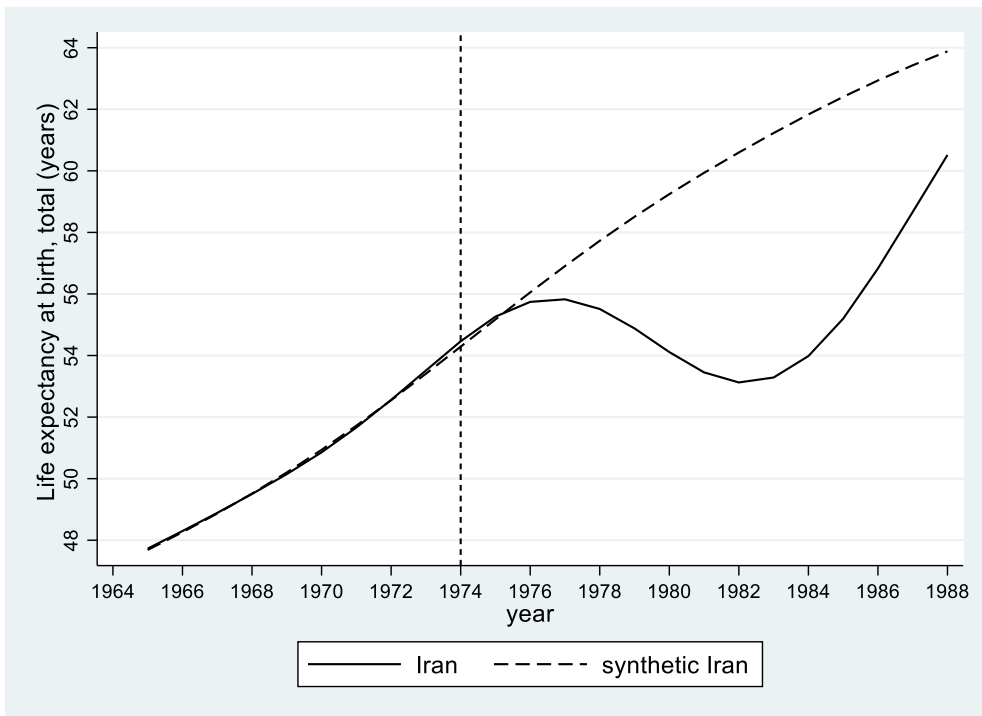


FIGURE 5 In-time placebo effect of 1974 life expectancy of Iran vs. synthetic Iran. [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

### 4.1.3 | Leave-one-out synthetic control

To what extent is the main result sensitive to the inclusion of a specific country in the donor pool? To elaborate on this issue, we conduct a leave-one-out analysis where the most influential countries are respectively excluded from the donor sample. For the main results, the synthetic Iran was generated by a combination of four countries: Saudi Arabia (61.5%), Nigeria (25.2%), Malta (6.8%), and Egypt (6.5%). The leave-one-out analysis generates four other counterfactual versions of Iran, in addition to the main synthetic version which was shown in Figure 1. These counterfactual versions of Iran are estimated after excluding Saudi Arabia, Nigeria, Malta, and Egypt, respectively. Figure 6 shows that the life expectancies of the additional counterfactual versions have significant gaps compared with the factual Iran. The synthetic control result in Figure 1 is robust to the exclusion of dominant countries from the donor pool, ensuring the reliability of the initial findings.

### 4.1.4 | Synthetic difference-in-differences

Synthetic difference-in-differences is based on a panel set-up, in which certain countries are treated (e.g., Iran) and the remaining countries are untreated. The synthetic difference-in-differences procedure calculates a treatment effect as the pre- versus post-difference-in-difference between treated units and synthetic control units, where synthetic control units are chosen as an optimally weighted function of the untreated units (unit-specific weights) and

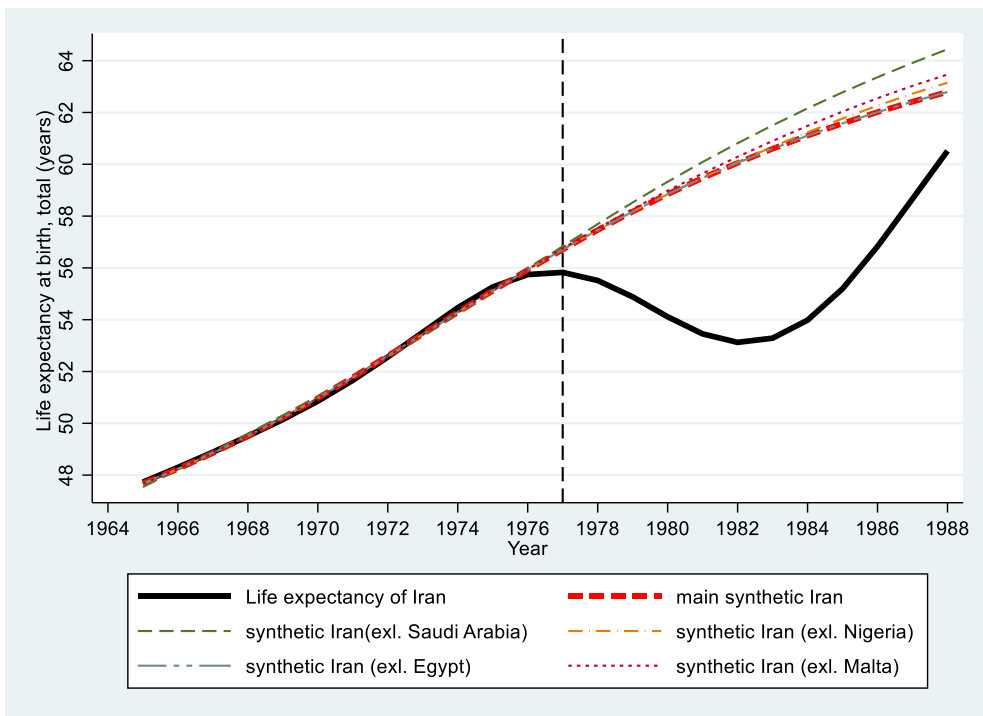


FIGURE 6 Leave-one-out distribution of the synthetic control for Iran. [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

pretreatment times (time-specific weights). This procedure is introduced and explained in detail in Arkhangelsky et al. (2021).<sup>18</sup> In our case of a single treated country (Iran), inference is based on placebo procedures (see Algorithm 4 on placebo variance estimation in Arkhangelsky et al., 2021). Table 3 shows the average treatment effect on the treated (ATT). The estimated ATT is approximately  $-4.5$  which is also highly statistically significant (at 99% confidence interval). The ATT is close to our earlier estimated average annual decline in life expectancy in Iran in the post-revolution period and during the war with Iraq.

## 4.2 | Discussion and further analysis

We discuss and examine some of the possible factors which may have resulted in a significant decline in life expectancy in Iran following the revolution and during the war with Iraq. This discussion may show whether the revolution and subsequent policy changes or the war caused this decline. Of course, in our “in-time” placebo checks, we showed that the shock of the revolution is the most relevant observation. The decline in life expectancy of Iran compared to its counterfactual intensified during the initial years of the war with Iraq.

The new regime in Iran cancelled previous family planning programs, leading to an initial increase in fertility and earlier marriages, with potential impacts on child and female mortality (Abbasi et al., 2002; Hoodfar & Assadpour, 2000). Increasing fertility rate in the absence of an adequate healthcare system may result in higher infant mortality rates, decreasing life expectancy. However, government expenditures on health and education in the new revolutionary regime increased, an efficient and low-cost health system was established and rural living conditions improved.<sup>19</sup> Thus, it may be the case that the revolution had both positive and negative effects on life expectancy.<sup>20</sup>

In this section, we conduct a synthetic control group analysis of female and male life expectancies separately. This can clarify which group's life expectancy was more negatively affected by the revolution and war. Moreover, we conduct the SCM analysis on female and male adult mortality rates separately. We have data on adult mortality rates for the entire period of analysis. Data for infant mortality rates (male and female) and under-five mortality rates (male and female) for Iran is available since 1971.

We start with the devolvement of fertility rates before and after the revolution in Iran and compare it to its synthetic. Data for fertility rates is published by the World Bank (2022). As mentioned earlier, one of the possible channels through which the Islamic Revolution and war with Iraq affected the life expectancy of Iranians is through fertility behavior. The Islamic government emphasized the value of larger family sizes, encouraging early marriage and increasing the costs of divorce.<sup>21</sup> The Islamic government defined motherhood and domesticity as the key

TABLE 3 Synthetic difference-in-differences.

Life expectancy (years)	Average treatment effect on the treated (ATT)	standard error	t statistics	p value	95% confidence intervals (CI)	
Treatment	-4.49	0.98	-4.58	.000	-6.41	-2.57

Note: The country under treatment is Iran, and the treatment is the revolution and the period of war with Iraq from 1978 to 1988. The 95% confidence intervals and p values are derived from Large-Sample approximations, and for theoretical derivations, refer to Arkhangelsky et al. (2021). The inference is based on a placebo procedure, with 200 repetitions used for the placebo standard error, which is higher than the default value of 50.



roles of women in the society and dismantled the 1967 and 1974 Family Protection Laws of the Shah regime (Moinifar, 2007). The post-revolutionary government reduced the legal age of marriage, eliminated restrictions on polygamy, and provided financial support and land to families with more than five children. Being rich in oil resources, most post-revolution religious and political leaders did not see rapid population growth as a major concern. In addition to policy changes under the new Islamic government, the war itself was another driver of higher fertility rates in Iran. A larger population and faster growth rates were seen as a competitive advantage for Iran against Iraq. Ayatollah Khomeini ordered the creation of the “Twenty Million Man Army”<sup>22</sup> which became a well-known national slogan. Increasing human losses during the war may also have influenced families to increase their reproductive behavior to offset expected losses. During the war, the government also introduced a universal rationing system to provide access to food and services at low prices. Larger families benefited more from the subsidized goods. The rationing system not only applied to basic goods but also to imported modern consumer goods such as television sets, refrigerators, etc. The benefits of having children in this rationing system exceeded the costs of raising them during the war and the significant intervention of the revolutionary government in regulating markets and prices. Abbasi et al. (2002) provide a more detailed picture of fertility development following the revolution in Iran.

The relationship between fertility rates and life expectancy is extensively studied. Antagonistic pleiotropy theory (Williams, 1957) and the disposable soma theory (Kirkwood, 1977; Kirkwood & Rose, 1991) of aging predict a trade-off between fertility behavior and life expectancy. According to the antagonistic pleiotropy theory, genes that enhance reproductive potential early in life increase the risk of disease and mortality later in life. The disposable soma theory explains that reproduction behavior is associated with energetic and metabolic costs, leading to worsening of maternal conditions. The latter increases the risk of disease and higher mortality rates, lowering life expectancy. For more discussion on the trade-off between fertility and human lifespan see Kuningas et al. (2011).

