Reconstruction of the US immigration history: demographic potential approach.

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Aggregate model of population dynamic based on demographic potential concept is used to reconstruct main factors of the US population history from the beginning of colonization. Model without migration is advanced to the case of population open to migration that allows to reconstruct net migration to the US – both legal and unauthorized. Reconstruction is based on data on total population, life expectancy at birth, and age-sex structure dynamic. Results obtained are valuable for study of the US demographic history and for other research in historical demography as well.

Introduction

History of the US from the colonial times (from 1610) is marked by continuous population growth (fig.1) caused both by natural increase, immigration, and population aging.

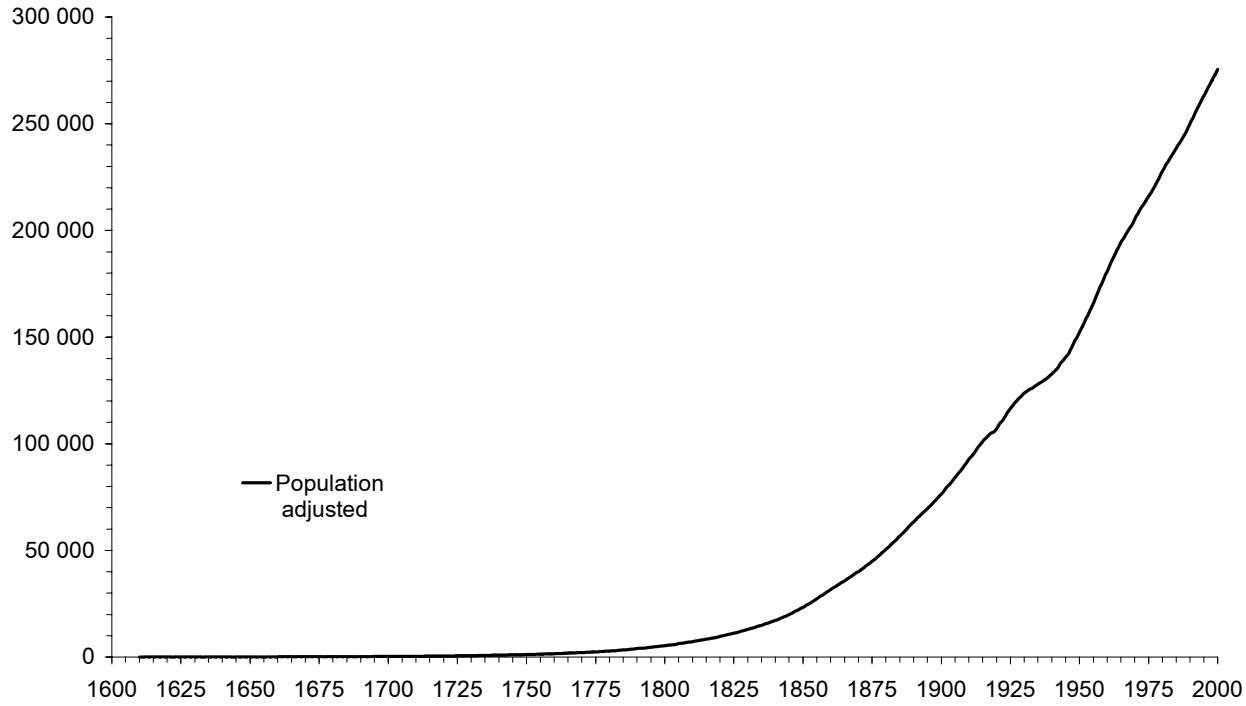

Fig.1. US Population in 1610-2000 (thousands)

Scarcity of demographic data and their low quality (especially for migration) prevents from direct estimation of the factors mentioned. Common approaches of backward projection, inverse projection, etc. (Lee 1974, 1985; Wrigley, Schofield, 1989; Oeppen 1993) are based on different methods of reversing the component method. They can't be used in reconstructing the US demographic trends since there is no data on age-sex structure, births and deaths for all the period from 1610 not to be mentioned the complexity and instability of backward projection techniques. Here the simpler, more robust and yet adequate aggregate model of population dynamic is used that is based on the concept of demographic potential (Ediev 1999, 2000, 2001a, 2001b). This approach allowed to reconstruct immigration waves from the time of colonization and to estimate the total effect of both legal and unauthorized migration. Intrinsic growth rate and aging impact on

population dynamic were reconstructed as well. Results obtained were compared to chronology of historical events having effect on immigration and reproduction conditions in the US. This comparison, along with the comparison to available US immigration and reproduction statistics, supported the efficiency of the method proposed.

Model and data

Concept of demographic potential (Ediev 1999; see full references in Ediev 2001b) close to Fishers' reproductive value (Fisher 1930) underlines aggregate population dynamic model used in the paper. Change rate of the population demographic potential equals to its intrinsic growth rate in the absence of migration (Ediev 1999, 2000, 2001a, 2001b). This fact allows building aggregate model of population – model that despite its aggregate nature adequately reflects population age-sex structure dynamic. In the absence of migration the model mentioned is following (Ediev 2000, 2001a):

continuous form : *discret form* :

$$\begin{cases} C(t) = C(t_0)\exp\left(\int_{t_0}^{t} r(\tau)d\tau\right), \\ \dfrac{d^2c(t)}{dt^2} = \beta\cdot\left(\dfrac{dc(t)}{dt} - \alpha\cdot\left(c(t) - c^*(t)\right)\right), \\ c^*(t) = c\cdot r(t) + d\cdot e_0(t) + const, \\ N(t) = \dfrac{C(t)}{c(t)} \end{cases} \qquad \begin{cases} C(t) = C(t_0)\exp\left(\int_{t_0}^{t} r(\tau)d\tau\right), \\ c(t+1) - c(t) = \\ = a\left(c(t) - c^*(t)\right) + b\left(c(t) - c(t-1)\right), \\ c^*(t) = c\cdot r(t) + d\cdot e_0(t) + const, \\ N(t) = \dfrac{C(t)}{c(t)} \end{cases} \quad (1)$$

here $C(t)$ is a demographic potential at time t; $N(t)$ is population size at time t; $r(t)$ is intrinsic growth rate of the population (Lotkas' coefficient; e.g. Andreev, Pirozhkov 1975); $c(t)$ – mean demographic potential; $c^*(t)$ - mean demographic potential for stable population consistent with current reproduction patterns (Bourgeois-Pichat 1968); $e_0(t)$ - life expectancy at birth; a, b, c, d, and $const$ – model parameters that can be estimated by common econometric procedures (a=-0.0126, b=0.683, c=8.86, d=-0.00325, $const$=0.619).

