The Economics of Immigration

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By

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The person that has contributed and forgone the most for my pursuing a doctorate is beyond doubt my wife, Elie. I would like to thank her for her patience, excitement and love.

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Chapter 1

Outline

1.1 General Introduction

"Immigration is the sincerest form of flattery," is the twist of an old proverb. Still, immigration is a debated and dividing issue in the U.S., Canada, Australia, and other countries that receive the bulk of international migrants.

Indeed, the flow of immigrants to the U.S. has surged over the last decades, from 30,000 annually in the mid 30s to over 1 million in the 90s. Immigration may have a significant effect on the economy because immigrants are quite different from natives. In particular, new immigrants are a lot younger than natives (Figure 1) and have very different wage profiles. Thus, immigration may have a dramatic impact on the age-structure of the population. It slows down the aging of the baby boom and may change the composition of the labor force.

Despite the stir created by immigration, very little work exists on the macroeconomic effects of immigration. The purpose of this thesis is to quantify the effects of immigration on the U.S. economy. I explore how the demographic structure of immigrants affects public finance, welfare, and the savings rate.

A necessary condition for doing quantitative analyses is proper measurement of the micro foundations. In Chapter 2, "What is an Immigrant?", I quantify how immigrants differ from natives in terms of productivity, work effort, and fertility. The data sources are the 1980 and 1990 Censuses. The results are used to parameterize the macroeconomic models in subsequent chapters.

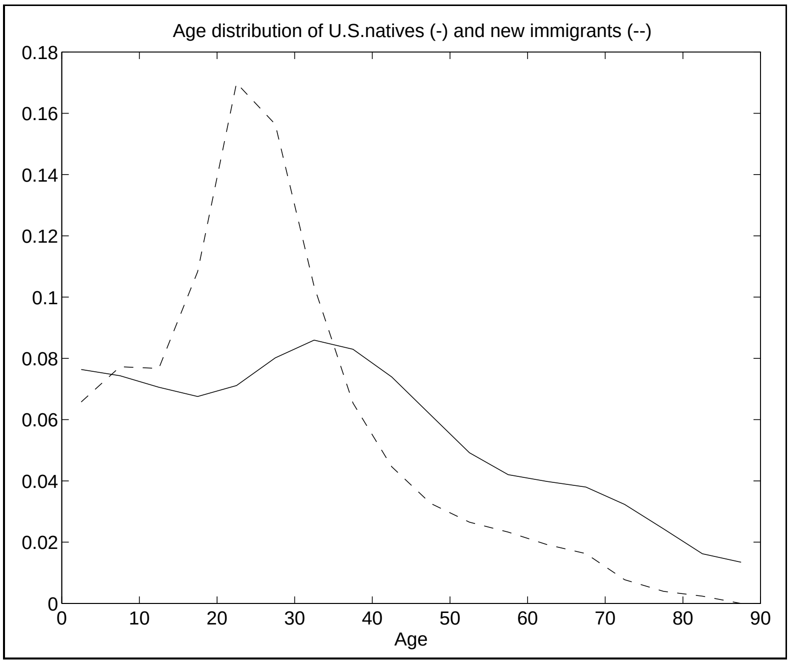

Figure 1.1: Age distribution of natives in 1991 (-) versus the average distribution of new immigrants during 1982-88 (- -).

A change in demographic structure may have large effects on capital accumulation because savings behavior is strongly influenced by age. In Chapter 3, "Immigration Policy and the Aggregate Savings Rate", I explore how sensitive the national savings rate is to changes in the immigration policy. A demographic change may also lead to changes in wages and interest rates, which have potential welfare effects. I quantify how much each native generation loses from shutting down immigration. The chapter also serves another purpose: Determine if immigration is quantitatively important in the U.S. economy.

While the level of immigration is worrisome to many, the future government deficit is of a much deeper concern. Big chunks of public expenditures are age dependent (Social Security, schools, etc.) and most of the tax revenues are collected from the working age population. Thus, with an aging baby-boom generation, the Social Security obligations are huge and the tax base small. However, as immigrants on average are younger than natives, an increase in immigration may alleviate some of the need for fiscal adjustment. In Chapter 4, I explore this relationship between immigration policy and fiscal policy. In particular, I quantify how much the immigration policy must be changed in order to sustain the current fiscal policy. I find that modest changes to the immigration policy would suffice to achieve fiscal balance.

The dissertation is closely related to the quantitative overlapping generations literature, represented by Auerbach & Kotlikoff (1987) and Ríos-Rull (1992b), among others. This literature accounts for demographic transitions in a general equilibrium framework. But the role for immigration has not been explored in this setting, and immigrants have not been separated as distinct agents.

Given the amount of public attention, surprisingly few attempts have been made at addressing the cost-benefit aspect of immigration. Two exceptions are Huddle (1994) and Passel (1994) who try to measure the annual gain of immigration for the U.S. government. These studies are static accounting exercises, but since Social Security and fiscal policy inherently are dynamic in nature, their analysis cannot address the public gain of immigration properly.

There exists a large literature on the effect of immigration on the labor market. See Borjas (1994) for a good review. This literature has focused mainly on the assimilation of immigrants in terms of wages and on the local effects of immigration on native wages and unemployment. The economic growth literature touches on the effects of immigration on growth, see e.g. Barro & i Martin (1994). But their analysis is not quantitative: Immigrants are not distinguished from natives.

The central methodology applied in this thesis to address macroeconomic questions quantitatively is to calibrate general equilibrium overlapping generations economies to U.S. data in the tradition of Kydland & Prescott (1982), Auerbach & Kotlikoff (1987), Ríos-Rull (1992a) and others. The approach involves calibrating, solving, and simulating a recursive stochastic overlapping generations economy with well defined mortality, fertility, and immigration processes.

The computational burden grows exponentially with the number of state variables, and the model would be prohibitively expensive to solve if agents were heterogenous along too many dimensions. Thus, using a standard wage equation approach to parameterize the agents in the model economy would not be a very useful approach. Instead, one would have to compute wage rate, fertility, etc. of natives and immigrants conditional on a small set of characteristics, for example age, national origin (native or immigrant) and (for immigrants) age at time of immigration. This is the purpose of Chapter 2.

Chapter 2

What is an Immigrant?

A quantitative measurement of how immigrants differ from natives.

2.1 Introduction.

How do changes in immigration policy matter for issues such as the accumulation of capital, the future of the Social Security system, and the financing of public debt? Building models that can address these issues quantitatively requires precise measurements of how immigrants differ from natives over their lifetime. This paper is an attempt to provide such measurements for the case of the U.S.A.

Solving dynamic macroeconomic models with large amounts of heterogenity of agents is very expensive. Existing wage-equations, for example, are therefore not very useful for parameterizing agents in dynamic general equilibrium models. In this paper, I estimate fertility, wages, participation rate and work effort for natives and immigrants to the U.S., conditional on a small set of characteristics: age, age at time of immigration, sex, and area of origin.

The data sources are the 1980 and 1990 Census of Population and Housing, A sample. These are cross-sectional data sets containing data on 5% of the U.S. population in 1980 and 1990. The composition of new immigrants (area of origin, age, etc.) has changed dramatically over the last half century, and immigrants that came 50-100 years ago had more education and earned a lot more, relative to natives, than recent immigrants.

"Cohort effects" (the notion that successive waves of immigrants have different human capital, measured as wages relative to natives) have been documented by Borjas (1990, 1992) and others. However, LaLonde & Topel (1992) find that for the case of hourly wages, all cohort effects can be accounted for by changes in national origin of new immigrants.

To alleviate the cohort effects and generate estimates conditional on a small set of characteristics, I adopt the following estimation strategy:

1. Split the sample in boxes (contingent on age, sex, area of origin, and age at time of immigration).
2. Estimate a vector of characteristics (wage, participation rate, etc.) as averages in each box.
3. Compute weights for each box based on data on new immigrants (to reproduce their composition).
4. Compute age-profiles (for wage, participation, etc.) for representative natives and immigrants as weighted averages of the estimates above.

If the composition of new immigrants remains unchanged in the future, these estimates identify characteristics of future immigrants to the U.S. The approach is non-parametric in nature, and the identifying assumption is that all cohort effects are picked up by accounting for changes in area of origin, sex, and age at time of immigration.

Data on the composition of new immigrants come from the 1992 Statistical Yearbook of the Immigration and Naturalization Service and the 1986 Congress Hearing on Illegal Immigration. Note that the legal status of immigrants is not identified in the decennial censuses. I assume that illegal immigrants are sampled as frequently as legal ones in the censuses (estimates on the number of illegal immigrants in the U.S. are based on the same assumption, e.g. in Passel (1986)). Unfortunately, microdata of the 1980 and 1990 Post-Enumeration Surveys (the special data sets collected by the Census Bureau to account for undercount in the 1980 and 1990 Census) are not published, and the published undercount rates do not identify undercount conditional on nationality, age at time of immigration or detailed geographical location (census tract). The Census does therefore not allow for undercount adjustment.

The results indicate that immigrants who migrate at later age than 15 on average start out with wages well below natives of the same age. Their earnings rise rapidly, though, and these findings are consistent with e.g. Friedberg (1993). Immigrants that come after age 30 never assimilate in terms of hourly wages. The results indicate that current new immigrants will have a higher wage profile than suggested in Borjas (1990).

I find that immigrants have a much lower participation rate and work significantly less hours than comparable natives immediately after arrival to the U.S. This is consistent with findings in e.g. Borjas (1990). After 10-15 years in the U.S., however, immigrants tend to participate and work at least as much as natives. Right before retirement age immigrants tend to work more hours and participate more than natives. Borjas (1990) finds that immigrant men assimilate (to white natives) in terms of labor force participation but not in terms of hours worked.