We estimate the SCM using fertility rate as the outcome of interest. The other details in estimation of SCM are similar to the earlier case. Focusing on fertility rate as the outcome of interest results in a synthetic Iran which is generated by three countries from the donor sample: Bahrain (47.1%), Oman (44%), and Malta (8.9%). There is a perfect match between fertility of the factual Iran and its counterfactual in selected years (1976, 1974, 1972, 1970, 1968, and 1966) before the revolution. The match with the covariates is also adequate. The SCM analysis result is shown in Figure 7 and the quality of matching on covariates is presented in Table 4.

While the development of fertility rate of Iran and its synthetic is similar in pre-1977 period, it deviates from each other following the Iranian Revolution and war with Iraq. The deviation reduces by the end of the war. This observation is in line with previous theoretical and stylized facts of Iran during the revolution and war. The gap in the fertility rate of Iran versus its synthetic is also shown in Figure 8.

Is the estimated excess fertility rate of factual Iran one of the drivers of decreasing life expectancy in the total and female populations, in particular through increasing infant and under-five mortality rates?

Despite the excess fertility rate of the factual Iran under revolution and war compared to its counterfactual, we may observe gender specific differences with reference to life expectancy. Specifically, it may be the case that the drop in total life expectancy is driven by the drop in male life expectancy and increase in male adult mortality rates due to the higher participation of the male population in the war and other internal conflicts after the Iranian Revolution. We conducted a separate SCM analysis on these intermediary channels. We find that while

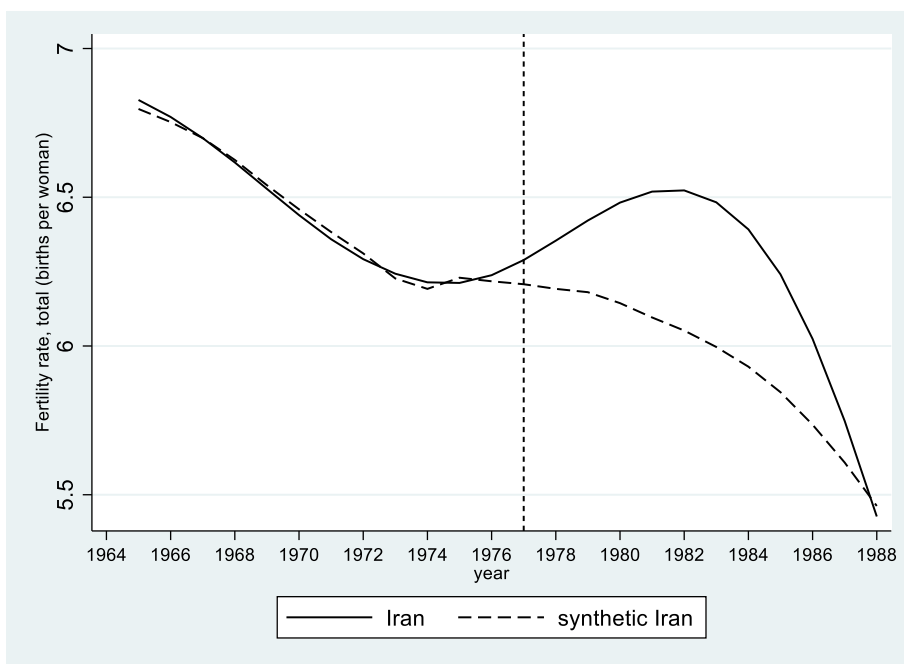


FIGURE 7 Fertility rate, total (births per woman): Iran versus synthetic Iran. [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

TABLE 4 The means of predictors during the pre-revolution period (1965–1976) for fertility rate.

Predictors	Iran (1)	Synthetic Iran (2)	Difference (1–2)
Fertility rate (1976)	6.24	6.22	0.02
Fertility rate (1974)	6.21	6.19	0.02
Fertility rate (1972)	6.29	6.31	–0.02
Fertility rate (1970)	6.44	6.46	–0.02
Fertility rate (1968)	6.62	6.63	–0.01
Fertility rate (1966)	6.77	6.75	0.02
log real GDP per capita	8.49	9.31	–0.82
Population growth (annual %)	2.73	3.23	–0.50
Age dependency ratio (% of working-age population)	90.21	87.33	2.88
Share of government consumption at current PPPs	0.12	0.13	–0.01

trajectory of factual Iran and its synthetic, with reference to infant and under-five mortality rates (for both male and female), is very similar before the revolution, it does not show a meaningful deviation after. Both rates continued to decline after the revolution and during the war, similar to the counterfactual Iran. Factual Iran performance was even marginally better than its counterfactual, in terms of reductions in infant and under-five mortality rates for the initial years after the revolution (results are available). This observation may support the positive role of increased social spending on health and education under the new regime and during the war in reducing the possible negative effects of higher fertility rates on mortality rates.

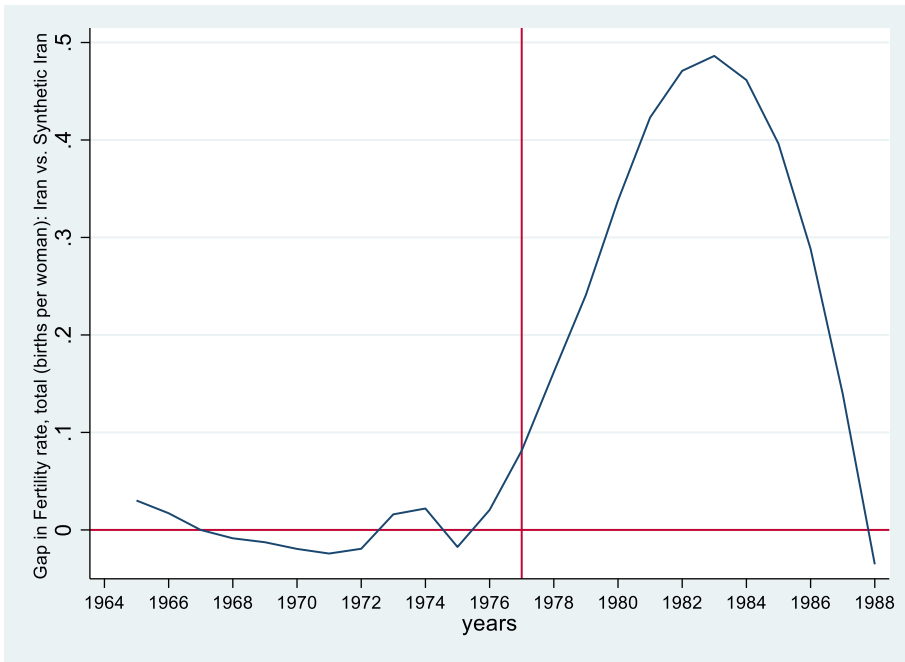


FIGURE 8 Fertility rate estimated gap between Iran and synthetic Iran. [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

Our main results show a significant decline in total life expectancy of factual Iran do men and women contribute similarly to this decline? We focus on male and female life expectancies in the following SCM analysis. Using male life expectancy as the outcome of interest and following similar predictors as in total life expectancy, results in a counterfactual Iran based on a combination of three countries from the donor sample: Saudi Arabia (61.5%), Nigeria (23.2%), and Malta (15.2%). The balance of predictors of the estimated SCM in this case show a perfect match in the outcome of interest (male life expectancy) in selected pre-revolution years and close similarity on the other covariates between the factual and counterfactual versions of Iran. Figure 9 shows the male life expectancy at birth and the trajectories of the factual Iran and its synthetic counterpart between 1965 and 1988. The synthetic Iran exactly reproduces the male life expectancy of Iran during the entire pre-revolution period, but the two lines significantly diverge starting in 1977.

The average annual loss in male life expectancy from 1978 to 1988 is estimated to be 9.75 years. In other words, in the absence of revolution and war, an average male Iranian's life expectancy would have been approximately 10 years longer. This finding highlights the significant damage that the revolution and war imposed on male life expectancy in Iran.

The gap in male life expectancy between the factual and counterfactual versions of Iran is illustrated and summarized in Figure 10 and the quality of matching on covariates is presented in Table 5.

Can we also observe a similar damaging effect on the life expectancy of women in Iran? To address this question, we focus on female life expectancy as the outcome of interest in the SCM analysis. In this case, the counterfactual Iran is based on the following combination of 16 countries, ordered based on weights: Oman (34.6%), Nigeria (18.6%), Tunisia (15.8%), Egypt (12.7%),

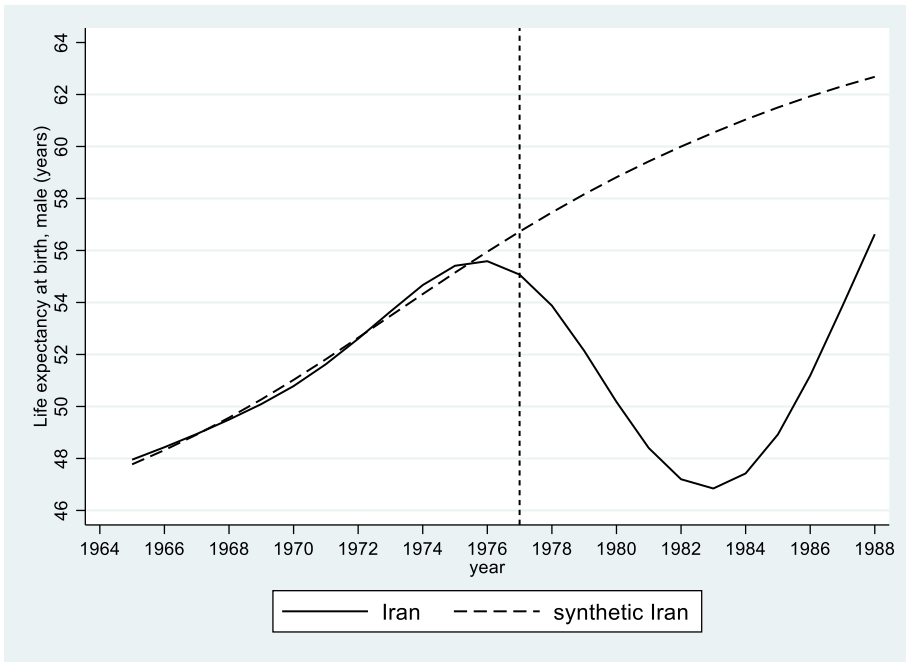


FIGURE 9 Life expectancy at birth, male (years): Iran versus synthetic Iran. [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