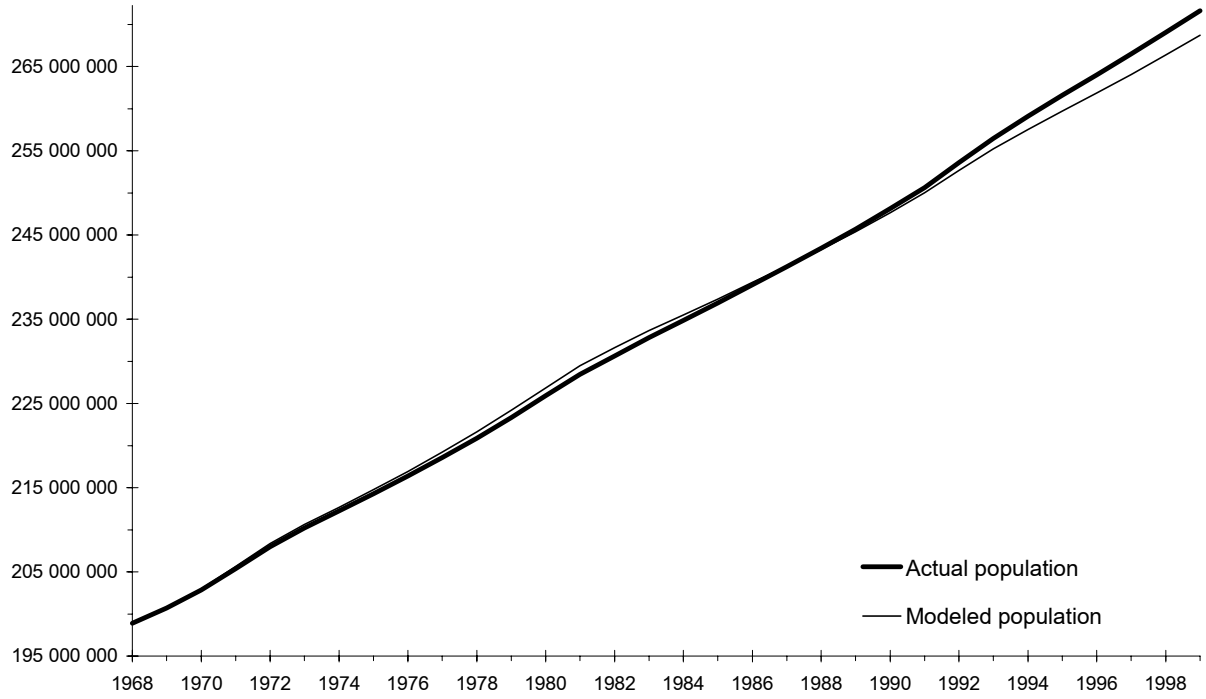

Fig. 2. Actual and modeled population of the US, 1968-1999.

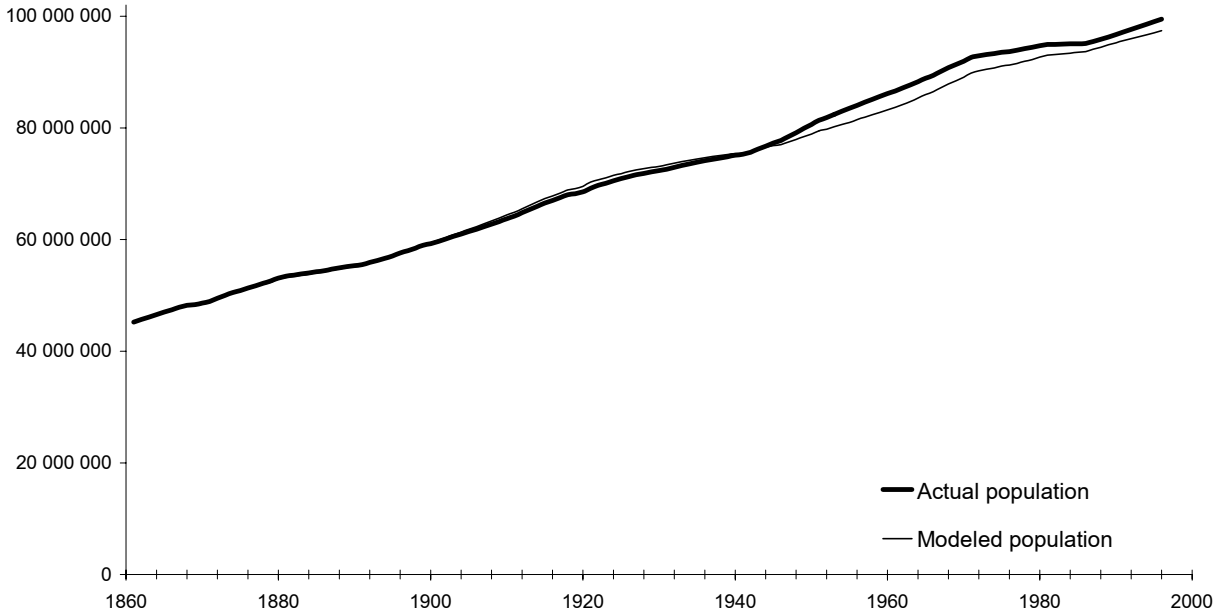

Fig. 3. Actual and modeled population of Sweden, 1861-1996.

Quality of the model (1) has been shown on data from different countries with different population trends (Ediev 2000, 2001a). Fig. 2 demonstrates actual trend of the US population in 1968-1999 years and the population trend obtained by the model (1) for the same period. Despite error cumulating during about 30 years model shows high fitness to actual trend. Even more impressive is the case of Sweden when errors cumulate during about a century and a half (fig. 3).

For population open to migration model (1) can be reformulated:

$$\begin{cases} C_{close}(t+1) = C(t)\exp(r(t)), \\ c_{close}(t+1) = c(t) + a\left(c(t) - c^*(t)\right) + b\left(c(t) - c(t-1)\right), \\ c^*(t) = c \cdot r(t) + d \cdot e_0(t) + const, \\ N_{close}(t+1) = \dfrac{C_{close}(t+1)}{c_{close}(t+1)}, \\ N_{migr}(t) = N(t+1) - N_{close}(t+1), \\ C_{migr}(t) = c_{migr}(t) \cdot N_{migr}(t), \\ C(t+1) = C_{close}(t+1) + C_{migr}(t), \\ c(t+1) = \dfrac{C(t+1)}{N(t+1)} \end{cases} \qquad (2)$$

here index '*close*' corresponds to population characteristics that would take place in the absence of migration, and '*migr*' – denotes migration flows of total demographic potential and population.

Model (2) contains 8 equations for any point of time and 12 time dependent functions. I.e. the model is over-parameterized for population history reconstruction. For the migration reconstruction purpose data on population size, life expectancy, and mean demographic potential (i.e. age-sex structure of the population) dynamic are used in the paper. Given these three functions, the number of unknown population characteristics in the model is still more then the number of equations. In order to equal the number of unknown population functions to the number of independent equations of the model, one more assumption concerning the migration age-sex structure was used. Namely, it was supposed that migrants on average are younger then the main

population and, therefore, mean demographic potential for migrants is higher then for general population. Based on the INS data (U.S. Immigration and Naturalization Service 1999) it was set that migrants mean potential is about 15% higher then that of the general population. For long-period analysis when population aging is crucial, this assumption is more adequate then the assumption of constant age-sex structure of migrants or constant migration rate used in other works on population reconstruction (e.g. Lee 1985; Wrigley, Schofield, 1989; Oeppen 1993).