Estimates of immigrants' fertility suggest that immigrant women have about 50% higher fertility than native women. This result contrasts sharply with Blau (1992). She finds that the fertility of female immigrants from traditional high-fertility countries is not significantly different from the fertility of native women, after immigration to the U.S.

2.2 Measurement

The purpose of this study is to measure wages, labor market participation, hours worked in the market, and fertility for natives and new immigrants, conditional on a small set of characteristics: Current age and age at time of immigration. That is, I want to know how newly arrived immigrants will fare over the remainder of their lifetime, compared with US natives. To this end, as mentioned above, I use the following estimation strategy:

1. Split the sample in $2 \times 6 \times 15 \times 12$ boxes, conditional on sex, area of origin, age, and age at time of immigration.
2. For each box, estimate wage rate, participation rate, annual hours worked in the market, and fertility rate.
3. Compute weights for each box based on data on natives and new immigrants (to reproduce their composition).
4. Aggregate over sex[1] and area of origin in the following way: Conditional on age and age at time of immigration, compute wage, participation rate, etc. for representative natives and immigrants by weighting the estimates in 2 by the weights in 3.

[1] I do not aggregate over sex when computing fertility.

For example, wage rate of an i-year old representative immigrant who came at age y is computed as $w(i,y) = \sum_{sex}\sum_{area} w(sex, area, i, y) * q_I(sex, area, i, y)$.

5. Use the weighted averages in 4 to construct age profiles conditional on age at time of immigration, for example $(w(y,y), w(y+1,y), ...)$ for immigrants who came at age y.

Definitions of area of origin, wage rate, etc. are discussed in section 3. The weights for computing labor force participation rate of natives (conditional an age) are computed as the fraction of sex g persons among age i natives:

$$q_{N,g,i} = \frac{\mu_N(g,i)}{\sum_{sex}\mu_N(sex,i)}$$

where $\mu_N(g,i)$ is the number of type (g,i) natives. Weights for computing fertility are 1 for each age-group of native women. Wage rate and annual hours worked in the market are computed conditional on participating in the labor force. Hence, the weights for computing wage and annual hours of natives are computed as the fraction of sex g persons among age i native labor participants:

$$q_{N,g,i} = \frac{\mu_N(g,i)\pi_(g,i)}{\sum_{sex}\mu_N(sex,i)\pi(sex,i)}$$

where $\pi_(g,i)$ is labor force participation rate of type (g,i) natives. Weights q_I of immigrants are computed in a similar fashion, but do in addition condition on area of origin a and age at time of immigration y. Weights for computing participation are

$$q_{I,g,a,i,y} = \frac{\mu_I(g,a,y)}{\sum_{sex}\sum_{region}\mu_I(sex, region, y)}$$

where $\mu_I(g,a,y)$ is the number of type (g,a,y) persons among *new* immigrants. Weights for computing immigrant women's fertility are the same as for labor force participation, but without summing over sex. Equivalently, weights for wage and hours are

$$q_{I,g,a,i,y} = \frac{\mu_I(g,a,y) * \pi(g,a,i,y)}{\sum_{sex}\sum_{region}\mu_I(sex, region, y) * \pi(sex, region, i, y)}$$

2.3 Data and definitions.

I use data from the 1980 and 1990 Censuses, 5% A Sample. The data sets contain data on 10.6 and 11.4 million natives and 704,000 and 988,000 immigrants in 1980 and 1990, respectively. A "native" is defined as a person being born in the US or by US parents. Thus, an "immigrant" is defined as a foreign born person without US parents. I sample only 3 in 100 non-Hispanic white natives (since this group represents 80% of the total sample) and only 1 in 10 other natives from the 1990 sample. For the 1980 sample I keep 2 in 100 non-Hispanic whites and 1 in 10 other natives. I exclude persons younger than 15 and all observations for which data on sex, age, country of origin, citizenship or year of immigration are missing. For the 1980 sample I also toss out all men and persons older than 45. The remaining 1980 sample has 35,035 non-Hispanic whites, 76,059 other natives and 111,094 immigrants. The remaining 1990 sample consists of 603,992 immigrants, 197,926 non-Hispanic white natives and 112,496 other natives. All "allocated" observations[2] are treated as missing.

Age is recorded in 15 5-year intervals from 15-19 to 85 and up. Age at time of immigration is zero for natives, and either 0-14, 15-19, 20-24, ..., 55-59, or 62 and above for immigrants. Age is recorded in 5-year intervals. The highest bracket is $\geq$65. Unfortunately, the Census variable identifying year of immigration is given in crude brackets. As an approximation I choose the midpoints of the brackets as year of immigration (e.g. immigration during the period 1965-69 is counted as mid 1967). Area of origin is either USA, Asia, Mexico, Latin America (excluded Mexico), Europe/Canada or the rest of the world (Oceania and Africa).

To calculate the weights needed for computing the profiles for representative natives and new immigrants, I use the 1992 Statistical Yearbook of the Immigration and Naturalization Service and the 1986 Congress Hearing on Illegal Immigration. INS(1992) reports the composition of age, sex, and area of origin for new immigrants during the 1982-88 period. I chose to stop in 1988 since this is the last year that does not include immigrants admitted under the 1986 IRCA legislation.[3] The 1986 hearing gives corresponding estimates for illegal immigrants. The number of illegal immigrants in 1992 is estimated to 300,000, see e.g. Fix & Passel (1994). That year 809,000 legal immigrants were admitted. I assume that the illegal fraction of immigrants (27%) remains constant in the future.

[2] The Bureau of the Census changes or adds ("allocates") observations if the answers are missing or inconsistent. An example: If the number of weeks employed and unemployed exceed 52, then one or both will be edited so that the sum is $\leq$ 52.

[3] The Immigration Control and Reform Act (IRCA) was enforced in 1989. In 1991 60% of all legal immigrants were admitted under the IRCA.

2.3.1 Wage, hours, participation.

Estimates for wage, participation and annual hours worked are based on the 1990 Census. Annual hours are computed as weeks worked[4] in 1989 times the usual number of hours worked per week in 1989. If annual hours exceeded 4745 (i.e. $\geq$ 13 hours per day), I set annual hours to 4745. I want to measure wages and hours conditional on working, and I choose the definition of participation accordingly: A person is said to *participate* in the labor force if annual hours ≥ 400[5].

In the 1990 Census income is divided in 8 categories:

- Wage or salary income
- Non-farm self-employment income
- Farm self-employment income
- Interest, dividend or net rental income
- Social security income
- Retirement income
- Public assistance income
- All other income

Labor income should be contained in the first three categories. LaLonde & Topel (1992) consider all three as labor income, while Borjas (1993) excludes self-employment income. As some of the self-employment income is capital income, I have chosen to consider only "Wage or salary income" as labor income. Thus, the wage rate per hour is computed as

$$w = \frac{\text{Wage and salary income, 1989}}{\text{Annual hours 1989}}$$

According to the discussion above, this should underestimate the wage rate for self-employed people. I therefore exclude wage observations where $w \leq \$0.75$. Given the restriction on annual hours, the estimates

[4] "Weeks worked" includes paid vacation and paid sick leave.

[5] If no restriction on hours worked is imposed, the measurement errors are pronounced. E.g. the highest wage rate per hour recorded in the sample is \$12000 (for the case of hours $\geq$400, the highest wage recorded is only \$188). Keeping the extreme observations in the sample produces non-conventional results, e.g. native workers older than 65 earn 50% more than any other age category.

of wage profiles are not sensitive to throwing out outliers (for example by restricting the wage rate to be $\leq$ \$150).

2.3.2 Fertility

The Census reports the number of children ever born for each woman. There is an open bracket on the number of children, namely ≥ 12. The Bureau of the Census has computed the average number of children to be 13, conditional on being ≥ 12. Average fertility during the 1980-90 period (conditional on being alive and in the U.S. in 1990) for a group x of women can then be computed as the average number of children for group x in 1990 less their average number of children in 1980. For convenience, "fertility" of an age i woman of type x is defined as the average fertility during the 80s for a type x woman of age $i + 5$ in 1990.

2.4 Results.

The results of the estimations are reported in figures 1 through 13, showing wage, participation, annual hours, and fertility profiles for representative immigrants versus natives.

The wage profiles of representative immigrants are displayed in Figure 1. Earnings of immigrants are strongly influenced by age at time of migration. Immigrants (except those who come before age 15) start out with low wages right after immigration, but experience some assimilation. Immigrants who migrate after age 30 tend to earn significantly less than natives. Immigrants who come at age 57 will earn on average 39% less then natives during the rest of their career, see Table 1. These findings are consistent with e.g. Friedberg (1993). Younger immigrants fare a lot better, though: Those who came before age 15 have on average a 4% higher wage profile than natives. Immigrants who come at age 25-29 surpass native wages at age 47 and earn on average 3.5% less then natives, while immigrants who come at age 15-19 do not achieve wage equalization with natives. One possible explanation for this is that the Mexican share of age 15-19 immigrants is very big (40%). Wages of immigrants broken down on area of origin are displayed in Figure 2. My results are at odds with Borjas (1990): Although he does not differentiate his findings on age at time of immigration, he finds that immigrants who came during 1975-79 will make 15-20% less than natives on average. Figure 3 and Figure 4 break down immigrants' wages on sex. Immigrant women do surprisingly well relative to native women, whereas immigrant men are at a pronounced wage disadvantage relative to native men. Only immigrants who came at age 25-29 surpass native men in terms of average wages, and the wage gap for immigrant men who come after age 45 increase after migration!