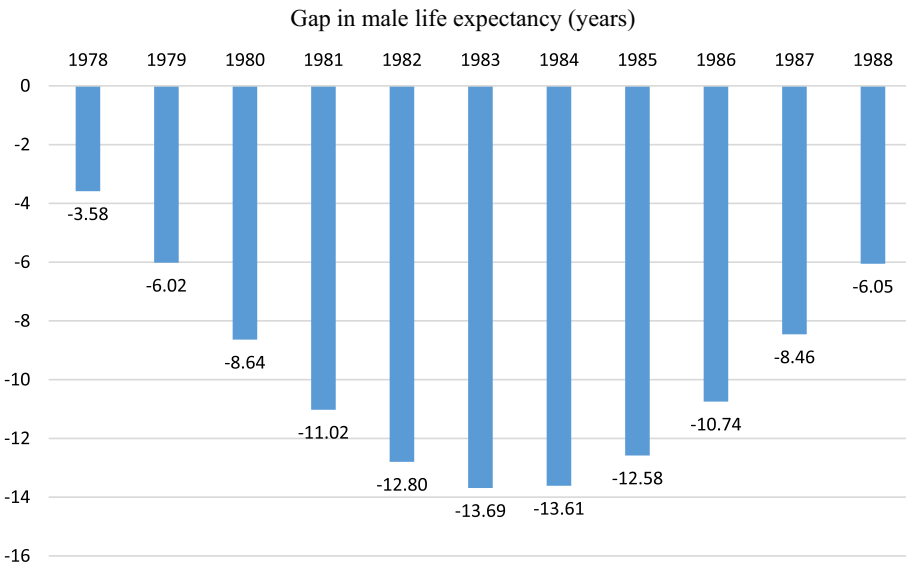
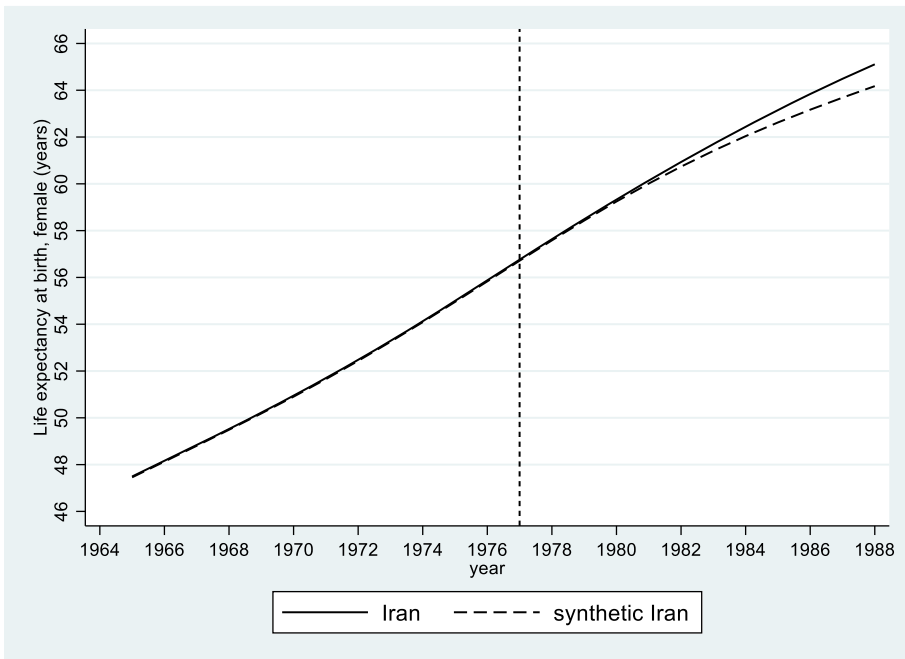


FIGURE 10 Estimated lost years of life for Iranian males during the revolution and war. [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

Saudi Arabia (12.4%), Djibouti (1.1%), Ecuador (1%), Turkey (1%), Angola (0.6%), Jordan (0.4%), Bahrain (0.3%), Kuwait (0.3%), Malta (0.3%), Qatar (0.3%), UAE (0.3%), and Gabon (0.2%). The predictors balance in this case shows a perfect match of outcome between the factual Iran and

**TABLE 5** The means of predictors during the pre-revolution period (1965–1976) for male life expectancy (years).

Predictors	Iran (1)	Synthetic Iran (2)	Difference (1–2)
Male life expectancy (1976)	55.59	55.95	−0.36
Male life expectancy (1974)	54.67	54.32	0.35
Male life expectancy (1972)	52.60	52.64	−0.04
Male life expectancy (1970)	50.78	51.02	−0.24
Male life expectancy (1968)	49.49	49.57	−0.07
Male life expectancy (1966)	48.43	48.32	0.11
log real GDP per capita	8.49	9.47	−0.98
Population growth (annual %)	2.73	3.11	−0.38
Age dependency ratio (% of working-age population)	90.21	84.33	5.88
Share of government consumption at current PPPs	0.12	0.10	0.02



**FIGURE 11** Life expectancy at birth, female (years): Iran versus synthetic Iran. [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

its counterfactual in selected pre-revolution years. The female life expectancies of factual Iran and its synthetic are illustrated in Figure 11 and the quality of matching on covariates is presented in Table 6. There is hardly any effect of the revolution and war on female life expectancies in the factual Iran compared to its counterfactual. As a result, the major driver of the drop in total life expectancy presented in Figure 1 is due to the substantial negative impact of the revolution and the war, especially, on male life expectancy.

**TABLE 6** The means of predictors during the pre-revolution period (1965–1976) for female life expectancy (years).

Predictors	Iran (1)	Synthetic Iran (2)	Difference (1–2)
Female life expectancy (1976)	55.88	55.83	0.04
Female life expectancy (1974)	54.13	54.09	0.04
Female life expectancy (1972)	52.48	52.43	0.04
Female life expectancy (1970)	50.94	50.90	0.04
Female life expectancy (1968)	49.53	49.49	0.04
Female life expectancy (1966)	48.16	48.13	0.04
log real GDP per capita	8.49	8.55	−0.06
Population growth (annual %)	2.73	3.09	−0.36
Age dependency ratio (% of working-age population)	90.21	90.65	−0.44
Share of government consumption at current PPPs	0.12	0.18	−0.06

Earlier we explained that infant and under-five mortality rates in Iran do not show a degradation compared to synthetic Iran following the revolution and during the war. We also mentioned that life expectancy is not only a function of infant mortality rate. Examining the development of male and female adult mortality rates may also be important for a better understanding of the decline in life expectancy resulting from revolution and war. It is expected that violence following the revolution and war would significantly affect more the male adult mortality rates, as this group was more engaged in internal and external conflicts during the mentioned period.

We start by using adult male mortality rate (per 1000 male adults) as the outcome of interest in the SCM analysis. This outcome is defined in the World Bank (2022) as the probability of dying between the ages of 15 and 60. This is the probability of a 15-year-old male dying before reaching the age of 60, if subject to the age-specific mortality rates of the specified year between those ages. The counterfactual Iran for this outcome is generated based on a combination of three countries from the donor sample: Ecuador (65.6%), Nigeria (21.3%), and Angola (13.2%), which all have oil-based economies. Figure 12 shows the development of male adult mortality in the factual Iran and its synthetic version from 1965 to 1988. There is a perfect match on this indicator between the factual Iran and its counterfactual until 1977. We then observe a deviation that reached its peak point in 1982–83, when there were high levels of political tension in Iran and war with Iraq. Figure 13 illustrates the estimated gap in male adult mortality rates between the factual Iran and its synthetic and the quality of matching on covariates is presented in Table 7. The average annual excess male adult mortality rate (per 1000 male adult) between 1978 and 1988 is estimated to be approximately 165.

How did female adult mortality rates in Iran developed pre- and post-revolution compared to its counterfactual? Is there a similar excess mortality rate among women during this period in Iran? To address this issue, we use female adult mortality rates (per 1000 female adults) from the World Bank (2022) as the outcome of interest. In this case, the synthetic Iran is generated based on the following combination: Gabon (35.7%), Bahrain (24%), Nigeria (13.7%), Angola (12.7%), Oman (10.4%), Ecuador (0.7%), Turkey (0.55), Egypt (0.4%), Djibouti (0.3%), Jordan (0.3%), Kuwait (0.3%), Malta (0.3%), Saudi Arabia (0.3%), Qatar (0.2%), Tunisia (0.1%), and UAE (0.1%). Figure 14 shows the development of female adult mortality rates in the factual Iran and

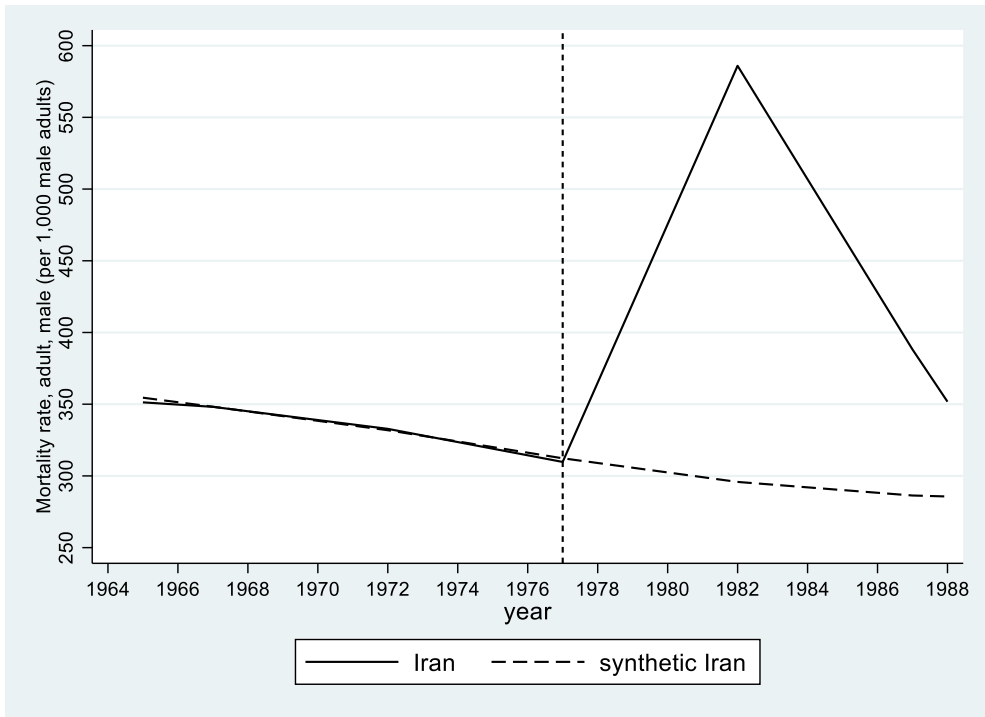


FIGURE 12 Mortality rate, adult, male (per 1000 male adults): Iran versus synthetic Iran. [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