Assumption on migration age-sex structure makes the number of unknown parameters and equations of the model close to each other. But still the number of equations is insufficient since some of the equations (2) can't be applied to the beginning time-points of the period to be considered. Besides, data on population age-sex structure are not readily available for all the period since colonization of the US. Therefore in order to be able to reconstruct the population history additional assumptions are to be used. Smoothness of the intrinsic growth rate was used as such assumption. This is similar to what was used by Oeppen (1993) in his work on back and inverse projection – goal function was constructed that is to be optimized in reconstructing the population history. Oeppen used the measure of migration smoothness; in this work the smoothness of migration dynamic is replaced by the smoothness of the intrinsic growth rate. The latter assumption is considered as more adequate since the migration (especially for the US) is an external factor and is less stable then intrinsic growth rate. As the age-sex structure data are not of high accuracy for all years, forth equation in (2) was removed but extent to which this equation is fitted was reflected in goal function:

$$Z = \sum_t \left(\left(c_{close}(t) - \frac{N(t) - N_{migr}(t-1)}{C(t) - C_{migr}(t-1)} \right)^2 + \lambda(t)\left(r(t-3) - 2r(t-2) + r(t-1)\right)^2 \right) \to \min \qquad (3)$$

here $\lambda(t)$ - is a smoothness parameter that was set higher for periods with less accurate age-sex structure data and varied from 0.3 to 0.5.

Some remarks are to be made about the preparation of data on population, life expectancy and mean demographic potential dynamic.

Annual population estimates for years after 1900 were taken from the US Census Bureau data (U.S. Bureau of the Census 1975, 2000). As for the period before 1900 (1610-1900), only decennial data of Census Bureau (U.S. Bureau of the Census 1975) was used, while annual numbers were interpolated. The reason was that Census Bureau annual estimates (U.S. Bureau of the Census 1975, 2000) for the period 1790-1900 were biased because of simple interpolation technique.

Fig. 4 shows annual population change rates derived from the Census Bureau estimates. Pattern of fig. 4 for years before 1900 is characteristic for linear interpolation of decennial data. As this simplification can bias estimates to be obtained by the model (2), and since before the 1790 annual population data aren't available, more sophisticated interpolation was made of decennial data. The essence of the method is in fitting the annual numbers in a way that leads to most smooth curve for population change rate dynamic (fig. 5).

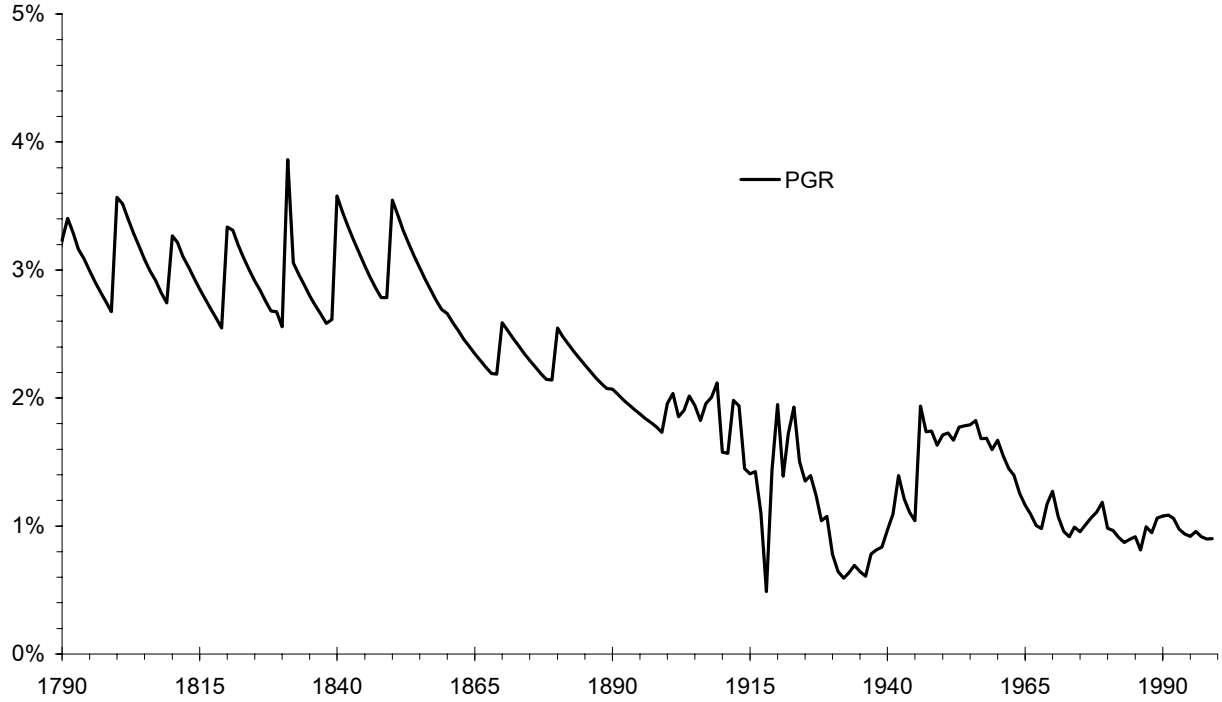

Fig. 4. US Population Growth Rate based on US Census Bureau annual population estimates for 1610-1900.

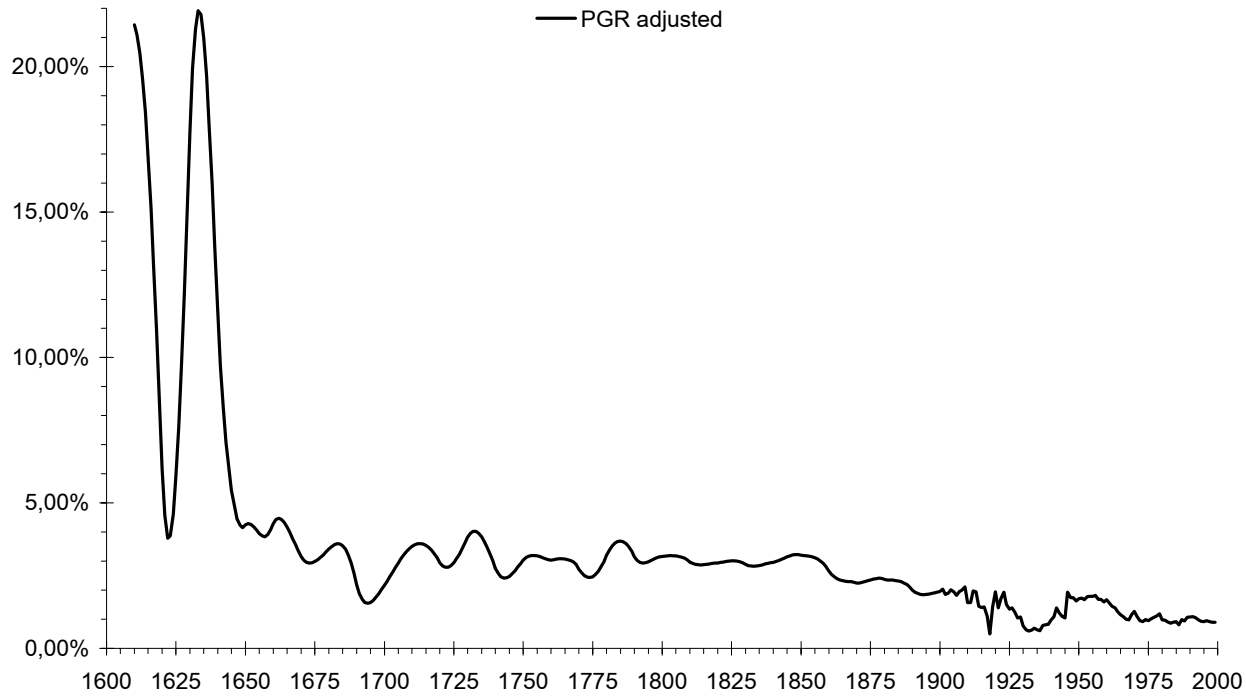

Fig. 5. US Population Growth Rate. 1610-1899 - estimated from decennial data, 1900 and later – from estimations of Census Bureau