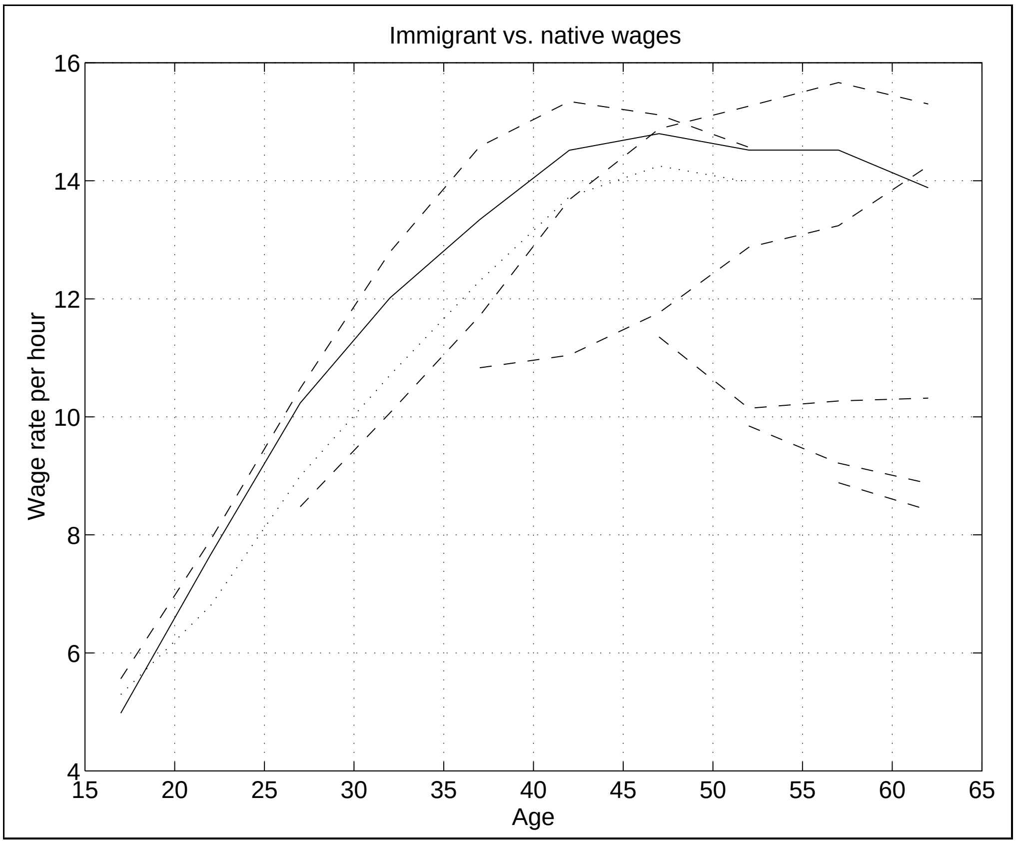

Figure 2.1: Wage rate, US natives (-) versus immigrants (- -) entering at age 0-14, 15-19, etc. (entering at age 15-19 are symbolized with (..)).

To get a sense of how my wage estimates compare with other studies using alternative data sources, the estimated efficiency unit profile (i.e. the wage profile normalized so that average efficiency units are 1) for US natives is plotted against a efficiency unit profile estimated with data from the Current Population Survey (see Figure 5). The wage profiles are similar, which strengthens the credibility of my results.

Figure 6 indicates that immigrants start out with significantly lower participation rate than natives. After 20-25 years in the U.S., however, the difference has disappeared (this is not the case for immigrants who come at age 15-19). One way to interpret this is that immigrants have a hard time to find work right after arrival in the U.S. After age 55 immigrants seem to be slightly more likely to participate in the labor force than natives. The findings are echoed when broken down on sex (Figure 7 and Figure 8). Note that the tendency to participate more often than natives after age 55 is driven by male immigrant labor supply. Note

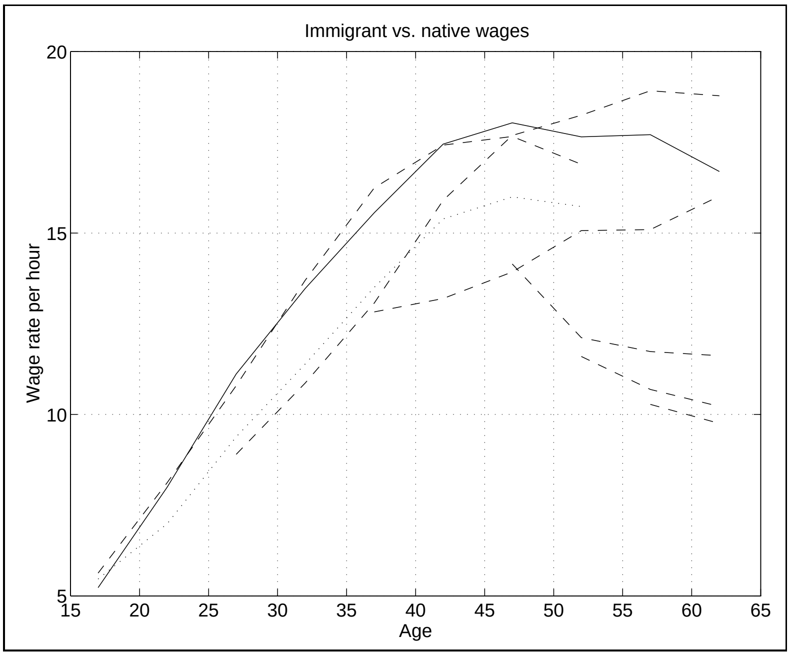

Figure 2.2: Wage rate, US men (-) versus immigrant men (- -) entering at age 0-14, 15-19, etc. (entering at age 15-19 are symbolized with (..)).

also that immigrant women who came at age 15-19 participate significantly less than native women. These findings are consistent with e.g. Borjas (1990).

The same patterns are repeated for annual hours worked (reported in Figure 9), although assimilation of immigrants to natives seem less pronounced in terms of annual hours. Note that immigrant men tend to work less then natives during the whole career (Figure 10), while immigrant women surpass native women after only 5-10 years in the U.S. (Figure 11). Borjas (1990) find evidence for some assimilation in terms of hours worked, although less than my results indicate.

The estimates of immigrant women's fertility are reported in Figure 12. The figure indicates that immigrant fertility is significantly higher than for native women (on average 50% higher). I did not find evidence for systematic differences among women who immigrated at different age. These findings contrast with Blau (1992). Using data from the 1970 and 1980 Census, she finds that fertility of female immigrants from traditional high-fertility countries is not significantly different from fertility of native women, after immigration to the U.S.

To evaluate how my estimates of fertility rates (based on synthetic cohorts) compare with more conventional measures of fertility, I compared estimated native fertility with 1988 average U.S. fertility, as reported by the

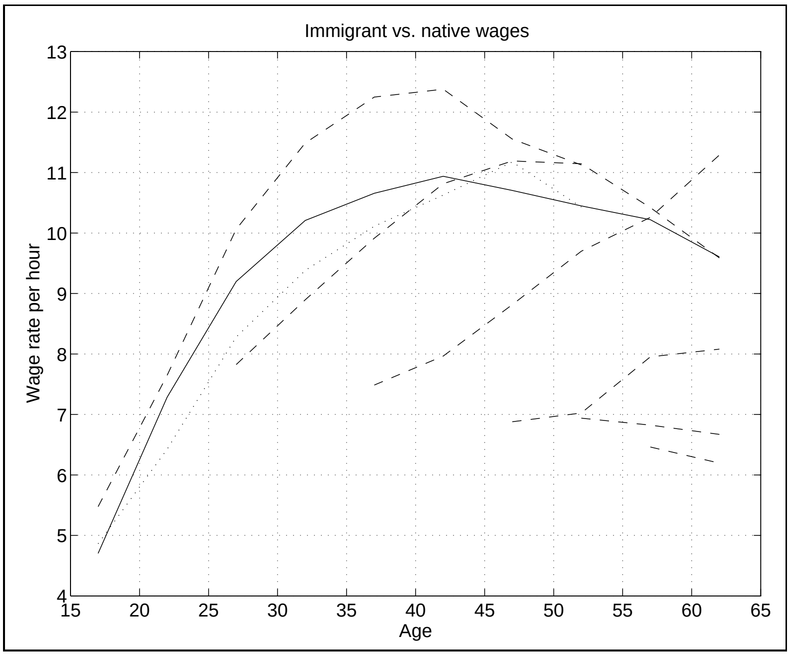

Figure 2.3: Wage rate, US women (-) versus immigrant women (- -) entering at age 0-14, 15-19, etc. (entering at age 15-19 are symbolized with (..)).

Current Population Survey, see Figure 13. The figure indicates that the estimated fertility profiles do a good job at capturing fertility. The Total Fertility Rate of native women (my estimates) is 1.82.