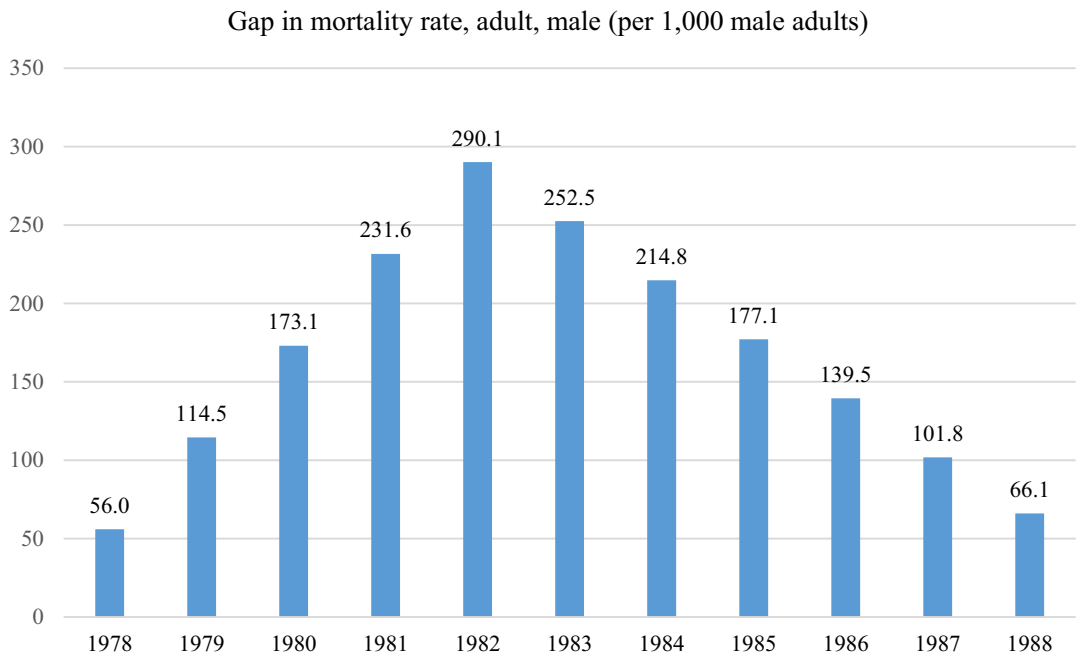
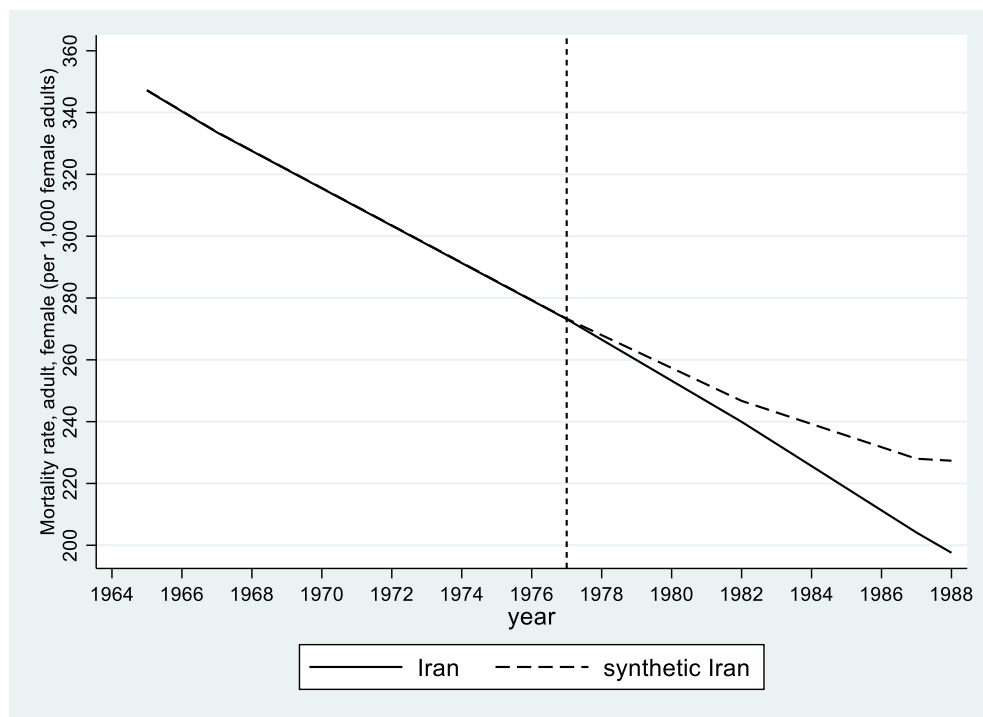


FIGURE 13 Estimated excess male adult mortality rate in Iran during the revolution and war. [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

**TABLE 7** The means of predictors during the pre-revolution period (1965–1976) for male adult mortality rate.

Predictors	Iran (1)	Synthetic Iran (2)	Difference (1-2)
Male adult mortality rate (1976)	314.38	316.23	-1.85
Male adult mortality rate (1974)	323.61	324.05	-0.44
Male adult mortality rate (1972)	332.83	331.87	0.97
Male adult mortality rate (1970)	338.97	338.42	0.55
Male adult mortality rate (1968)	345.11	344.98	0.13
Male adult mortality rate (1966)	349.74	351.40	-1.66
Log real GDP per capita	8.49	8.44	0.06
Population growth (annual %)	2.73	2.65	0.08
Age dependency ratio (% of working-age population)	90.21	91.83	-1.62
Share of government consumption at current PPPs	0.12	0.17	-0.04



**FIGURE 14** Mortality rate, adult, female (per 1000 female adults): Iran versus synthetic Iran. [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

its counterfactual from 1965 to 1988 and the quality of matching on covariates is shown in Table 8. There is no observed negative effect of the revolution and war on increasing female adult mortality rates in Iran. The female adult mortality rates in the factual Iran even performed a bit better than its counterfactual. As previously mentioned, post-revolution



**TABLE 8** The means of predictors during the pre-revolution period (1965–1976) for female adult mortality rate.

Predictors	Iran (1)	Synthetic Iran (2)	Difference (1–2)
Female adult mortality rate (1976)	279.23	279.36	–0.13
Female adult mortality rate (1974)	291.32	291.45	–0.13
Female adult mortality rate (1972)	303.40	303.54	–0.13
Female adult mortality rate (1970)	315.49	315.61	–0.13
Female adult mortality rate (1968)	327.57	327.69	–0.12
Female adult mortality rate (1966)	340.39	340.50	–0.11
log real GDP per capita	8.49	8.89	–0.40
Population growth (annual %)	2.73	2.65	0.08
Age dependency ratio (% of working-age population)	90.21	82.05	8.16
Share of government consumption at current PPPs	0.12	0.12	0.00

government expenditures on health and education increased, an efficient, low-cost health system was established, and rural living conditions improved. The male population was more engaged in the conflict and violence of the revolution and war with Iraq and thus is driving the overall negative effects on life expectancy in Iran during 1978–1988.

## 5 | CONCLUSION

More than four decades ago, Iran experienced a series of momentous political events with substantial implications for its socioeconomic development. The Islamic Revolution, which started in 1977 (see Kurzman, 2005) and led to the collapse of the monarchy in 1979, as well as the subsequent war with Iraq (1980–88), imposed significant economic costs. Farzanegan (2022a) examined the causal joint effect of the revolution and war on the economy of Iran and showed that the average annual income per capita lost to the revolution and war was approximately US \$ 3000 from 1978 to 1988. While the economic costs of conflict and violence (with a greater focus on the war with Iraq) have been studied in the literature, the human and health consequences of these violent events are underinvestigated.

This study aims to answer the question of how the longevity of Iranians may have developed in the absence of the Islamic Revolution and war with Iraq. This is an important question given the significant body of evidence linking longer life expectancy to positive long-term development effects. It is also crucial to have a robust estimation of the causal effects of regime changes and wars on a key health indicator of a nation. To accomplish this, we employed a counterfactual analysis based on the synthetic control method, estimating the lost years of life in Iran following the Islamic Revolution and war with Iraq. Our findings demonstrate that the trajectories of life expectancies of factual Iran and its synthetic counterpart were similar before the shock of the revolution but significantly diverged afterward.

The main results indicate that the *average annual loss in life expectancy* from 1978 to 1988 was estimated to be five years. In other words, if there had been no revolution and war, the life expectancy of an average Iranian would have been five years longer. We also conducted various sensitivity checks, including in-space and in-time placebo analyses, as well as leave-one-out

synthetic control. These robustness checks confirm the initial findings of a significant negative causal effect of the revolution and war on the life expectancy of Iranians.

In addition, we explore the potential factors underlying the significant decline in life expectancy in Iran following the revolution and war. Our findings indicate that these events had a more profound impact on health indicators such as life expectancy and adult mortality rates for the male population. The institutional changes that occurred after the Islamic revolution and war led to excess fertility rates, but higher healthcare spending by the revolutionary government mitigated the theoretical negative effects on infant and under-five mortality rates for both female and male populations. However, the gap between male and female life expectancy widened mainly due to excess male adult mortality rates.

The case study of Iran highlights the destructive effects of war and internal conflict following a revolution on male adult mortality rates. The initiation of the war was partly related to the opportunistic behavior of Iraq's leader Saddam Hussein, following an imbalance of power after the revolution in the region. However, the idea of exporting the Islamic revolution to other Islamic countries, particularly in the MENA region, as well as the radical international politics of the Islamic government under the leadership of Ayatollah Khomeini with reference to the US and Israel, contributed to the initiation of the conflict in 1980 and its continuation.

Our results emphasize the costs of radical regime changes and interstate war for the sustainable development of affected nations. Ample evidence in the literature shows that lost longevity has negative long-term impacts on the willingness to invest in human capital, public funding on education, cognitive development, saving rates, labor force productivity, fertility behavior of individuals, investment rates, and economic growth. The political shock of the Islamic revolution, which changed formal institutions, and the subsequent eight-year war with Iraq not only damaged the nation's physical infrastructure but also took a significant human toll.

The estimated loss of years of life for Iranian males during the Islamic revolution, civil violence, and war is substantial and highlights the importance of peaceful conflict resolutions and stable political transitions. Our study underscores the need for policymakers to prioritize investments in public health and well-being, particularly in post-conflict settings, to mitigate the long-term consequences of political upheavals and armed conflicts. Furthermore, our findings provide a cautionary tale for other countries considering similar radical changes in governance and/or engaging in interstate wars, underscoring the significant human costs of such actions.

## ACKNOWLEDGMENTS

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## DATA AVAILABILITY STATEMENT

Data available on request from the author.