The consistency of the trend obtained can be checked with use of historical data relevant to population history of the US. Almost all the time before late XIX century American population was growing at annual rate of about 3% - fact that was in time widely used in population analyses and forecasting (Spengler 1936). Growth rate at the beginning of 1600s was high due to the small size of population (actually, at that time Indians were not counted; population trends analyzed here could be attributed mostly to immigrated population of the US). As for deviations from general trend, they were caused by some political or economic factors. At the period of colonization most

important events affecting population change were wars, famine, epidemics, and other social cataclysms, which declined the immigration at there beginning and increased it afterwards. Later, economic cycles both in Europe and in the United States, and US immigration policy played important role in population dynamic in addition to the social factors. Some historical events of XVII-XX centuries, which are relevant to population growth rate changes, are presented in table 1 (Wesley 1913; Mendelson 1949; Roger 1936; Benett 1963; Stephenson 1964; Martin 1986; Ueda 1994; WWW 2000; etc.). Almost all the deviations from the trend of population growth rate match historical events, which do affect population growth. This is evidence that these changes, though partly reconstructed on the basis of decennial data, reflect real population history rather than methodical bias. Further this conclusion will be supported by comparing the chronology presented in table 1 to reconstructed dynamics of immigration and reproduction of the US population.

Table 1. Political and economic events relevant to the population change rate alterations in the US.

Date	Events
-1625	James I in England, protestant-catholic and King-Parliament tensions
1625-49	Charles I, continuation of James policy, defeat in war with Spain
1639	Scots invaded England
1642-49	Civil War in England
1649-58	Oliver Cromwell's dictatorship in England
1660-85	Restoration, Charles II
1665	Plague epidemic
1667	London's Great Fire
1675-76	Bacon's Rebellion in Virginia, king Phillip's war in New England
1685-88	James II, struggle for the throne in England
1688	The Glorious Revolution, William III
1689-1704	Britain -French war
1689-97	King William's war in Canada and Upper New England
1702-13	Queen Anne's war in New England
1704-42	Prime Minister Walpole, prosperity in England
1709	Big emigration from Germany, following postwar devastation, severe winter, and rumors about assistance from Britain Queen.
1744-48	King George's war in Georgia and Virginia
1745	Stuart’s attempt to come to the throne
1754-63	French and Indian war in New England and Virginia
1759-1806	George III, prosperity in England
1775-83	Revolutionary war
1786	Shay’s Rebellion in Massachusetts
1788	First economic crisis in England
1789	French Revolution and domination on the Continent
1791	Panic
1791-1802	Yellow Fever, 10771 causalities In Philadelphia
1793	Economic crisis in England. Britain-French war began
1797	Economic crisis in England
1803	Louisiana purchase
1807-10	US embargo on import of Britain-maid goods
1810	Economic crisis in England
1811	US embargo on import of Britain-maid goods is reinforced
1812-15	Napoleon wars in Europe; Britain and Indian war
1815	Economic crisis in England that had an effect on the US economy
1817-90	Frontier Indian wars

Date	Events
1819	Economic crisis in England that had an effect on the US economy
1825	First general economic crisis (depression)
1831-32	Black Hawk war in Illinois and Wisconsin
1836	Alamo, Texas independence war
1837-42	Panic (1837). Depression – most severe in the Britain and the US
-1840	Industrialization and social adjustments in Britain, beginning of massive emigration
1846-47	Potato famine in Ireland, massive emigration
1847	Depression – weak in the US
1846-48	Mexican war
1850s	Rise in German emigration to the US
1857-59	Panic (1857), depression
1861	Depression
1861-65	Civil war
1865-68	Depression
1869-71	Panic (1869), depression
1873-78	Panic (1873), depression
1880s	Rise in Scandinavian emigration to the US
1880-90s	Rise in Dutch emigration to the US
1880-1920s	'New Immigration' (East and South Europe: Italians, Slavs, Jews)
1882-85	Depression
1882	Chinese Exclusion Act
1885	Alien Contract Labor Law
1887-88	Depression
1890s	Colonization of free farm lands is completed
1890-91	Depression
1893-94	Panic (1893), depression
1896-97	Depression
1898-1915	Spanish American war
1899-1902	Philippine Insurrection
1900-01	Depression
1903-04	Depression
1907-08	Panic (1907), depression
1910-11	Depression
1913-15	Depression
1914-18	World war I
1918	Influenza pandemic
1918-19	Depression
1920-22	Panic (1920), depression
1921	First Quota Act
1923-24	Depression
1924	Second Quota Act
1927-28	Depression
1929	National Origins Quota System goes into full effect
1929-33	Panic (1929), depression (*Great Depression*)
1930	Immigration policy: "*Public charge*" regulation
1931	Panic
1937-39	Panic (1937), depression
1939-45	World war II

Date	Events
1942	Initiation of Mexican Foreign Laborer (*bracero*) program (lasted for several decades)
1950-53	Korean war
1959-75	Vietnam war
1966-68	Panic (1966, *Credit Crunch*), depression (first after the World War II)
1970-71	Panic (1971, *Penn Central*), depression
1973-80s	Energy crisis
1974-75	Strong depression (*Franklin National*)
1980	Panic, depression (*Silver Crisis*)
1982-83	Depression
1987	Panic
1989	Panic
1990	Overall Flexible Cup of admissions replaced Quota system
1990-91	Persian Gulf war
1990s	Fall of soviet block, economic growth in the USA
1995-96	Bosnian operation
1998	Panic