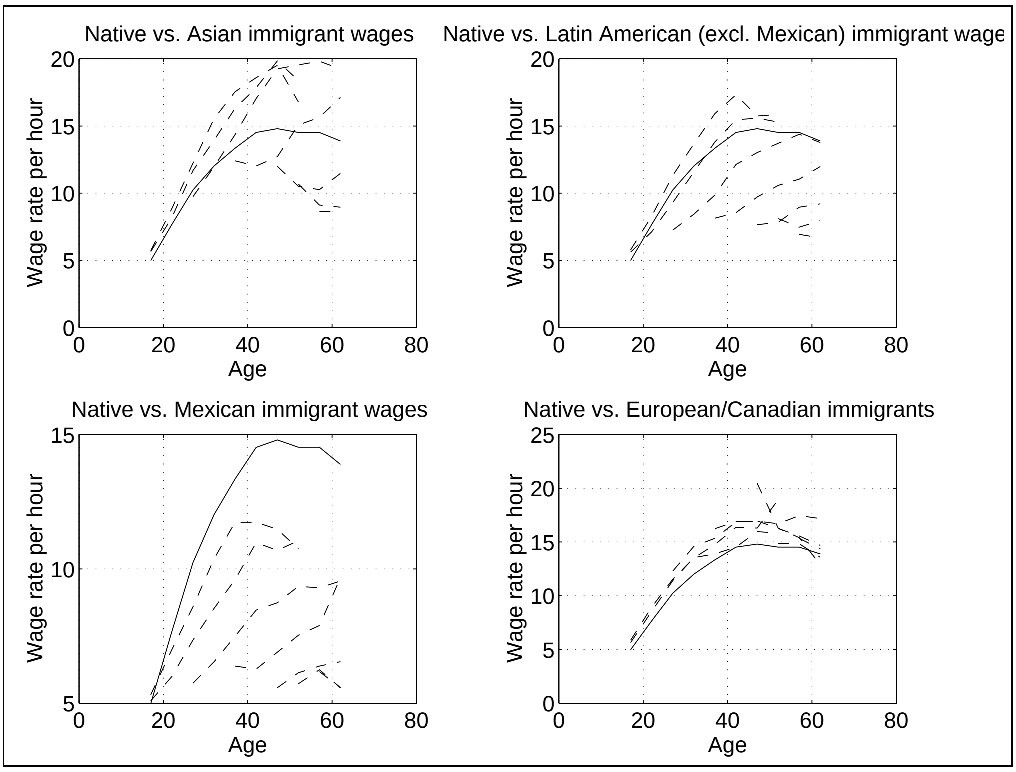

Figure 2.4: Wage rate, US natives (-) versus immigrants (- -) from Asia, Latin America (excl. Mexico), Mexico, and Europe/Canada.

	Age at time of immigration										
	0-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64
Difference	-4%	8%	8%	3.5%	11%	13.5%	20%	27%	35%	39%	35%

Table 2.1: Average wage difference over remaining working career between immigrants and natives.

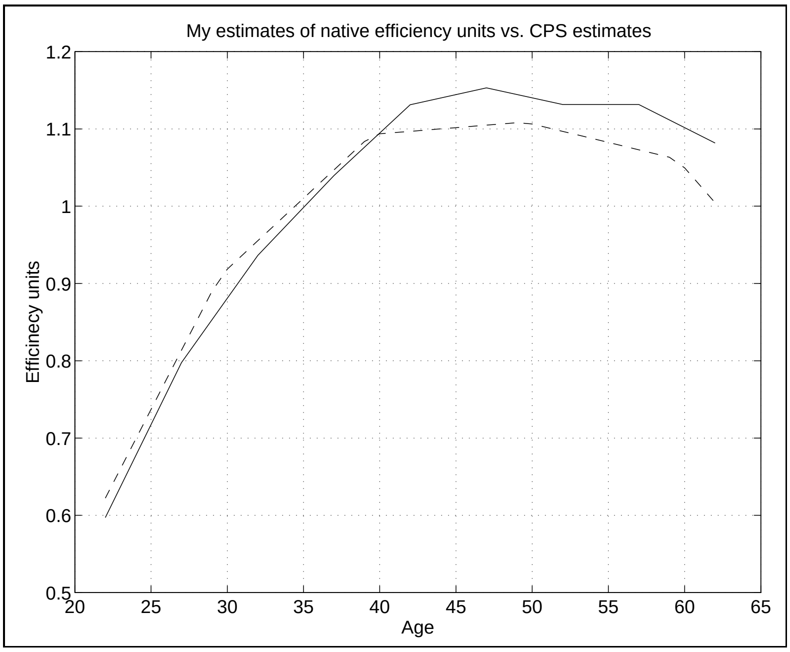

Figure 2.5: Efficiency units (i.e. wage profile normalized to 1 on average) for US natives, 1990 Census (my estimates) versus estimates from Current Population Survey.

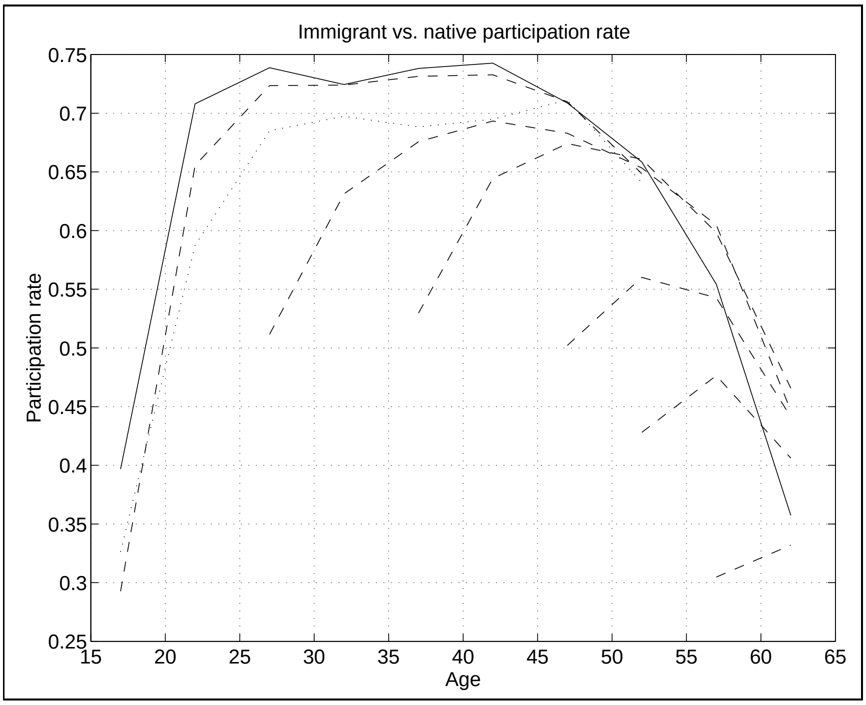

Figure 2.6: Participation rate, US natives (-) versus immigrants (- -) entering at age 0-14, 15-19, etc. (entering at age 15-19 are symbolized with (..)).

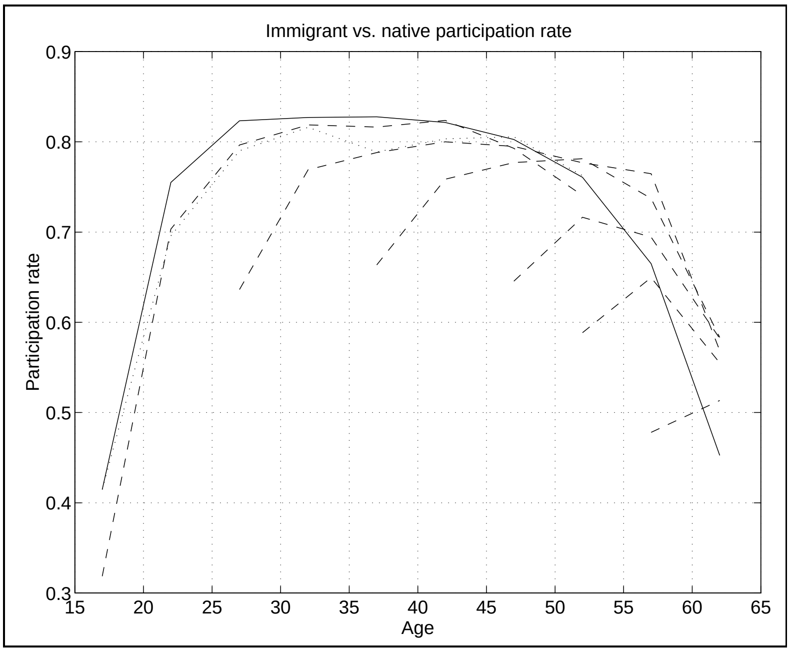

Figure 2.7: Participation rates, US men (-) versus immigrant men (- -) entering at age 0-14, 15-19, etc. (entering at age 15-19 are symbolized with (..)).

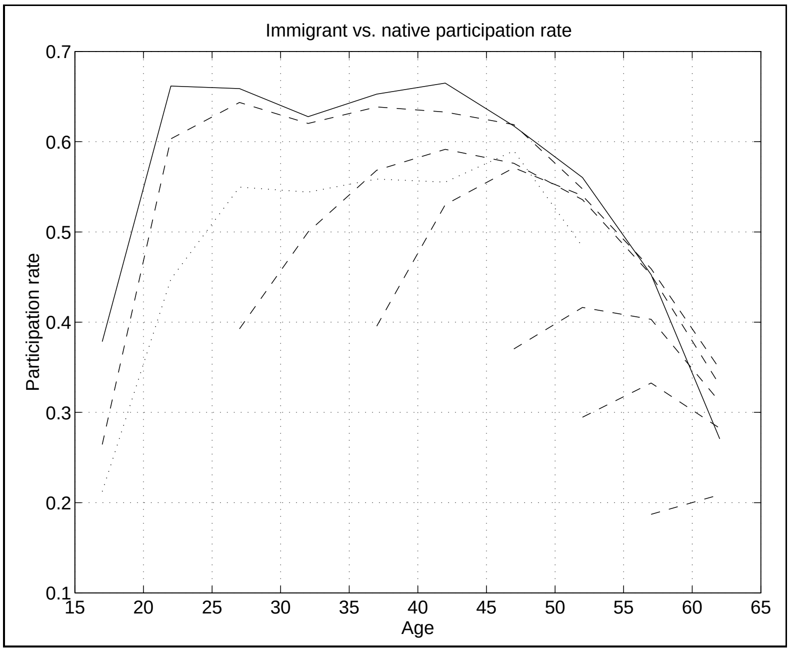

Figure 2.8: Participation rate, US women (-) versus immigrant women (- -) entering at age 0-14, 15-19, etc. (entering at age 15-19 are symbolized with (..)).