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## ENDNOTES

- <sup>1</sup> Until mid-1978, the CIA's assessment was that Iran was not on the brink of revolution, nor in a state of revolution (Levitsky & Way, 2022, p. 229).
- <sup>2</sup> Jervis (2011, p. 16) points out that the revolutionary protests began in 1977, initiated by the secular opposition rather than the groups that eventually toppled the Shah.
- <sup>3</sup> The SCM has been used in different contexts including development effects of conflicts, revolutions, and populism (Abadie & Gardeazabal, 2003; Echevarría & García-Enríquez, 2020; Farzanegan, 2022a, 2022b; Farzanegan & Kadivar, 2023; Grier & Maynard, 2016; Jales et al., 2018; Lawson et al., 2019; Matta et al., 2022; Mawejje & McSharry, 2021), among others. Farzanegan & Batmanghelidj (2023) explain how the SCM can be used to measure the socio economic effects of sanctions, providing examples from Iran.
- <sup>4</sup> For more insight on whether the treatment effect we find for Iran is because of the revolution or war with Iraq, one may want to conduct a similar analysis for Iraq that experiences a similar war treatment effect as with Iran. However, even in the case of Iraq, we observed another joint event, which was the capture of political power and the establishment of a totalitarian regime by Saddam. On July 22, 1979, Saddam Hussein organized a coup and took the power from President Hassan al-Bakr. For more details, see <https://theconversation.com/saddam-hussein-how-a-deadly-purge-of-opponents-set-up-his-ruthless-dictatorship-120748>.
- <sup>5</sup> This line of literature argues that reductions in life expectancy are damaging to economic development, for example, via the detrimental effects on human capital formation. Much of this depends on why life expectancy decreases. There may be different implications for human capital formation and ultimately, the effect on growth, if the reduction in life expectancy is due to higher child, young adult, or earlier-than-expected elder adult mortality, such as during the COVID-19 pandemic. We also acknowledge that the impact of life expectancy on economic development is likely to go in both directions.
- <sup>6</sup> Other studies find a nonlinear association between life expectancy and economic growth (Azomahou et al., 2009; Cervellati & Sunde, 2011; Hansen, 2012; Husain et al., 2014).
- <sup>7</sup> Our results for Iran differ from the findings of Plümper and Neumayer (2006) “that over the entire conflict period, interstate and civil wars on average affect women more adversely than men.” In their study, the significant negative effects on females were due to the displacement and sexual violence from the war and the reduction of access to economic resources for women. They also argue that these negative effects on the female population is stronger during ethnic conflicts (and thus widespread sexual violence between competing ethnical groups) and in places where the government is not capable of provisioning public goods. None of them apply in the case of Iran.
- <sup>8</sup> For a simple explanation of this indicator see: <https://blogs.worldbank.org/opendata/what-does-life-expectancy-birth-really-mean>.
- <sup>9</sup> See also <https://ourworldindata.org/life-expectancy-how-is-it-calculated-and-how-should-it-be-interpreted>.
- <sup>10</sup> We follow the classification of the World Bank for the MENA region which includes 21 countries: <https://data.worldbank.org/country/ZQ>.
- <sup>11</sup> OPEC members are listed here: [https://www.opec.org/opec\\_web/en/about\\_us/25.htm](https://www.opec.org/opec_web/en/about_us/25.htm).
- <sup>12</sup> We did not exclude Egypt and Jordan as their level of tension and confrontation with Israel was short-lived. Egypt normalized its relationship with Israel in 1979 after Egyptian president Anwar Sadat signed a peace agreement with Israeli Prime Minister Menachem Begin. Since then, the main confrontation of Israel with Arab world was focused on Lebanon, Syria, and Iraq. These countries are excluded from our donor pool. For more information see <https://irqnow.com/saddam1979/>.
- <sup>13</sup> Using 1977 as treatment year helps to capture the full impact of revolutionary period which peaked in 1978 and resulted in the collapse of monarchy in February 1979. Furthermore, using 1977 as treatment year results in a significantly lower Root Mean Squared Prediction Error (the gap between pretreatment characteristics for the treated unit and the untreated units) in the SCM analysis.
- <sup>14</sup> Appendix B also presents the results based on the global donor pool instead of focusing solely on the sample of MENA/OPEC. The findings demonstrate a high level of robustness when considering this broader donor pool.

- <sup>15</sup> In one of our sensitivity tests, we conduct Leave-One-Out exercise following Abadie et al. (2015). We iterate over the model to leave out one selected country (with non-zero weight) each time to assess whether one of the countries is driving the results. In our case, we generate four additional synthetic controls to compare with the original one by excluding Saudi Arabia, Nigeria, Malta, and Egypt, respectively. We show that the leave-one-out synthetics closely match the original synthetic Iran that includes all four donor countries, verifying the robustness of the original finding.
- <sup>16</sup> We used the suggested procedure by Bibek Adhikari to calculate the pretreatment fit index for SCM which is available at: <https://bibekadhikari.com/research/pre-treatment-fit-index-for-scm/>.
- <sup>17</sup> Another notable difference between the effects of sanctions on life expectancy and our observations in the case of the revolution and war in Iran is the pronounced impact on women. Gutmann et al. (2021) provide evidence suggesting that women are more severely affected by the imposition of sanctions. In our analysis of Iran (refer to Section 4.2 for detailed discussion and further analysis), we illustrate a substantial decrease in male life expectancy.
- <sup>18</sup> On advantages of SCM over regression-based solutions (e.g., matching on key variables, or propensity score matching) and other quasi-experimental designs such as the Difference-in-Differences method see [https://bookdown.org/mike/data\\_analysis/synthetic-control.html](https://bookdown.org/mike/data_analysis/synthetic-control.html).
- <sup>19</sup> According to the World Bank (2022), the total government expenditure on education (% of GDP) in Iran increased from an average of 2.8% during 1972–1975 to an average of 4.47% from 1981 to 1988. For a critical review of literature on the post-revolution social performance in Iran, see Kadivar (2022).
- <sup>20</sup> The revolution and Iran-Iraq war, 1980–1988 as well as the academic cleansing program (well-known as cultural revolution) of 1980–1983 caused an increase in out-migration of Iranians that were better educated and presumably healthier than the remaining population (Azadi et al., 2020). This will affect life expectancy in subsequent years. Any increase in mortality following the revolution and war will amplify the outmigration effect on life expectancy.
- <sup>21</sup> For a review of marriage and divorce rates in Iran and the socioeconomic factors behind them see Farzanegan and Gholipour (2016, 2018), Gholipour and Farzanegan (2015).
- <sup>22</sup> <https://www.washingtonpost.com/archive/politics/1979/11/27/iran-told-to-prepare-for-war/f48bc2af-4d6c-4f62-95ae-6f3cddf9d824/>.

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## APPENDIX A

Tables A1 and A2

**TABLE A1** Human costs of war.

Iraq	Iran
Casualties (total: 680,000 dead and missing)	
About 180,000 fatalities and disappearances	About 500,000 fatalities and disappearances
125,000 military	380,000 military and IRGC
5000 civilians	80,000 Basiji
50,000 Iraqi Kurds	10,000 civilians
	30,000 Iranian Kurds
Around 520,000 injured and disabled.	Around 1,300,000 injured and disabled.
Approximately 70,000 POWs captured by the Iranian army.	Approximately 45,000 POWs were captured by the Iraqi army.

Source: Razoux (2015, p. 569).



TABLE A2 Financial costs of war.

	Financial cost of the war to Iraq	Financial cost of the war to Iran
Loss of oil revenue	160 billion dollars (35%)	350 billion dollars (54%)
Debt (financing of the war effort)	110 billion dollars (24%)	
Expenses related to war effort		20 billion dollars (3%)
Damage to infrastructure	90 billion dollars (20%)	180 billion dollars (28%)
Purchase of war equipment	80 billion dollars (18%)	20 billion dollars (3%)
Compensation to families of casualties	9 billion dollars (2%)	25 billion dollars (4%)
Construction of new pipelines	3 billion dollars (~1%)	
Loss of industrial revenue		35 billion dollars (5%)
Importing of refined petroleum products		12 billion dollars (~2%)
Increase in insurance premiums (oil trade)		3 billion dollars (~1%)
Total	452 billion dollars (1988)	645 billion dollars (1988)

Source: Razoux (2015, pp. 573–574).

## APPENDIX B: GLOBAL DONOR POOL

We have also extended our model to include a global sample, excluding countries that experienced similar shocks such as revolution and/or war during the period of analysis. In short, the key findings remain robust when using a global donor pool instead of the MENA/OPEC sample in the main analysis.

In the main analysis, we chose to focus on a MENA/OPEC sample as a donor pool to identify possible contributing countries to the synthetic Iran, based on the recommendation of Abadie et al. (2015) (p. 499, footnote 10). They suggest that using weights that sum to one and fall in the  $[0, 1]$  interval prevents extrapolation biases, but interpolation biases can be severe if the donor pool includes units with characteristics very different from those of the unit representing the case of interest. To reduce interpolation biases, they recommend restricting the donor pool to units that are similar to the one representing the case of interest. Therefore, studies often rely on comparable geographic locations to find the best match if the data permits.

However, we demonstrate that our main results are not sensitive to relaxing this restriction on the donor pool. Additionally, we show the estimation of “bias-corrected” synthetic control gaps, which adjust for discrepancies in predictor variable values between a treated unit and its donor pool, as proposed by Abadie and L’Hour (2021) and Ben-Michael et al. (2021). The results of this bias correction SC are also similar to our main findings based on the MENA/OPEC donor pool.

Focusing on a global sample and excluding countries that have had similar experiences of conflict, war, regime change, or missing data on outcome variables and income per capita for the period of analysis, we identified 103 countries from the global sample as the donor pool.

The synthetic difference-in-differences (which merges Difference-in-Differences and Synthetic Control methods for identifying the treatment effect with panel data into a single estimator) results in a similar average treatment effect of a decline of five years in annual life expectancy (comparable to the main results using a restricted sample of MENA/OPEC in Table 3). This annual decline in life expectancy for Iranians following the revolution and during

the war with Iraq is also statistically significant at the 1% level. The synthetic difference-in-differences estimator estimates the ATT (see Table B1) which is the joint effect of the Islamic revolution and war on life expectancy in Iran averaged across all post-treatment time periods (1978–1988).

Synthetic control analyses, using a global sample of 103 countries, resulted in very similar estimations of the joint effect of revolution and war on life expectancy in Iran (see Figure B1 and compare it to the main Figure 1, based on MENA/OPEC donor pool).

The contributing countries to the synthetic Iran in this global donor pool are Tunisia (38.7%), Cote d'Ivoire (22.8%), Romania (20.3%), Senegal (17.8%), and Japan (0.4%). Other countries received a weight of 0.

TABLE B1 Synthetic difference-in-differences: Global donor pool.

Life expectancy (years)	Average treatment effect on the treated (ATT)	Standard error	t statistics	p value	95% confidence intervals (CI)	
Treatment	-5.06	1.09	-4.64	.000	-7.20	-2.92

Note: The country under treatment is Iran, and the treatment is the revolution and the war with Iraq from 1978 to 1988. The 95% confidence intervals and p values are derived from Large-Sample approximations, for theoretical derivations, refer to Arkhangelsky et al. (2021). The inference is based on a placebo procedure, with 200 repetitions used for the placebo standard error, which is higher than the default value of 50.