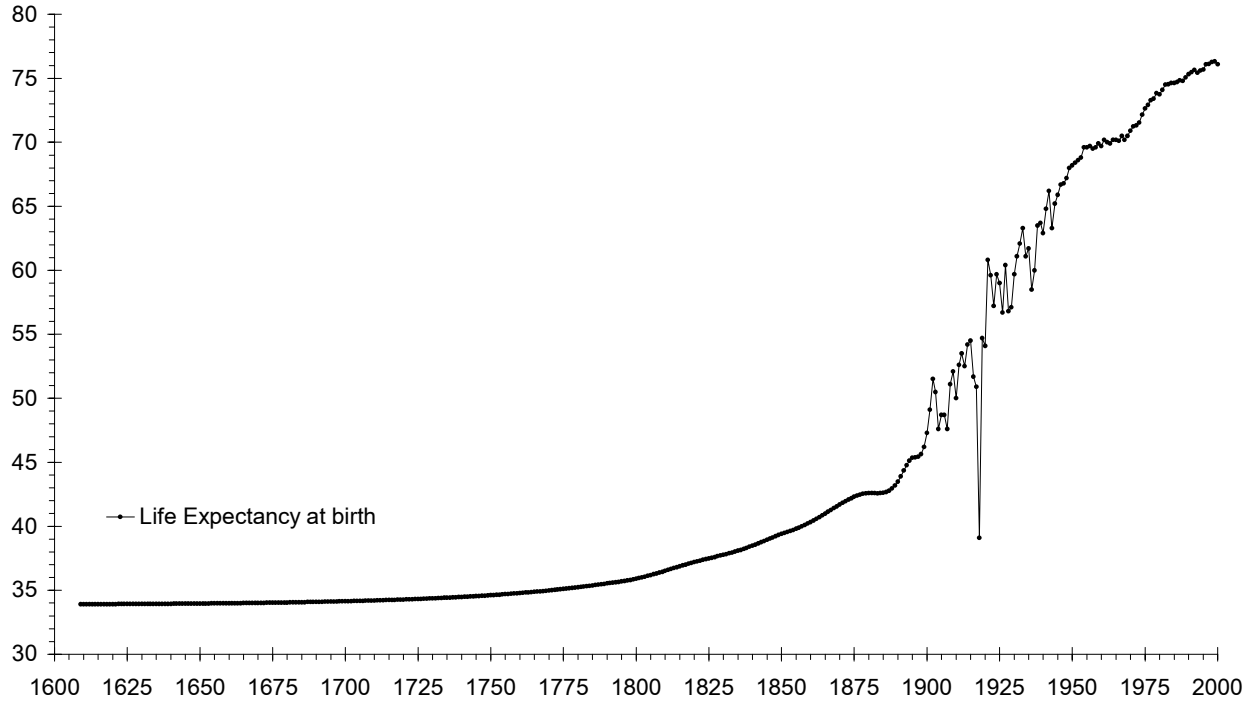

Fig. 6. Life expectancy at birth for the US reconstructed and used in the paper.

Another population parameter to be used in the paper – life expectancy at birth was partly reconstructed as well. Rare mortality data for the period before 1900 and annual data available for years after 1900 (Dublin, Lotka 1935; Rao 1973; Haines 1977; University of California, Berkeley 1998; U.S. Bureau of the Census 1975) and smooth interpolation together with the model of exponential growth of life expectancy at the beginning of the US history produced the trend presented on the fig. 6.

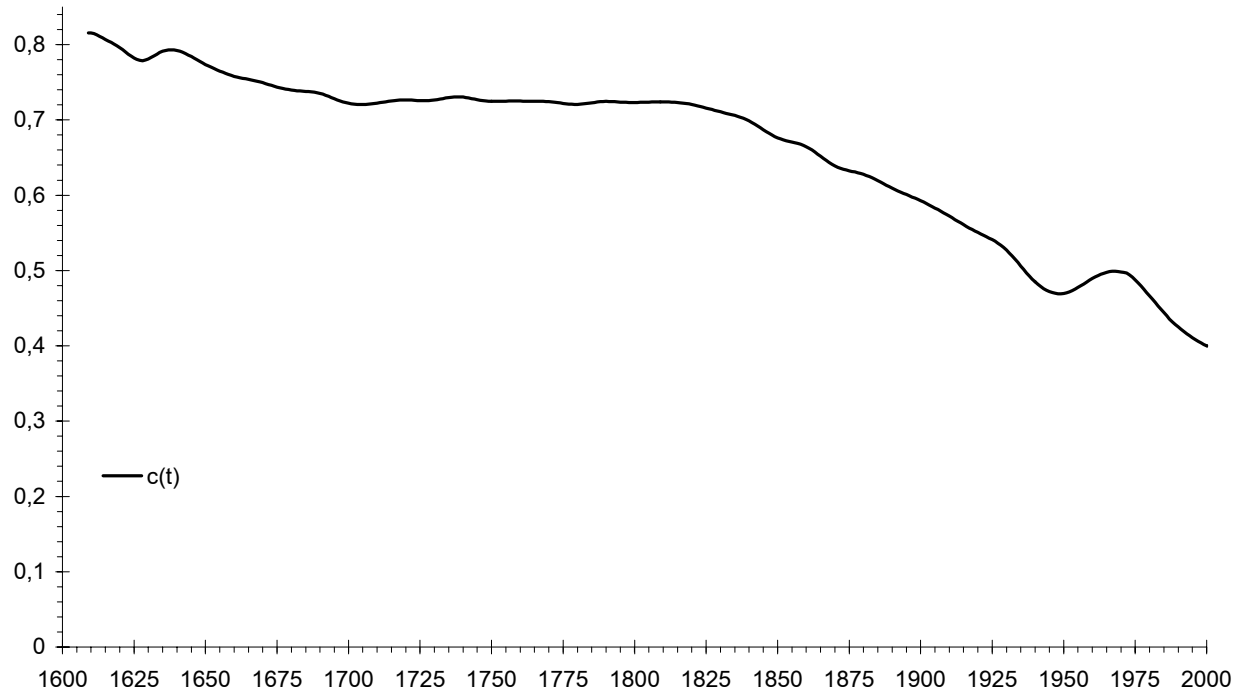

Fig. 7. Reconstructed dynamic of mean demographic potential of the US.

Third population characteristic to be used – the mean demographic potential – reflects population age-sex structure. For years with known age-sex structure of the US population (1968-2000, decennially – for 1800-1968) it was estimated directly from data. For 1800-1968 annual estimates were smoothly interpolated from decennial numbers. As for the years before 1800, intrinsic growth rate for that period (before the demographic transition took place) was set to be constant and that allowed to reconstruct mean demographic potential rather then intrinsic growth rate form the model (2). Resultant trend of mean demographic potential is presented of the fig. 7. High values for the very beginning of colonization history are explained by very high proportion of new-migrants at that stage (native Indians are not counted). Global trend from the level of about 0.72 to about 0.36 reflects the process of demographic transition accompanied by aging of the population. Remarkable deviations from the general trend at the very beginning were due to migration waves, while in the XX century that happened due to Depressions' decline in fertility and postwar baby boom.

Model assumptions and data sources used for different years of US demographic history reconstruction are summarized in the table 2.

Table 2. Model assumptions and data sources.

Period	Model assumptions
1610-1789	• Constant (though unknown) intrinsic rate of natural increase • Mean demographic potential of migrants is 15 % higher then that of stable equivalent population consistent with current vital parameters • Population mean demographic potential for two beginning years (1610, 1611) is set to be equal to that of immigrants, and later - is calculated from the model (2) • Annual population numbers are interpolated from decennial data • Exponential growth model is used for life expectancy reconstruction
1790-1799	• Constant (though unknown) intrinsic rate of natural increase • Mean demographic potential of migrants is 15 % higher then that of stable equivalent population consistent with current vital parameters • Population mean demographic potential is calculated from the (2)

	• Annual population numbers are interpolated from decennial data • Life expectancy trend is smoothly interpolated
1800-1899	• Intrinsic growth rate smoothness and 4th equation of (2) are used in goal function (3) • Annual population numbers are interpolated from decennial data • Annual mean demographic potential numbers are interpolated from decennial data • Life expectancy trend is smoothly interpolated
1900-1967	• Intrinsic growth rate smoothness and 4th equation of (2) are used in goal function (3) • Annual mean demographic potential numbers are interpolated from decennial data
1968-2000	• Intrinsic growth rate smoothness and 4th equation of (2) are used in goal function (3)

Reconstruction results

After the data sets were prepared and the model was formulated, the goal function (3) was minimized by the means of variation of those variables, which couldn't be estimated directly from data or from the constraints of the model (2). Namely, following variables were adjusted in order to minimize the goal function: the constant level of the intrinsic growth rate for years before 1800 and net immigration numbers for years 1799-1999. Other variables were calculated from the model (2) constraints.