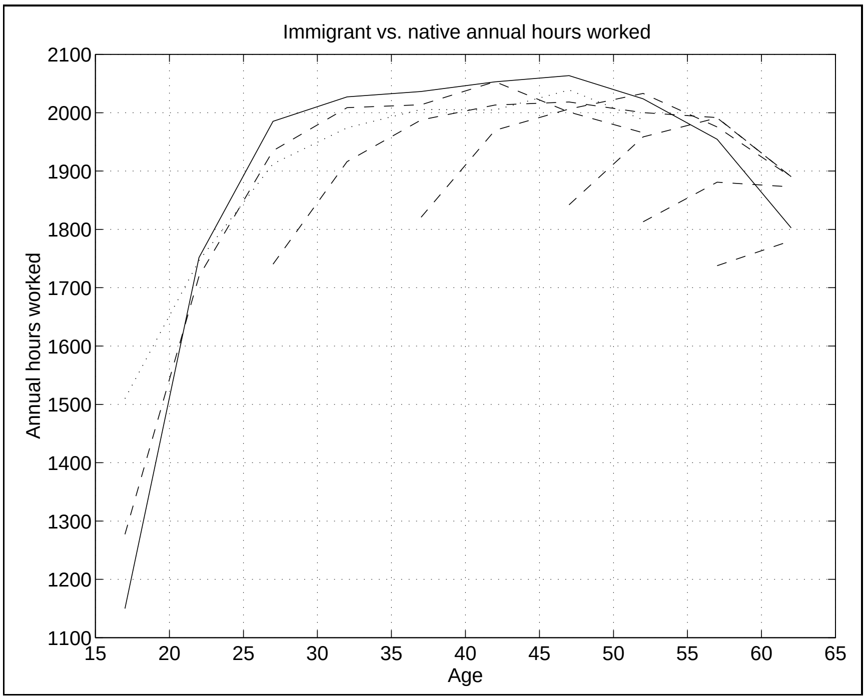

Figure 2.9: Annual hours worked, US natives (-) versus immigrants (- -) entering at age 0-14, 15-19, etc. (entering at age 15-19 are symbolized with (..)).

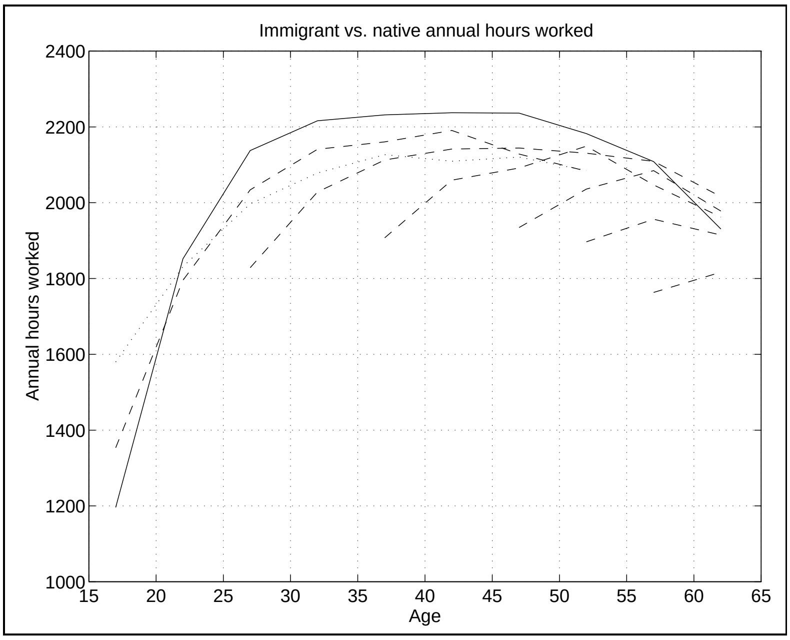

Figure 2.10: Annual hours worked, US men (-) versus immigrant men (- -) entering at age 0-14, 15-19, etc. (entering at age 15-19 are symbolized with (..)).

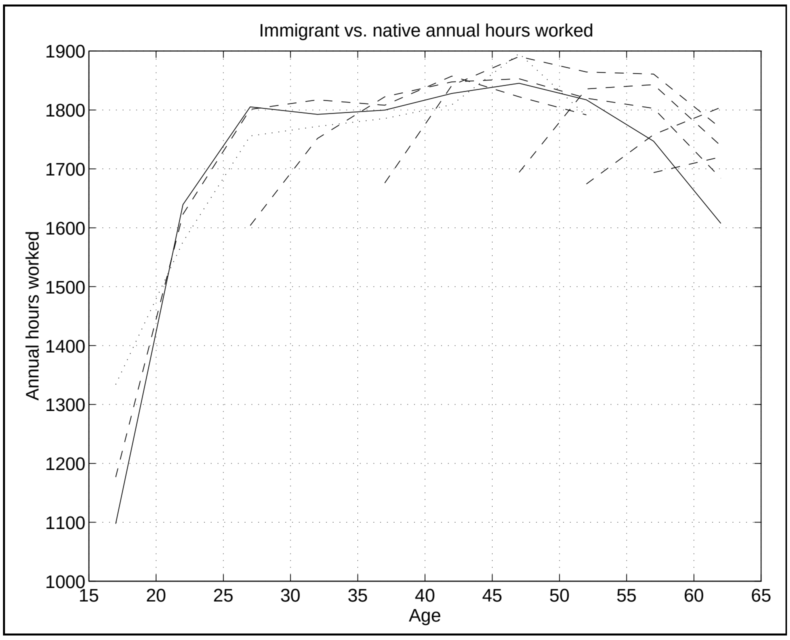

Figure 2.11: Annual hours worked, US women (-) versus immigrant women (- -) entering at age 0-14, 15-19, etc. (entering at age 15-19 are symbolized with (..)).

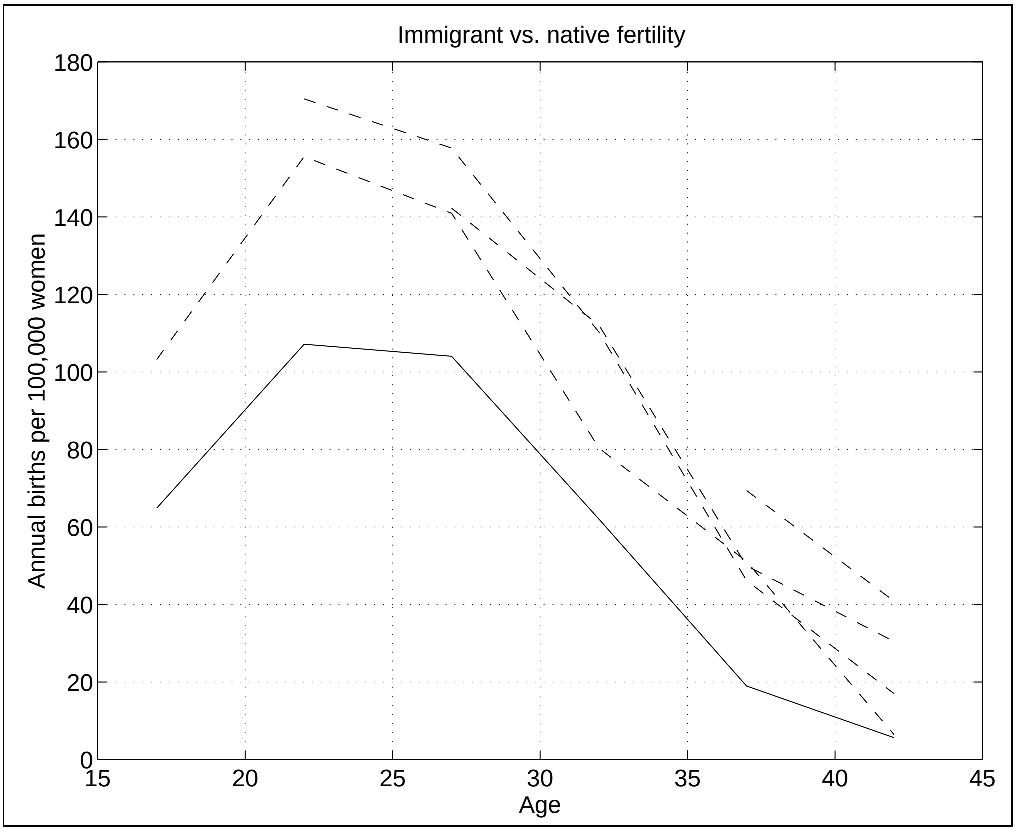

Figure 2.12: Fertility rate, US women (-) versus immigrant women (- -) entering at age 0-14, 15-19, etc. (entering at age 15-19 are symbolized with (..)).