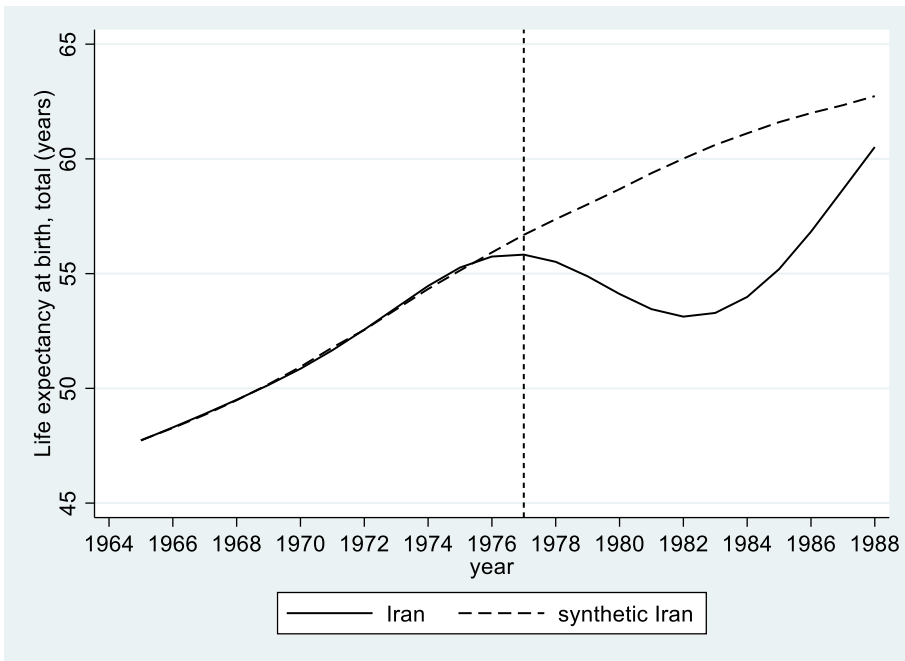


FIGURE B1 Iran and synthetic Iran using a global donor pool: Life expectancy (years). [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

The synthetic Iran in this robustness check is similar to Iran in terms of the outcome variable (life expectancy) in the selected year before the revolution. There is also a good level of matching between the covariates, as shown in Table B2.

To evaluate whether the comparison unit created using SCM is a suitable counterfactual, we need to measure how closely it resembles the treated unit (i.e., Iran) before the revolution, just as we did in the main analysis. Abadie et al. (2010) used the root mean square prediction error (RMSPE) of the outcome variable to assess the fit or lack of fit between the trend of the outcome variable for the treated unit and its synthetic version. When the RMSPE is 0, the counterfactual unit perfectly replicates the trajectory of the factual unit before treatment. If the RMSPE deviates from 0, measuring the synthetic unit's goodness of fit becomes difficult. Adhikari and Alm (2016) devised a "pretreatment fit index" to encourage the evaluation of the quality of the pretreatment fit. A pretreatment fit index of 0 denotes a perfect fit. In this robustness case, the pretreatment fit index is 0.002, which is the same as in the main result. It indicates that there was a very good match between Iran and its synthetic control with respect to the life expectancy rate before the revolution.

We further our analysis by focusing on possible reasons for the development of life expectancy by checking variables such as fertility rate, female and male life expectancy, and female and male adult mortality rates (to compare our results with the main findings based on the MENA/OPEC donor pool).

Using the global donor pool, fertility rate as the outcome variable results in the following estimation, which is comparable to Figure 7 in the main analysis. The fertility rate of factual Iran increased compared to synthetic Iran. The Revolutionary and Islamic government emphasized the traditional role of women in raising children and early marriage (Asna-Ashary et al., 2020). Additionally, the war and its uncertain path of development justified pro-marriage and higher fertility behavior to secure available human resources if the war continued. This approach was also mirrored in the idea of establishing the Basij militia. After the Islamic Revolution, Ayatollah Khomeini mobilized volunteers to engage in civil defense operations and to

**TABLE B2** The means of predictors during the pre-revolution period (1965–1976) for life expectancy at birth, total (years)—Based on a global donor pool.

Predictors	Factual Iran (1)	Synthetic Iran (2)	Difference (1–2)
Life expectancy (1976), years	55.74	55.92	–0.18
Life expectancy (1974), years	54.46	54.33	0.13
Life expectancy (1972), years	52.56	52.55	0.01
Life expectancy (1970), years	50.86	50.94	–0.08
Life expectancy (1968), years	49.50	49.48	0.02
Life expectancy (1966), years	48.30	48.27	0.02
log real GDP per capita	8.49	7.95	0.54
Population growth (annual %)	2.73	2.53	0.20
Age dependency ratio (% of working-age population)	90.21	84.26	5.94
Share of government consumption at current PPPs	0.12	0.24	–0.12

fight in the Iran–Iraq War (1980–1988). His goal was to arm as many young people as possible to support the regular forces.

High fertility rates may be indicative of poor health outcomes for women and children, which can ultimately impact life expectancy. For example, in areas with high fertility rates, women may have less access to healthcare, nutrition, and education, which can lead to higher rates of maternal and infant mortality. Additionally, larger family sizes may result in a lower quality of life for individuals due to scarce resources and greater competition for access to healthcare, education, and other basic needs. This latter situation was evident in the case of Iran during the war with Iraq, when limited resources forced the state to adopt a rationing system based on coupons. While income inequality declined after the revolution and war, poverty remained high (Farzanegan & Kadivar, 2023; Salehi-Isfahani, 2017). Higher income and upper middle-class individuals left the country and outmigration increased significantly. All in all, higher fertility was associated with lower income, higher poverty, and a lower quality of life, which are all detrimental to the life expectancy indicator.

In this exercise, the synthetic Iran is based on Paraguay (41.3%), Rwanda (29.4%), Haiti (26.6%), Costa Rica (2.4%), and Malta (0.3%). The estimation results are shown in Figure B2 and Table B3.

Next, we consider female and male life expectancy separately. Using the global donor pool, the analysis for male life expectancy results in the following findings.

In this exercise, the synthetic Iran for the outcome of male life expectancy is generated based on a combination of Gambia (42.2%), Japan (24.6%), Tunisia (22%), and Romania (11.2%). The results shown in Figure B3 and Table B4 are similar to those in the main analysis based on the restricted MENA/OPEC donor pool (Figure 9).

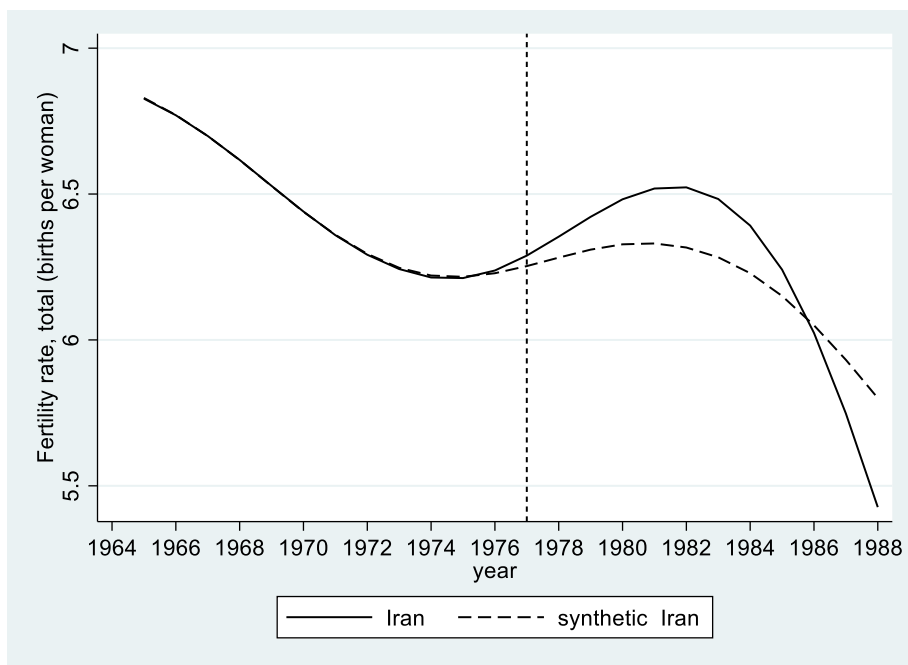
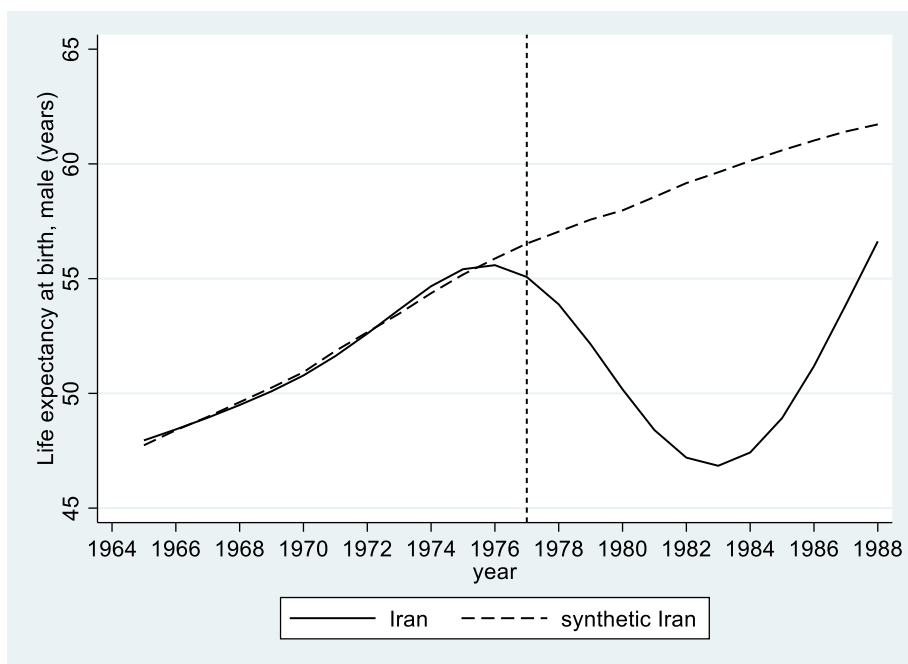


FIGURE B2 Iran and synthetic Iran using a global donor pool: Fertility rate (number of children per woman). [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

What about female life expectancy? In the main analysis and the restricted donor pool, we did not observe a significant gap between the female life expectancy for factual and counterfactual Iran following the revolution and during the war with Iraq. Opening the donor pool does not change the main results regarding the lack of a significant causal impact of the revolution and war on female life expectancy. See Figure B4 and Table B5.

**TABLE B3** The means of predictors during the pre-revolution period (1965–1976) for fertility rate—Based on a global donor pool.