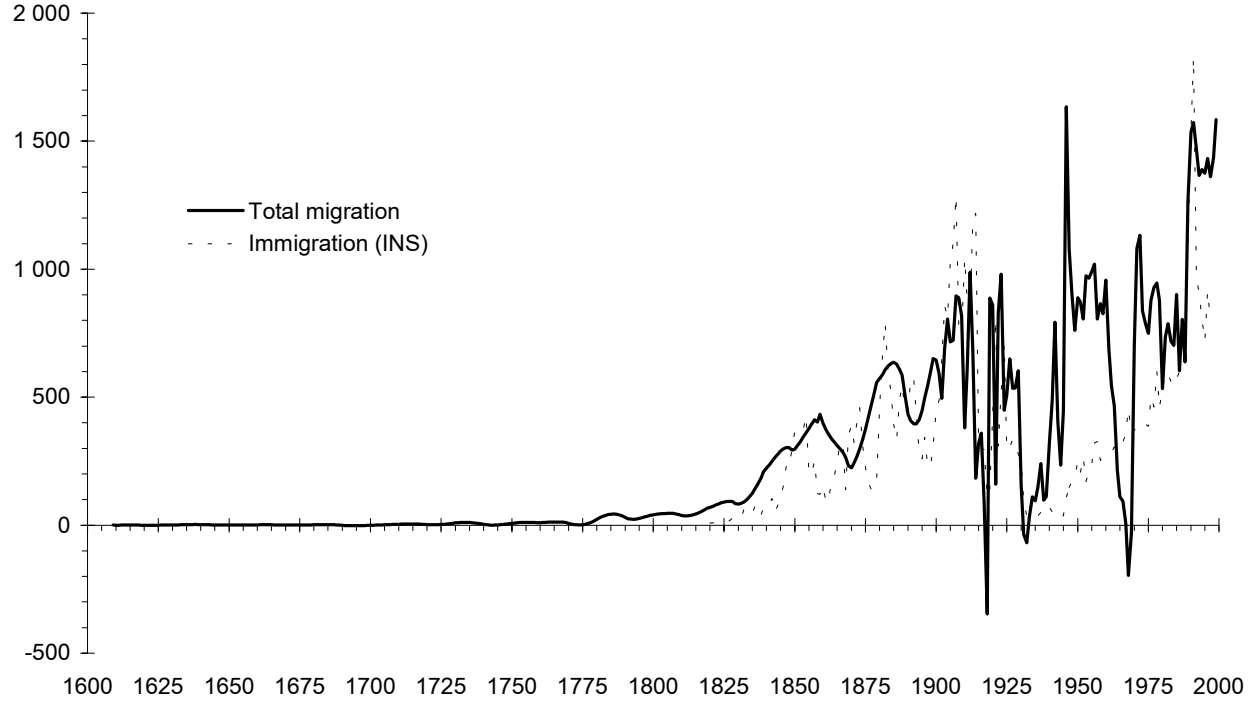

Fig. 8. Reconstruction of the net migration to the US (1610-1999) and INS data on immigrants admitted (1820-1997). Thousands.

Fig. 8 presents net migration reconstructed from the US historical data as well as INS data on official immigration (US Immigration and Naturalization Service 1999). Given the considerable lag between naturalization and immigration, reconstruction looks very reliable. One can refer to the table 1 to check the causes of different migration waves. It is useful to refer also to fig. 9 representing the dynamics of immigrants share in US population. It's seen that immigration falls were mainly caused by wars and US immigration policy. Slight immigration decrease in near the 1850 was caused by overlapping of two immigration waves (Ireland and German). Economic crisises and depressions of the XIX century seem to have no effect on immigration, while the Great and other depressions of the beginning of the XIX century do decreased the immigration to the US. Perhaps, similar was the effect of post-war depressions, while Persian Gulf war and Bosnian operation had no consequences on the immigration dynamics. According to the reconstruction, from

the 1610 about 96 795 000 immigrants settled in the USA. Timing of this immigration is presented in the table 3.

Table 3. Immigration to the US by the period of immigration.

Period	Immigrants settled
1610-1699	67 000
1700-1799	1 145 000
1800-1899	27 093 000
1900-1999	68 491 000
Total	96 795 000

There is remarkable difference between the reconstructed trend and data on official immigration for post-war years, especially for 1940-1980 years (not to mention official net migration that is even less then official immigration). Excess of reconstructed net migration over numbers of immigrants admitted can be attributed to several factors: refugees arrival to the US; unauthorized immigration to the US; sufficient errors in the interpolation of mean demographic potentials before 1968; sufficient errors in data on annual population; model bias. The fact that immigration was correctly estimated even for period before 1900, when the quality of data used was worse then for postwar years, and that postwar years were the years of strict regulation of the immigration leads to conclusion that perhaps the main reason of discrepancy is unauthorized immigration to the US (it worth to highlight the potential role of *bracero* program that initiated migration flows from the Mexico). Yet the final explanation of the reconstruction results for postwar years can't be obtained without deeper analysis of immigration in that period.

Official data on immigration and especially for other components to be used in net migration assessing aren't available for all the years analyzed. This prevents from making conclusion about possible unauthorized immigration. The only conclusion can be made for the period 1901-1990 that is provided by INS estimations of net migration to the US. Table 4 summarizes results for that period. High numbers of unauthorized immigration for 1941-1960 can partly be attributed to the *bracero* program (accompanied by immigration) of attracting the Mexican labor force to the US and to massive arrival of refugees.

Table 4. Estimation of the level of unauthorized immigration to the US.

Period	Net immigration reconstructed	INS estimation of net immigration	Possible unauthorized immigration and net non-immigrants arrival (refugees, etc)		
			Number	%	Annual rate
1901-1910	7007	5787	1220	17,41%	122
1911-1920	4627	3579	1048	22,65%	105
1921-1930	5410	2422	2988	55,23%	299
1931-1940	1049	-121	1170	111,53%	117
1941-1950	7634	754	6880	90,12%	688
1951-1960	9082	2090	6992	76,99%	699
1961-1970	2603	2422	181	6,95%	18
1971-1980	8755	3317	5438	62,11%	544
1981-1990	8693	5738	2955	33,99%	296
Total	54860	25988	28872	52,63%	321

Fig 9. presents annual migration rate trend (estimated as the ratio of migrants to the population at the beginning of the year). Very high migration rates at the beginning years are due to small size of initial population. In general the rate of migration is close to 0.3-0.5%; it can be noted that immigration rate became lower when migration regulation began (XX century).