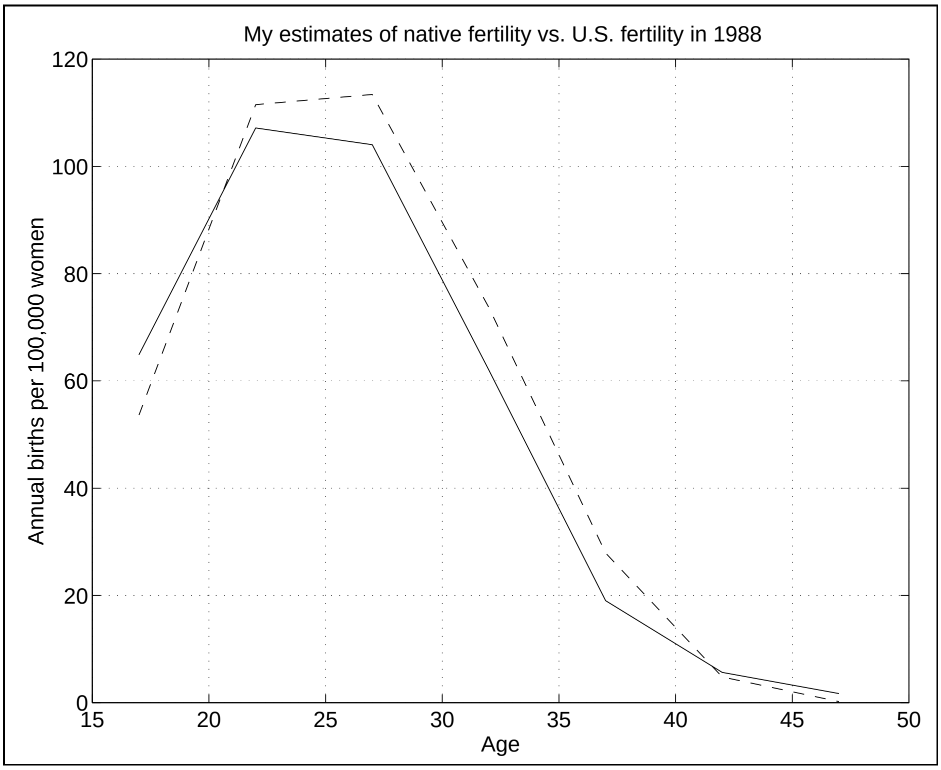

Figure 2.13: My estimates of U.S. women's fertility rate (-) (based on synthetic cohorts in 1980 and 1990 censuses) versus 1988 average U.S. fertility (- -), according to the Current Population Survey.

Chapter 3

Immigration Policy and the Aggregate Savings Rate

3.1 Introduction

Over the last 50 years several major demographic changes have occurred in the US:

- Fertility rates rose after World War II, and fell sharply in the 60s and 70s.
- Mortality rates have been decreasing throughout the period.
- Net immigration has surged from being negative in the 30s to over 800,000 annually in the 90s.

The first two changes are shared by most western countries, and are driving the aging of the US population. This demographic transition is expected to induce drastic changes in savings over the next century because people tend to accumulate wealth while young and spend while old, see e.g. Feldstein (1980).

Immigration, however, slows the aging process down because immigrants to the US are relatively young. Immigration is largely determined by the immigration policy, and thus by changing this policy, the government can influence national saving. If policy makers worry about how their decisions affect savings and capital accumulation, they should understand the relationship between immigration policy and aggregate saving. The key purpose of the current paper is to provide a prediction of the future savings rate in the US under the current immigration policy, and to evaluate the quantitative importance of immigration policy as a determinant of the savings rate. In particular, I address two questions:

1. How much does the savings rate change when the immigration policy is altered?

2. What fraction of the fluctuations in savings rate can be explained by shocks to the immigration policy?

To address these questions I model explicitly the immigration process and the immigrants' choices in a general equilibrium framework. There is considerable uncertainty about the future immigration, fertility, and mortality, so the model economy should be stochastic in nature. The recursive dynamic equilibrium models of population transition, see Ríos-Rull (1992a, 1992b, 1994), thus provides a natural framework. This approach involves calibrating, solving, and simulating a recursive stochastic overlapping generations economy with well defined mortality, fertility, and immigration processes. The agents in the model economy differ with respect to age, national origin (native or immigrant) and (for immigrants) age at time of immigration. In the model economy the government chooses how many immigrants to admit, and the age distribution of new immigrants.

I use the following methodology to investigate how much the savings rate changes when the immigration policy is altered: Solve for the model economy's competitive equilibrium under the *current* immigration policy and simulate the future savings rate by shutting down shocks to immigration policy and fertility. Then solve the model and simulate the savings rate under some alternative immigration policies. The effect of change in immigration policy is then measured in terms of how much the savings rate path is perturbed.

The results show that the projected savings rate is surprisingly sensitive to changes in the immigration policy, indicating that the immigration policy is indeed an important determinant of national savings. For example, closing down all immigration will immediately reduce the savings rate by 0.5% points relative to the predicted savings rate under the current immigration policy. This difference will grow to 1.5% points over the next 50 years. The results are driven by two opposing effects. Agents in the model accumulate wealth while young and spend while old. Thus, since immigrants are younger than natives, reduced immigration should lower the savings rate. However, since immigrants in the model bring little wealth with them from abroad, reduced immigration should lower the labor to capital ratio. This will push wages up, which tend to increase savings. The former effect dominates, though.

The fraction of fluctuations in savings rate that can be explained by shocks to the immigration policy is measured as the ratio of 1) The variance in the model economy's savings rate when shocks to immigration is the only uncertainty present, to 2) The variance in the US savings rate. In terms of this methodology, the shocks to the immigration policy are said to explain at least 5% of the fluctuations in the savings rate.

This model can pick up welfare effects that stem from changes in prices due to a change in immigration policy (i.e. the rise in interest rate and fall in wage rate that accompany a rise in immigration). I quantify these effects for each native generation and find that adult natives are willing to pay a lot to avoid closing the borders for immigration, up to 25% of annual GNP for age 65 retirees. The increase in wages that follow a reduction in immigration cannot compensate capital owners for the corresponding fall in interest rates.

This work relates to the literature concerned with quantifying the economic effects of an aging population. Contributions include Auerbach & Kotlikoff (1984, 1987, 1990, 1992), Auerbach, Kotlikoff, Hagemann, & Nicoletti (1989), Auerbach, Cai, & Kotlikoff (1991), and Ríos-Rull (1992b). This literature accounts for the economic effects of demographic transitions in a general equilibrium framework. But the role for immigration has not been explored in this setting, and immigrants have not been separated as distinct agents. Since immigrants to the U.S. differ significantly from natives (see e.g. Chapter 2 and Borjas (1990)), distinguishing immigrants from natives may be quantitatively important.

3.2 The model

3.2.1 Law of motion for the population

The economy is populated by agents that live up to I periods. Agents of age i differ in national origin (domestic or foreign), and, if immigrant, age at time of immigration. The "type" of an agent in the economy is denoted by im, where i is age and m is the age at time of immigration ($m = 0$ indicates native-born). The key difference between immigrants and natives in the model is in the labor productivity. Note that the productivity of immigrants is strongly influenced by m, see Chapter 2 and Friedberg (1993). Children of immigrants (born after their parents immigrated) are assumed to be identical to natives. Findings in Borjas (1992) indicate that it may take several generations for the skills of descendants of immigrants to converge to the skills of natives, though second generation immigrants look much more like natives, in terms of skills, than do their parents.

Agents face longevity uncertainty. Conditional on being alive at age i, the probability of surviving to age $i+1$ for a type im agent is $s_{i,m}$. The number of births at time t, $\mu_{1,0,t}$ are given by the stochastic type-specific fertility rates $\phi_{i,m,t}$. Following Lee (1974) and Ríos-Rull (1992b), the birth process can be approximated by $\mu_{1,0,t} = \sum_m \sum_i \phi_{i,m}\mu_{i,m,t} + z_t$ where $\phi_{i,m}$ are average fertility rates and z_t is an error term proportional to the population.

A basic premise in this paper is that the government chooses who to admit. Borjas (1987) argues that the inflow and attributes of new immigrants are determined by what the US can offer to the newcomers ("self selection"). But the pool of would–be immigrants is very big, though, and the immigration authorities limits the inflow of any type of immigrants. Thus, on the margin, the US government chooses who to admit. The role of government in the model is limited to choose (i.e. commit to) a specific immigration policy in the beginning of time. An immigration policy specifies a fixed age composition of new immigrants and a process for the number of new immigrants.

3.2.2 Preferences, technology and market structure

Agents derive utility from consumption of a standard good. Preferences are time separable. The instantaneous utility takes the form $u(c,n)$, where c is the current consumption, n is time spent working in the market, and $u(.)$ is strictly concave and increasing. At a certain age all agents retire. Immigrants and natives are assumed to have the same preferences. The role of children is minimized in the sense that they make no economic decisions in the model economy, and do not consume. Furthermore, agents do not care about their children and have no bequest motives. An adult agent of age τ then maximizes his expected utility over the remaining lifetime, given by

$$\max_{\{c_t,n_t\}} E_\tau \sum_{t=\tau}^{I} \beta^{t-\tau}\pi_{t,m}u(c_t,n_t)$$

subject to the intertemporal budget constraints. $\pi_{t,m}$ is the probability for an agent of type m to be alive at age t (so $\pi_{t,m} \equiv \prod_{j=m}^{t-1} s_{j,m}$).