Predictors	Iran (1)	Synthetic Iran (2)	Difference (1–2)
Fertility rate (1976)	6.24	6.23	0.01
Fertility rate (1974)	6.21	6.22	–0.01
Fertility rate (1972)	6.29	6.29	0.00
Fertility rate (1970)	6.44	6.44	0.00
Fertility rate (1968)	6.62	6.62	0.00
Fertility rate (1966)	6.77	6.77	0.00
log real GDP per capita	8.49	7.44	1.06
Population growth (annual %)	2.73	2.45	0.28
Age dependency ratio (% of working-age population)	90.21	94.73	–4.52
Share of government consumption at current PPPs	0.12	0.13	–0.01



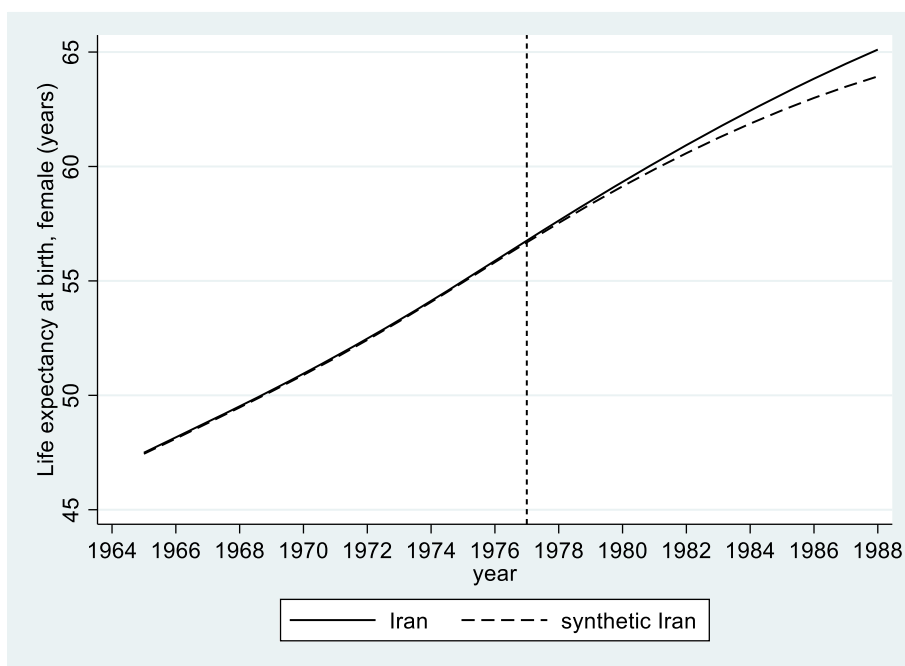
**FIGURE B3** Iran and synthetic Iran using a global donor pool: Male life expectancy (years). [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

In this exercise, the synthetic Iran for the outcome of female life expectancy is generated based on a combination of Tunisia (25%), Gabon (18.1%), Cote d'Ivoire (17.3%), Mexico (15.8%), Bangladesh (9.2%), Senegal (8.5%), Nicaragua (5.5%), Iceland (0.3%), and Portugal (0.2%).

The decline in male life expectancy in Iran during the revolution and the war with Iraq was more significant compared to the (insignificant) gap in female life expectancy. This gender difference in life expectancy could have been influenced by various factors, including exposure to

**TABLE B4** The means of predictors during the pre-revolution period (1965–1976) for male life expectancy—Based on a global donor pool.

Predictors	Iran (1)	Synthetic Iran (2)	Difference (1-2)
Male life expectancy (1976), years	55.59	55.88	-0.29
Male life expectancy (1974), years	54.67	54.36	0.30
Male life expectancy (1972), years	52.60	52.67	-0.06
Male life expectancy (1970), years	50.78	50.93	-0.14
Male life expectancy (1968), years	49.49	49.62	-0.12
Male life expectancy (1966), years	48.43	48.39	0.04
log real GDP per capita	8.49	8.37	0.13
Population growth (annual %)	2.73	2.11	0.62
Age dependency ratio (% of working-age population)	90.21	72.07	18.14
Share of government consumption at current PPPs	0.12	0.18	-0.06



**FIGURE B4** Iran and synthetic Iran using a global donor pool: Female life expectancy (years). [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

**TABLE B5** The means of predictors during the pre-revolution period (1965–1976) for female life expectancy—Based on a global donor pool.

Predictors	Iran (1)	Synthetic Iran (2)	Difference (1–2)
Female life expectancy (1976), years	55.88	55.82	0.06
Female life expectancy (1974), years	54.13	54.08	0.05
Female life expectancy (1972), years	52.48	52.42	0.06
Female life expectancy (1970), years	50.94	50.89	0.05
Female life expectancy (1968), years	49.53	49.47	0.05
Female life expectancy (1966), years	48.16	48.11	0.05
log real GDP per capita	8.49	8.25	0.24
Population growth (annual %)	2.73	2.72	0.01
Age dependency ratio (% of working-age population)	90.21	90.12	0.09
Share of government consumption at current PPPs	0.12	0.15	–0.03

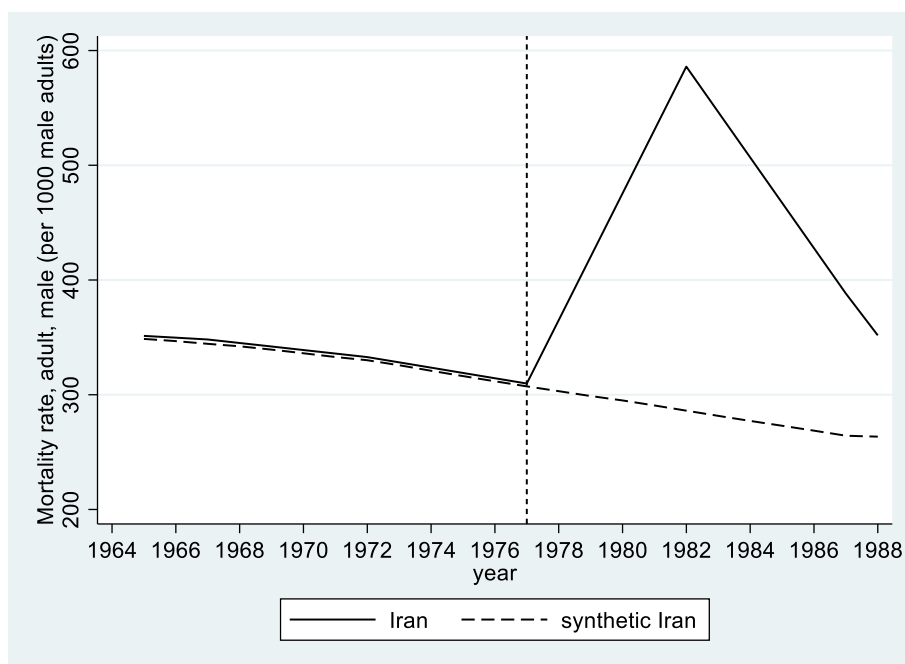
conflict and violence. Men in Iran were more likely to be exposed to violence during the revolution and the war, either as combatants or targets of violence, which has been linked to worse health outcomes. On the other hand, the lower female labor force participation rate in Iran may have contributed to lessen their exposure to occupational hazards, such as exposure to chemicals or physical labor, which could negatively impact health. Therefore, the significant gender gap in life expectancy during this period could be attributed to a combination of factors, including exposure to violence and differences in occupational hazards between males and females.

Next, we re-examine the mortality rate among male adults based on the extended donor pool. The result is shown in Figure B5 and is very similar to the main findings (Figure 12 in the main text based on the restricted donor sample of MENA/OPEC). In the extended donor pool, the synthetic Iran is based on a combination of Mexico (26.4%), Ghana (18.7%), Cote d'Ivoire (14.8%), Bangladesh (10.4%), the United States (9.9%), Senegal (9.4%), Rwanda (2.2%), and a few other countries with weights of less than 0.1%. Also see Table B6 for the good match between Iran and synthetic Iran on this outcome.

The excessive decline in life expectancy in Iran during the Iranian Revolution and subsequent war with Iraq can be attributed to several factors. One significant factor was the increase in mortality rates, particularly among young adult males who were conscripted into the military and fought on the front lines. The war also caused an increase in injuries, displacement, and disruptions to healthcare services, further contributing to the decline in life expectancy.

In addition to the violence experienced during the interstate war, domestic terrorism, especially during the first few years after the revolution, also played a role in increasing mortality rate of young adult males. Different political factions, including the Mojahedin-e-Khalq-Organization, initiated waves of assassinations and bombings. The Islamic government responded with large-scale arrests and executions, which further fueled the violence and contributed to the decline in life expectancy.

What about the development of the female mortality rate in Iran compared to the synthetic Iran? In our main analysis with a restricted donor pool, we showed that no significant excessive mortality rate was observed for the female population in Iran. In the following, we re-examine this result using a global donor pool. The new exercise, by opening the donor pool, reproduces



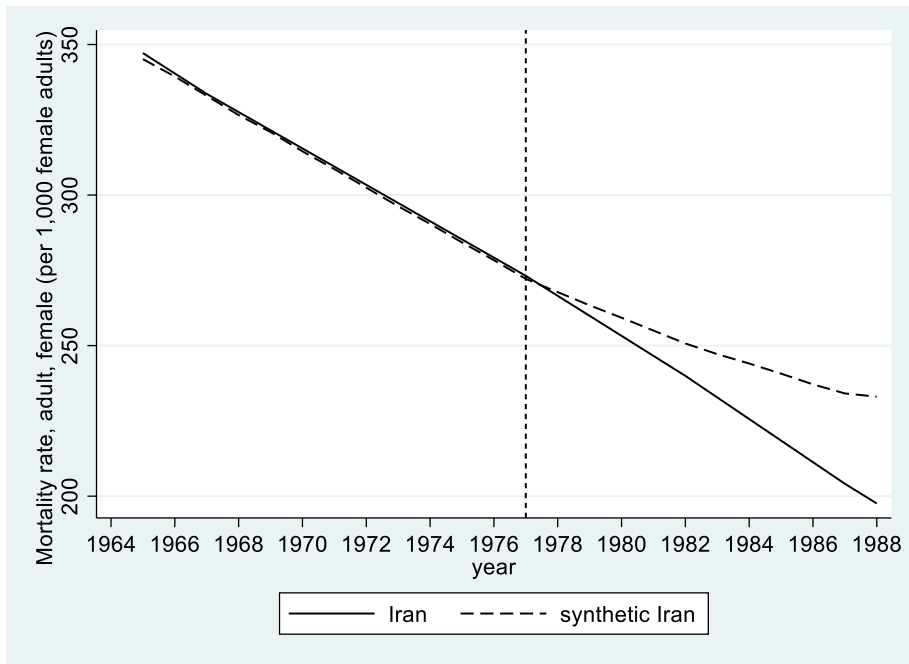
**FIGURE B5** Iran and synthetic Iran using a global donor pool: Male adult mortality rate. [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

**TABLE B6** The means of predictors during the pre-revolution period (1965–1976) for male adult mortality rate—Based on a global donor pool.

Predictors	Iran (1)	Synthetic Iran (2)	Difference (1–2)
Male adult mortality rate (1976)	314.38	311.74	2.64
Male adult mortality rate (1974)	323.61	320.91	2.70
Male adult mortality rate (1972)	332.83	330.09	2.75
Male adult mortality rate (1970)	338.97	336.15	2.83
Male adult mortality rate (1968)	345.11	342.21	2.90
Male adult mortality rate (1966)	349.74	346.75	3.00
log real GDP per capita	8.49	8.43	0.06
Population growth (annual %)	2.73	2.71	0.02
Age dependency ratio (% of working-age population)	90.21	89.48	0.72
Share of government consumption at current PPPs	0.12	0.12	0.00

similar results (see Figure B6 and Table B7) as in the main analysis. The female adult mortality rate continued to decline after the revolution and during the war. There was no excess mortality among the female population in Iran compared to the counterfactual Iran. In this exercise, the synthetic Iran is based on a combination of Nicaragua (40.2%), Nigeria (22.7%), Gabon (10.6%), Congo DR (7.7%), Jordan (7%), Portugal (2.6%), and a few other countries with minor weights.