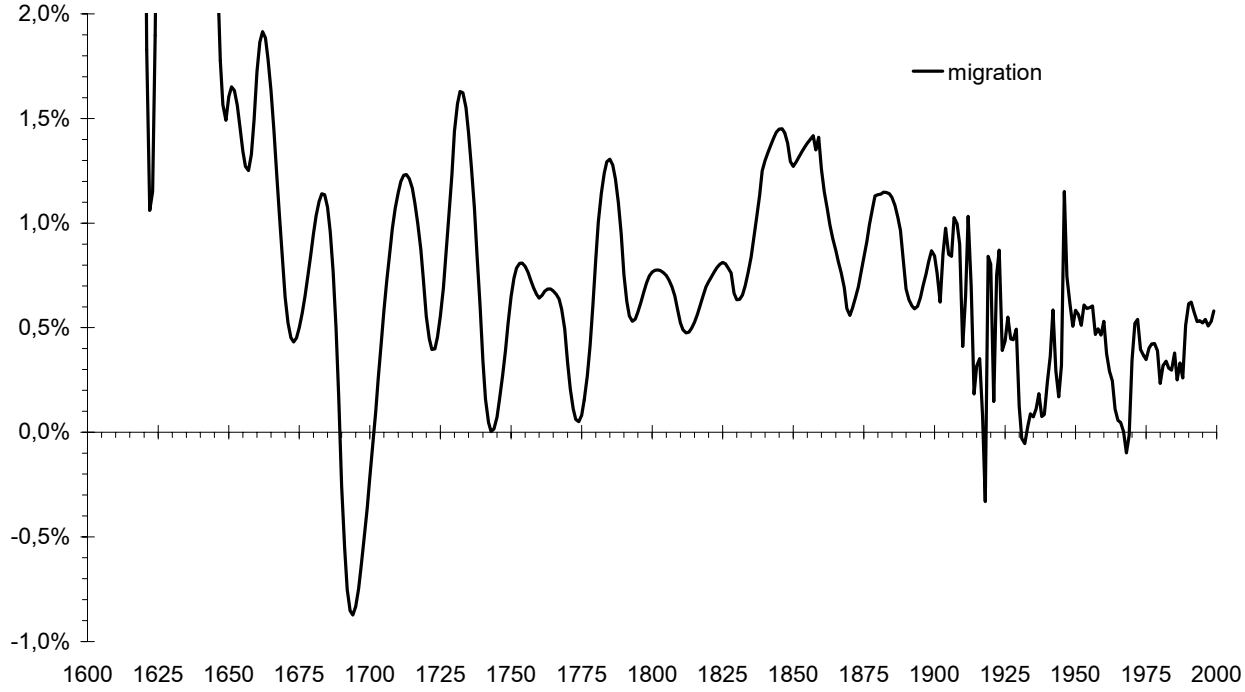

Fig. 9. Reconstruction of the net migration rate to the US (1610-1999).

Another demographic factor of crucial role in population dynamic – intrinsic growth rate – is presented of the fig. 10. Before the demographic transition took place in the US (before 1810) this rate was around 2.3% annually. During the XIX-XX centuries demographic transition lead to dramatic decline in intrinsic growth rate – to about –0.3%. Intrinsic growth rate as well as migration is affected to different economic and political events (table 1). Unlike the immigration, intrinsic growth was more sensitive to economic crisises. The most dramatic decline was due to the Great and other depressions of the beginning of XX^{th} century. Baby boom after the World War II was most likely the compensation for pre-war fertility decline caused by several depressions and prolonged because of the war.

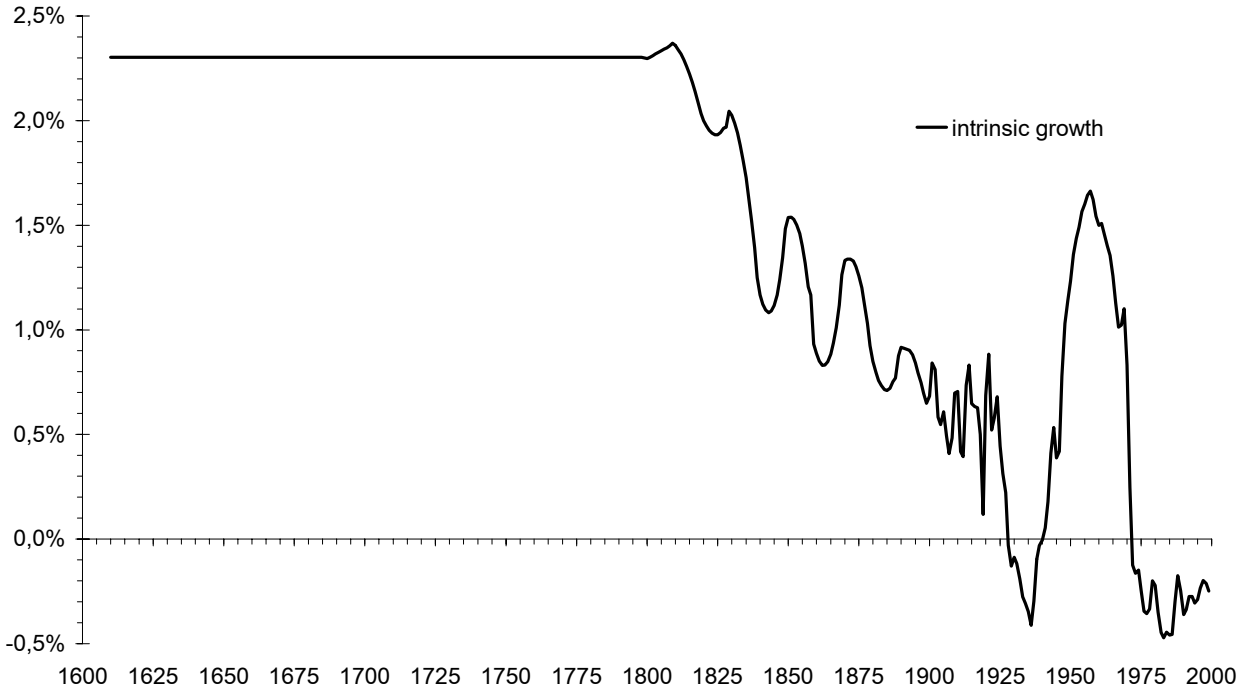

Fig. 10. Reconstruction of the intrinsic growth rate of the US population (1610-1999).