Production is given by a standard neoclassical production function $f(K,L)$ with constant return to scale and labor N and capital K as inputs. The good produced is used for consumption and investment in new capital. The labor productivity of an agent is measured in equally productive efficiency units[1]. The aggregate labor

[1] This implies that native and immigrant labor are perfect substitutes. There is some support for this assumption in the literature, see Borjas (1990).

input L is the sum of efficiency units supplied, i.e. $\sum_{i,m} e_{i,m} n_{i,m} \mu_{i,m}$, where $n_{i,m}$ is time spent working and $e_{i,m}$ is the number of labor efficiency units for agents of type im. Firms rent labor and capital from the agents at given wage rate W and interest rate R each period (on a spot market). The firms solve the problem

$$\max_{K,L} \{f(K,L) - (R+\delta)K - WL\}$$

where δ is the depreciation rate.

While an individual agent faces longevity uncertainty, there is no aggregate uncertainty about deaths.[2] The risk for an agent of dying with non-zero wealth is hedged on perfect annuities markets. One way to implement these markets is to let agents write contracts with members of their own type, where the surviving agents share the wealth of those who died. The recursive budget constraint for agent im is then

$$We_{i,m} + (1+R)a = c + s_{i,m}a'$$

where a and a' are the agent's holdings of capital this and next period, respectively.

Markets are incomplete, however, in that agents cannot write contracts on the future shock to fertility and immigration policy. Findings in Ríos-Rull (1994) indicate that the difference between this economy and a complete market version are not quantitatively important.

3.2.3 Recursive formulation of the problem

The aggregate state of the economy is given by

1. The distribution of population (the number of people of each type): $\mu \in \mathbf{R}^{M_1}$, where M_1 is the total number of different agents (including children).
2. A vector $z \in \mathcal{Z}$ containing lagged values of the immigration and birth processes necessary to form expectations of the future path of these processes.
3. The distribution of capital (how much capital is owned by agents of each type): $k \in \mathbf{R}^{M_2}$, where M_2 is number of economically active agents (adults).

[2] Recall that the probability of surviving till next period for a type i,m agent is $s_{i,m}$. Since there is a continuum of agents, this fraction of type i,m agents will survive.

An agent's state variable is then his/her private capital, $a \in \mathbf{R}$, plus the aggregate state variables $(\mu, z, k) \equiv x \in \mathbf{R}^{M_1} \times \mathcal{Z} \times \mathbf{R}^{M_2} \equiv \mathcal{X}$. Let $\Gamma(x)$ denote the law of motion for μ and let the law of motion for z be given by the stochastic process $F(z' \mid x)$.

3.2.4 Equilibrium

Following Prescott & Mehra (1980), Ríos-Rull (1992b) among others, the recursive equilibrium is defined as

1. A price function $p(x) \in \mathbf{R}^2$ that computes the wage rate and interest rate, and functions $L(x) \in \mathbf{R}_+$ and $K(x) \in \mathbf{R}_+$ computing aggregate labor and capital.
2. A set of individual decision rules:
   - Asset holdings: $a'_{i,m}(x,a) \in \mathbf{R}$.
   - Work effort: $n_{i,m}(x,a) \in [0,1]$.
3. A set of value functions $v_{i,m}(x,a) \in \mathbf{R}$.
4. A law of motion for the distribution of capital, $A(x) \in \mathbf{R}^N$.
5. A function H describing the work effort of each agent, $H(x) \in [0,1]^N$.

such that for all $(x,a) \in \mathcal{X} \times \mathbf{R}$ the following holds:

a) The rental prices for labor and capital, W and R_k, given by the price function p clear the markets for capital and labor (firms maximize their profits),

$$\begin{aligned} \frac{\partial z f(K(x), L(x))}{\partial K} &= W(x) \\ \frac{\partial z f(K(x), L(x))}{\partial L} &= R(x) + \delta \end{aligned}$$

b) The goods market clears

$$f(K(x), L(x)) + (1-\delta)K(x) = \sum_{i,m} \mu_{i,m} c_{i,m}(x, A_{i,m}) + \Gamma(x)^T \cdot A(x)$$

where $c_{i,m}$ is agent i,m's consumption:

$$c_{i,m}(x, A_{i,m}) = W(x) e_{i,m} n_{i,m}(x, A_{i,m}) + (R(x)+1)A_{i,m} - s_{i,m} a'_{i+1,m}(x, A_{i,m})$$

c) Given the price functions and value functions, the decision rules $a'_{i+1,m}(x,a)$ and $n_{i,m}(x,a)$, solve agent (i,m)'s objective function,

$$\max_{a',n} \{u_{i,m}(c) + \beta s_{i,m} \int_{z'} v_{i+1,m}(\Gamma(x), z', A(x), a') dF(z' \mid x)\}$$

subject to

$$c + s_{i,m} a' = W(x) e_{i,m} n + (R(x)+1) a$$

d) The agents are using appropriate value functions. Thus, given price functions, decision rules and aggregate laws of motion for population and capital, for any state variables $(x,a) \in \mathcal{X} \times \mathbf{R}$ the following holds:

$$\begin{aligned} v_{i,m}(x,a) &= u_{i,m}\left(c_{i,m}(x,a)\right) \\ &\quad + \beta s_{i,m} \int_{z'} v_{i+1,m}\left(\Gamma(x), z', A(x), a'_{i+1,m}(x,a)\right) dF(z' \mid x) \end{aligned}$$

e) The law of motion for the distribution of capital is consistent with individual decision rules, i.e. for each m

$$A_{m,m}(x) = 0$$

$$A_{i,m}(x) = a'_{i,m}(x, A_{i-1,m}) \qquad i \in \{m+1, \ldots, I\}$$

where $A(x) = (A_{1,0}(x), \ldots, A_{I,I}(x))$.

f) The rule for agents' work effort is consistent with individual decision rules, i.e. for each m

$$H_{i,m}(x) = n_{i,m}(x, A_{i,m}) \qquad i \in \{m, \ldots, I\}$$

where $H(x) = (H_{1,0}(x), \ldots, H_{I,I}(x))$.

g) Aggregate functions K and L are generated by population, debt, wealth distribution, and the rule for agents' work effort:

$$\begin{aligned} K(x) &= \sum_m \sum_i \mu_{i,m} A_{i,m} \\ L(x) &= \sum_m \sum_i \mu_{i,m} e_{i,m} H_{i,m}(x) \end{aligned}$$

3.2.5 Approximation

This problem does not have a closed form analytical solution (except for some special choices of preferences and technology), so the problem must be solved numerically. Since the problem has so many state variables, methods relying on discretizing the state space are prohibitively expensive. Instead, I follow the approach of Ríos-Rull (1992a, 1992b, 1994) which I describe below.

The key problem is to find a law of motion for asset holdings, $A(x)$, and a rule for agents' work effort, $H(x)$, that are consistent with individual behavior (equilibrium conditions e) and f), which are equivalent to impose rational expectations). The equilibrium rules $A(x)$ and $H(x)$ are found by iterating on the agents' expectations: For an initial set of expectations (not necessarily rational), compute the optimal decisions of each agent. Use the new individual decision rules as a new guess of agents' expectations. A fixed point of this mapping is a set of rational expectations.

The central trick to find the fixed point is to make a linear-quadratic approximation of the agents' utility functions and to restrict the law of motion of population, $\Gamma(x)$, to be linear in the state variables. Agents' optimal decision rules are then linear, and each iteration can be reduced to linear algebra. I demonstrate in the appendix that the equilibrium law of motion for the approximated economy is linear, and the algorithm is described in detail there. Finding the equilibrium for the calibrated economy takes about 2 hours on an HP 715.

3.3 Parameterization of the model economy

The model economy is calibrated to US data. The parameter choices are described in detail below.

3.3.1 Population parameters

One period in the model is taken to be 5 years. Each agent can live up to 18 periods and retires after period 13 (i.e. agents retire at age 65 and die before 90). The age of new immigrants (at arrival) is restricted to be 2, 7, 12, 17, 22, or 37, and the distribution is fitted to the average age distribution for new U.S. immigrants during the 1982-88 period (plotted in Figure 1 of Chapter 1. Note that adding more possible arrival ages is computationally very expensive.

Using data from the 1980 and 1990 Censuses, I estimate the fertility of immigrants to be about 50% higher than for natives (see Chapter 2). The age-specific average fertility rates for U.S. natives are estimated by averaging over the 1960-90 time period. Lee (1974) found that the error term for the US birth process can be represented by an AR(2) process. This specification fitted well also for the 1960-90 period. The estimated coefficients are $\rho_1 = 1.28$ and $\rho_2 = -0.65$ and the standard deviation of the white noise is 0.15% of the population. The R^2 of the regression is 0.86. Ríos-Rull (1992b) found that a similar process (AR(2) with complex roots) fitted well for Spanish data. I assume that immigrants face the same age specific mortality rates as natives. Mortality rates are fixed at the 1988 U.S. levels.

3.3.2 Current immigration policy.

In order to quantify the effects of changing the immigration policy, I need to model the current immigration regime. As argued in section 2.5, a desirable property of this process is that it be linear in the state variables. I model the immigration policy process as a term proportional to the population plus an innovation term d_t.

$$b_t = \eta \sum_{i,m} \mu_{i,m} \ + d_t$$

where b_t is the number of new immigrants in period t. I restrict the age distribution of new immigrants to be fixed over time. In the simulations I use the average distribution during the 1982-88 period. The innovation term d_t is normalized with the average growth rate in population (during the sample period) in order to ensure stationarity of the d_t process. This is not an arbitrary choice since U.S. immigration policy always has been restrictive after big hikes in immigration, see Borjas (1992).[3] Annual data on legal immigrants are published in the INS Statistical Yearbook, and I estimate illegal immigration as a fixed fraction of apprehended aliens (also published in the INS Yearbook).