**FIGURE B6** Iran and synthetic Iran using a global donor pool: Female adult mortality rate. [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

**TABLE B7** The means of predictors during the pre-revolution period (1965–1976) for female adult mortality rate—Based on a global donor pool.

Predictors	Iran (1)	Synthetic Iran (2)	Difference (1–2)
Female adult mortality rate (1976)	279.23	278.38	0.84
Female adult mortality rate (1974)	291.32	290.42	0.89
Female adult mortality rate (1972)	303.40	302.46	0.95
Female adult mortality rate (1970)	315.49	314.51	0.97
Female adult mortality rate (1968)	327.57	326.56	1.00
Female adult mortality rate (1966)	340.39	339.37	1.01
log real GDP per capita	8.49	8.40	0.09
Population growth (annual %)	2.73	2.72	0.01
Age dependency ratio (% of working-age population)	90.21	89.51	0.70
Share of government consumption at current PPPs	0.12	0.12	0.00

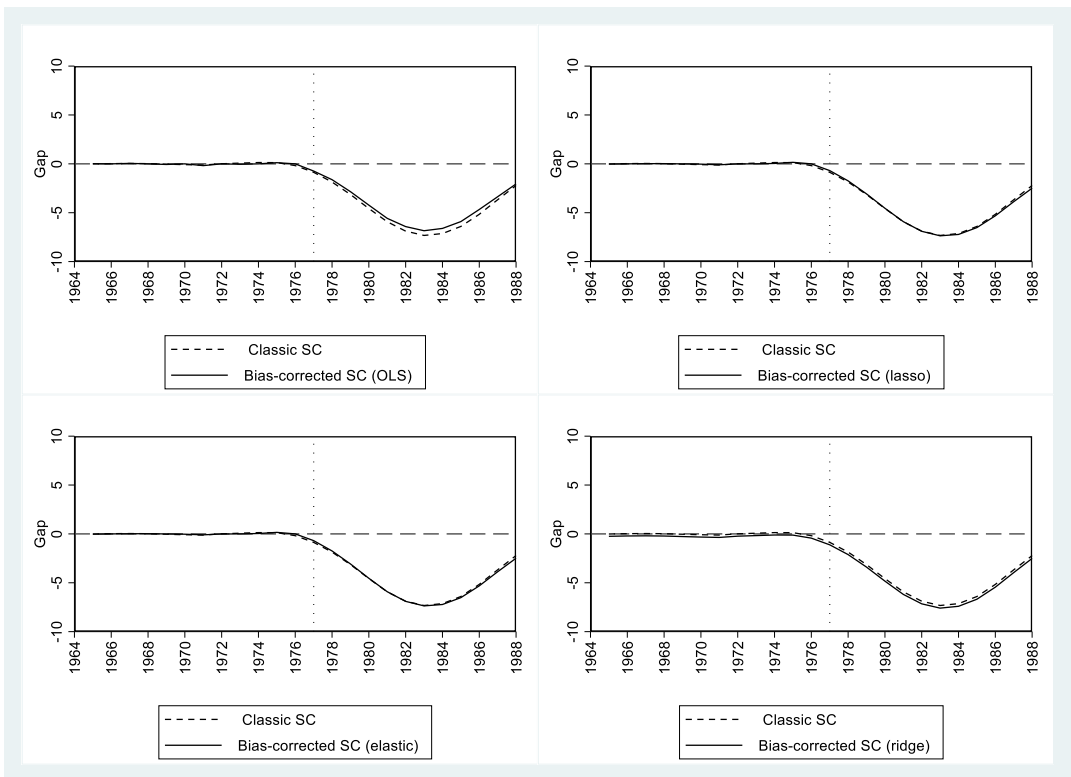
The excessive decline in life expectancy in Iran was mainly driven by a reduction in male life expectancy and an increase in male adult mortality rates. Additionally, the higher fertility rate in Iran compared to a counterfactual Iran may have contributed to an increase in infant mortality rates.

During the war, women in Iran took on greater roles in households and contributed to the war effort in other ways, which may have protected them from fatal mortality risks. In contrast, men were conscripted into the military and fought on the front lines, increasing their exposure

to violence and injury during the civil disorder, conflict, and terrorism following the revolution and war. Furthermore, men tend to engage in riskier behaviors than women in general, including smoking and drug use, which may have contributed to their higher mortality rates.

In short, the reasons behind the excessive decline in life expectancy of Iranians after the revolution and during the war are multifaceted and our analysis has highlighted some possible explanations.

Finally, we have re-examined the original results on the development of life expectancy in Iran, based on a global donor pool, and have estimated the bias-corrected synthetic control gaps or “treatment effects.” We followed the procedure developed by Wiltshire (2022). The results, shown in the Figure B7, indicate a significant similarity between the classic synthetic control and the bias-corrected synthetic control gaps in the life expectancy of Iran and the counterfactual Iran. The bias-corrected synthetic control gaps adjust for discrepancies in the predictor variable values between a treated unit and its donor pool, as proposed by Abadie and L’Hour (2021) and Ben-Michael et al. (2021). Similar outcomes are observed when we use other methods for bias correction, such as elastic, lasso, and ridge.

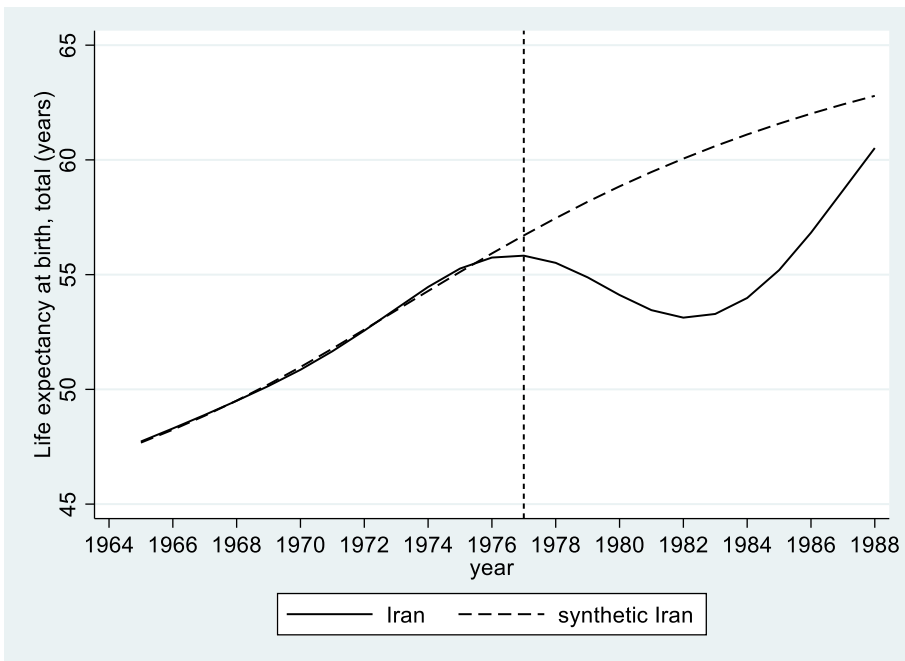


**FIGURE B7** Bias corrected synthetic control based on a global donor pool: Life expectancy (years). [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

## APPENDIX C: DIFFERENT PERIOD AVERAGES FOR PRETREATMENT

In the main analysis, we selected the period averages of 1965–1976 to perform the matching for most covariates. However, this is a long period and the overall average could obscure different dynamics among different periods. For a robustness check, in this section, we use two different averages: 1965–1970 and 1971–1976. The synthetic Iran in this exercise is based on a combination of Saudi Arabia (61.5%), Nigeria (25.2%), Malta (6.8%), and Egypt (6.5%).

The results are identical to the main finding based on the period average of the entire pre-treatment period of covariates in the main analysis. Figure C1 shows the development of life expectancy in Iran and synthetic Iran. Additionally, Table C1 shows a very good match between the covariates of Iran and synthetic Iran in the pretreatment period.



**FIGURE C1** Life expectancy at birth (years): Iran versus synthetic Iran based on different period averages of co-variates. [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

**TABLE C1** The means of predictors during the pre-revolution period (1965–1970) and (1971–1975) for life expectancy—Based on MENA/OPEC donor pool.

Predictors	Iran (1)	Synthetic Iran (2)	Difference (1–2)
Life expectancy (1976)	55.74	55.93	–0.18
Life expectancy (1974)	54.46	54.29	0.18
Life expectancy (1972)	52.56	52.60	–0.04
Life expectancy (1970)	50.86	50.98	–0.12
Life expectancy (1968)	49.50	49.51	–0.01

TABLE C1 (Continued)

Predictors	Iran (1)	Synthetic Iran (2)	Difference (1-2)
Life expectancy (1966)	48.30	48.24	0.06
log real GDP per capita (1965-1970)	8.18	9.03	-0.85
log real GDP per capita (1971-1976)	8.81	9.52	-0.71
Population growth (annual %) (1965-1970)	2.66	2.92	-0.26
Population growth (annual %) (1971-1976)	2.80	3.77	-0.97
Age dependency ratio (% of working-age population) (1965-1970)	92.34	86.23	6.11
Age dependency ratio (% of working-age population) (1971-1976)	88.08	86.54	1.54
Share of government consumption at current PPPs (1965-1970)	0.08	0.14	-0.06
Share of government consumption at current PPPs (1971-1976)	0.16	0.12	0.04

#### APPENDIX D: USING FEWER LAGS OF THE OUTCOME VARIABLE AS PREDICTORS

Kaul et al. (2015) suggest not using the entire pretreatment path of the outcome variable as predictors, as that would make other covariates irrelevant by reducing their weight to zero. Indeed, we also do not use all preintervention outcomes together with covariates in our main analysis. Instead, we match on the outcome itself (every even year in the preintervention period: 1976, 1974, 1972, 1970, 1968, and 1966) and the preintervention averages of other covariates.

However, we noticed that the sum of weights allocated to the lagged outcome in these years exceeded 95%. To check the robustness of the results with fewer lags of the outcome, we re-examined the main analysis on life expectancy by using only three lags of the outcome variable in years 1976, 1972, and 1968. The results were identical to those in Figure 1. The sum of weights allocated to the three lags was about 70% and we were thus less concerned that the other covariates were redundant in the analysis.

We also used only one lag of the outcome (in 1976) and the key results were identical to the initial findings (in Figure 1). The allocated weight to the lag of the outcome was only 5% and the covariates received higher weights.