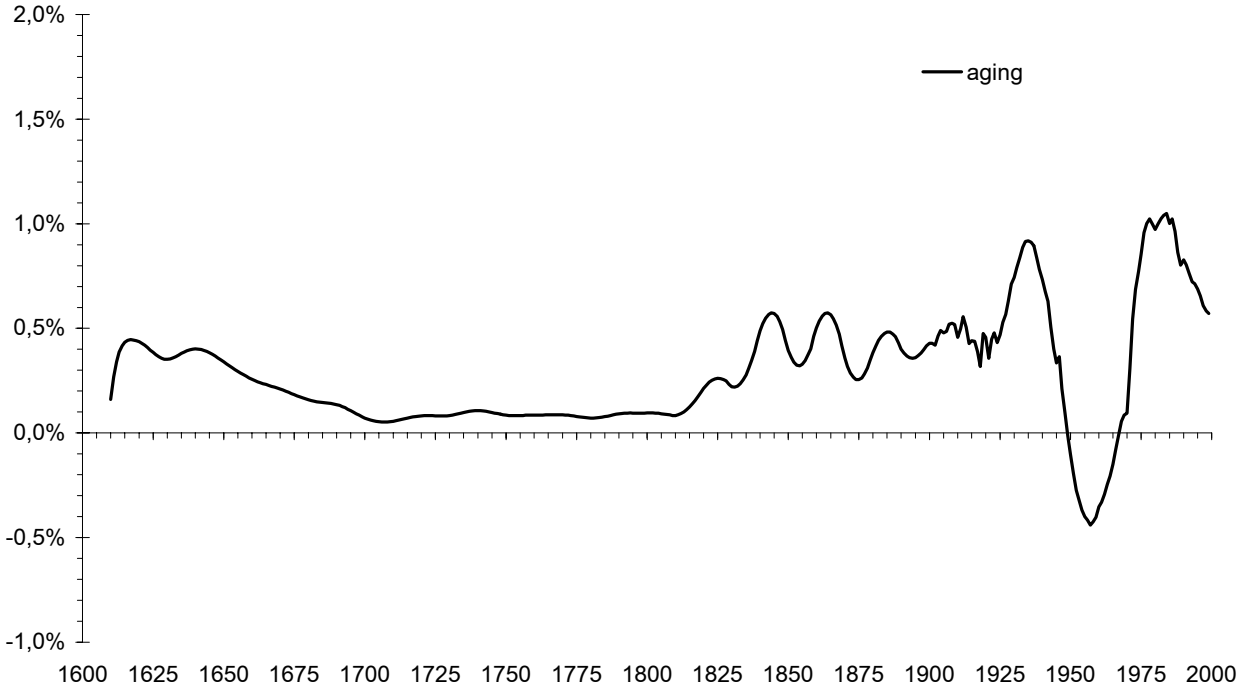

Fig. 11. Reconstruction of the effect of aging on US population dynamic (1610-1999).

Effect of third factor of population dynamic – the aging – is shown on fig. 11. It fills the gap between the rate of population increase (with migration set to be zero) and intrinsic growth rate. Because of high immigration, aging was always the positive factor in the US population dynamic except for baby boom years when the population age structure was older than that of stable equivalent population.

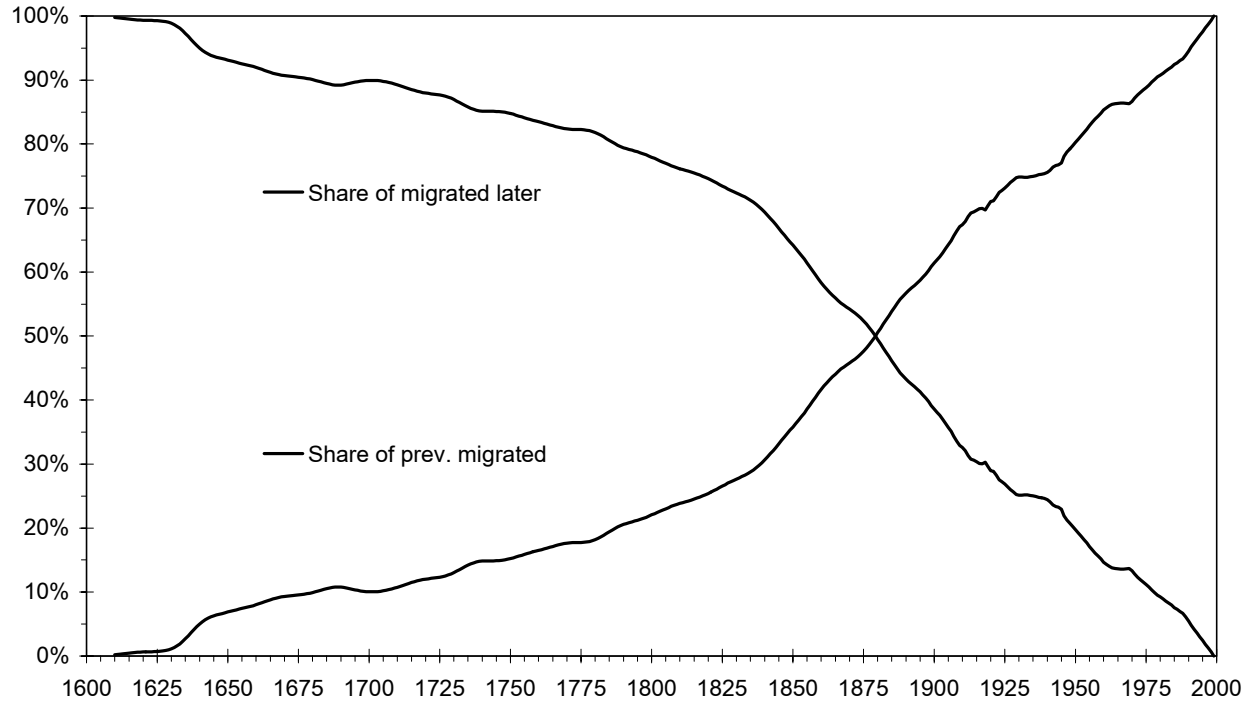

Fig. 12. Posterity shares in the US 2000 population (native Indians are excluded).

Integral effect of immigration at different periods is presented on the fig. 12. This figure depicts shares in the 2000 US population of immigrants arrived at different periods and/or of their descendants. Left upper curve shows a share of immigrated to the country after a moment of the time, shown on axis of abscissas, and lower curve shows a share those arrived later. At the beginning of colonization first curve gets through the value of 1.0 (since all immigrants of arrived afterwards; native Indians are not taken into account), the same curve drops to zero at 2000 (since immigrants, which will arrive in future, have no share in the 2000 population). The second curve, on the contrary, increases monotonously from zero to the value 1. Cross point of two curves indicates a "turnover" date, when a contribution of those immigrated earlier becomes equal to that of those who will arrive later. Estimation was made under the assumption of reproductive rates equal for all the contemporarily living people. This assumption can't be considered as perfect since reproductive parameters depend on origin, ancestry, etc. Yet fig. 12 reflects general pattern of the US population. Only about half the US population have ancestry arrived to the country before the Civil War, and less then 20% of the 2000 population can be attributed to colonists arrived before the US independence – these figures graphically demonstrate the role of immigration in the US history.

Conclusions

The model of demographic potential reproduction, earlier developed and tested for close population, is extended to the case of population open for migration. Using the developed model immigration rates to the US from the 1610 are reconstructed. Due to gaps in initial data sets, some simplifying suggestions are used, while some data sets were interpolated. Results obtained are compared to available immigration data and to set of historical events relevant to the US demographic dynamic. Analysis conducted indicates efficiency and robustness of the method proposed and reliability of the results received.

US population has continuously grown from the Colonization period under the effect of three factors - immigration, high level of the intrinsic growth rate, and a significant momentum of population growth. With a time a role of second factor diminished and become negative because of falling birth rate at the end of past century. However, other two factors (immigration and aging) are still significant and play a positive role in the dynamics of the population size, resulting in high probability of population growth in future.

Immigration was sensitive to social-political and economic conditions and events. At the beginning of colonization greater role was played by events in the Europe and, first of all, in England, while later an accent was displaced to the immigration policy of the USA themselves, to the influence of economic crisises and of other global factors (world wars, pandemic). The most significant was, probably, the influence of series prewar economic crisises in 20s-30s of last century. These crisises also explain to a some extent an origin of postwar baby boom, which arose as a compensational ascent of birth rate after a long-lasted crisis of fertility. Unauthorized immigration grew significantly at the period of active regulation of the immigration to the USA; it was estimated comparing the obtained figures of immigration to official statistics.

Most likely, recent tragic events in the USA, international tensions, and economic uncertainty, as well as tightening of immigration policy will bring about observable, though temporary, shortening of immigration to the country. Less likely that this reduction can bring about the negative net-immigration, and by no means can it cause the depopulation of the USA since the age structure of population has a considerably high momentum of population growth.

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