The d_t process could potentially depend on a lot of observable and unobservable variables like real wages, past immigration, general receptiveness towards immigrants in host country, etc. Trying with a long array of observable series (growth rates in real wages and GNP per capita, unemployment rate, lagged values of d, the ratio of retirees to workers) in an ARMA framework, the only variable I found to explain d_t is lagged values of d.

[3] Immigration to the U.S. was restricted in the 1870s (curbing Chinese immigration to western states), in 1917 (after the great wave of immigrants at the turn of the century), and it is to some extent happening today, for example through Proposition 187 and major efforts to stem illegal immigration in California.

Using data from 1965[4] to 1992, I estimate η to be 0.28% per year, which corresponds to 714,000 immigrants in 1992 (actual immigration to the US in 1992 was 1,000,000-1,100,000, including illegal immigration). I found that an AR(1) fitted well for the d_t process, with an annual persistence of 0.87 and a standard deviation of the error term of 0.03% of the population (corresponds to 75,000 in 1992). The estimation procedure is described in detail in the appendix, and the projected future immigration is plotted in Figure 2.

The resulting annualized (steady state) growth rate of the population under the status quo immigration policy is 0.73%. For comparison, the annual growth rate with no immigration is 0.3%, and with twice the current level of immigration (i.e. η twice as big), the growth rate is 1.12%.

3.3.3 Preferences

The instantaneous utility of any agent is assumed to take the form

$$u(c,n) = \frac{(c^{\alpha}(1-n)^{1-\alpha})^{1-\rho}}{1-\rho}$$

This functional form implies a unit elasticity of substitution between consumption and leisure, which is supported by fairly constant yearly hours in the postwar period. The parameter α is set to 0.33. Ríos-Rull (1992a) finds that this value yields life cycle patterns of agents' work effort consistent with U.S. data. The inverse of the intertemporal elasticity of substitution, ρ, is 4 as in Ríos-Rull (1992b). The time preference parameter β is set to 1.011 (annualized), based on estimates from Hurd (1989).

3.3.4 Technology and efficiency unit profiles

Accounting for the differences in labor productivity between natives and immigrants is crucial when quantifying the effects of immigration. This work was done in Chapter 2, and based on the 1990 Census and several issues of the INS Statistical Yearbook. The estimates of wage profiles of natives and of immigrants are used as efficiency unit profiles in the model. The estimated wage profile of immigrants who come at age 27 implies that these immigrants earn on average 11% less than natives over their remaining lifetime. Borjas (1990) and others find the difference in earnings to be bigger. Since the public finance implications of immigration

[4] I chose 1965 because this was the last time the immigration policy underwent a fundamental amendment, see Borjas (1992) . To evaluate the time series properties of the savings rate, I estimate the immigration policy using data from 1869 to 1992, the years that data on the savings rate are available. The resulting autoregressive process is similar to the one estimated from 1965–92 data, but with much higher variance of the shocks.

is sensitive to wage income of natives, I also try with an alternative earnings profile where immigrants earn 20% less than natives.

A big share of the migration to the US is in the form of illegal immigration. Passel (1986) estimates the number of illegal immigrants in the US in 1986 to be between 3 and 4 million, or 20% to 25% of all foreign born residents in the US. Illegal immigrants are potentially very different from legal immigrants, and distinguishing between these types could be important for the question I want to address. The Census surveys do not identify the legal status of immigrants, however. So, any labor–wage estimate based on the Census data will describe some composite of legal and illegal immigrants. I assume that the illegal immigrants share in total immigration has been constant during the post war period and will continue to be so in the future. Estimates of labor–wage profiles of immigrants (ignoring the heterogeneity in legal status) would then identify labor–wage profiles of future immigrants. The ratio of legal to illegal[5] immigrants is plotted in Figure 1 in the appendix. I use these estimates as efficiency unit profiles for the agents in the model economy.

Assume a standard neoclassical Cobb-Douglas production function taking labor and capital as inputs, $Y = zK^{\theta}L^{1-\theta}$. The parameter θ is set to capital's share of income. Using data from the National Income and Product Accounts and measuring U.S. capital as fixed capital plus inventories plus government capital plus consumer durables, Cooley & Prescott (1995) estimates capital's share of income to be 40%.

Based on estimates in Bureau of Economic Analysis (1987) the aggregate depreciation rate on capital in the US is 7.8%. The average annual growth in US GNP per capita has been 1.5% over the last two decades. The rate of technological growth (growth in z) is set to match this figure in steady state.

3.3.5 Initial conditions

I use the 1991 distribution of natives and immigrants as initial condition for the population. The innovation term for 1991 of the estimated immigration process and the fertility process provide starting points for d and z

Auerbach et al. (1989) generate the 1989 distribution of assets by starting in steady state in 1960 and simulating the economy until 1989 under perfect foresight about the demographic changes. A generalization of this idea to a setting with uncertain fertility is to simulate the calibrated economy over a large number of periods, hitting it with shocks to fertility and immigration until the model population distribution happens

[5] The number of illegal immigrants are based on my own estimates, see the appendix.

to be "close" in an Euclidean sense to the 1991 US distribution. The capital holdings in the last period is taken to be the 1991 asset distribution for the model economy. This corresponds to "endogenous assets" in Ríos-Rull (1992b). I test how sensitive the results are to this parameterization of the asset distribution by trying a more arbitrary alternative: the steady state capital distribution.

3.4 Results

I define savings as net production less consumption. The corresponding figure for the US economy is computed as net national product less private consumption expenditures less government purchases of goods and services. The savings rate is savings to net production.

Solving for the competitive equilibrium of the calibrated economy (under the current immigration policy) and shutting down future shocks to immigration and fertility yields a projection of the future savings rate, which is plotted in Figure 1. The savings rate starts out at 12.4%, falls temporarily, and reaches a peak of 12% in 2006, and falls to 8.4% in 2036. The timing of the peak is consistent with Auerbach et al. (1991), but in contrast with e.g. Auerbach et al. (1989) (who predict a steady decline in the US savings rate).

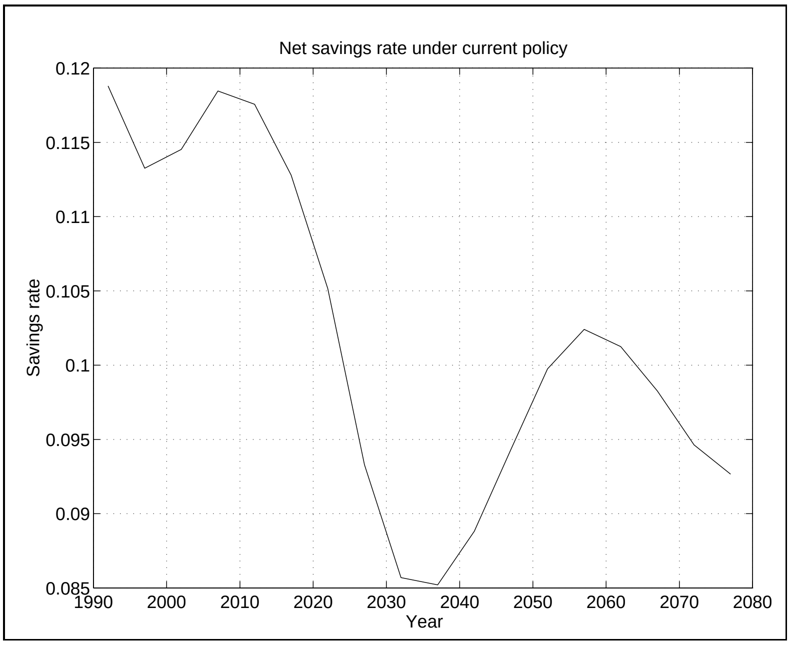

Figure 3.1: Savings rate predicted by the model under the current US immigration policy.

According to NIPA data, the U.S. savings rate was around 3% during the 1989-91 period. The discrepancy with the model's predictions does not necessarily imply that this is a bad model of saving. First, the model abstracts from government, which should rise the savings rate.[6] The benchmark economy in Chapter 4 has a government but is otherwise similar. The savings rate in that economy is 3% points lower in the initial period. Second, as Auerbach et al. (1991) point out, NIPA mismeasures the national savings rate because it does not account for services from the stock of government capital and the stock of consumer durables. They find the real savings rate to be 3-4% points higher than the NIPA measurements indicate.

3.4.1 Effects on savings rate from changing the immigration policy.

One end of this chapter is to quantify how sensitive the savings rate is to changes in the immigration policy. I measure this by quantifying how much the savings rate under some alternative immigration policy regimes would move away from the savings rate path under the current policy regime. I explore 3 alternative policy changes:

1. Shut down all future immigration.
2. Increase the future immigration to twice the current level.
3. Sustain the current number of immigrants, but admit only young ones.

These alternatives mimic suggested amendments to the current immigration policy: Huddle (1994) suggests a drastic reduction in the inflow of new immigrants. Simon (1989) advocates a sharp increase in the immigration quotas, while Borjas (1990) and others propose changes in the composition of new immigrants, favoring admission of high-skilled and young immigrants. I use the initial conditions and shut down future shocks to generate a future path for the savings rate under each policy.

Figure 2 and Figure 3 shows projected immigration and savings rate under each of the policy alternatives. For this set of initial conditions, all experiments project a hump in savings rate in 2006–2011, and then a tough in 2036–2041. Figure 4 plots the changes in the savings rate under each regime, relative to the savings rate under the current policy.

[6] The mere fact that the government eats a chunk of output lowers the savings rate since there is less to save and consume from. Also, possible distorting taxes on capital would lower the capital stock (and thus the savings rate), and in an unfunded pay-as-you-go social security system reduces the incentives to save for retirement.

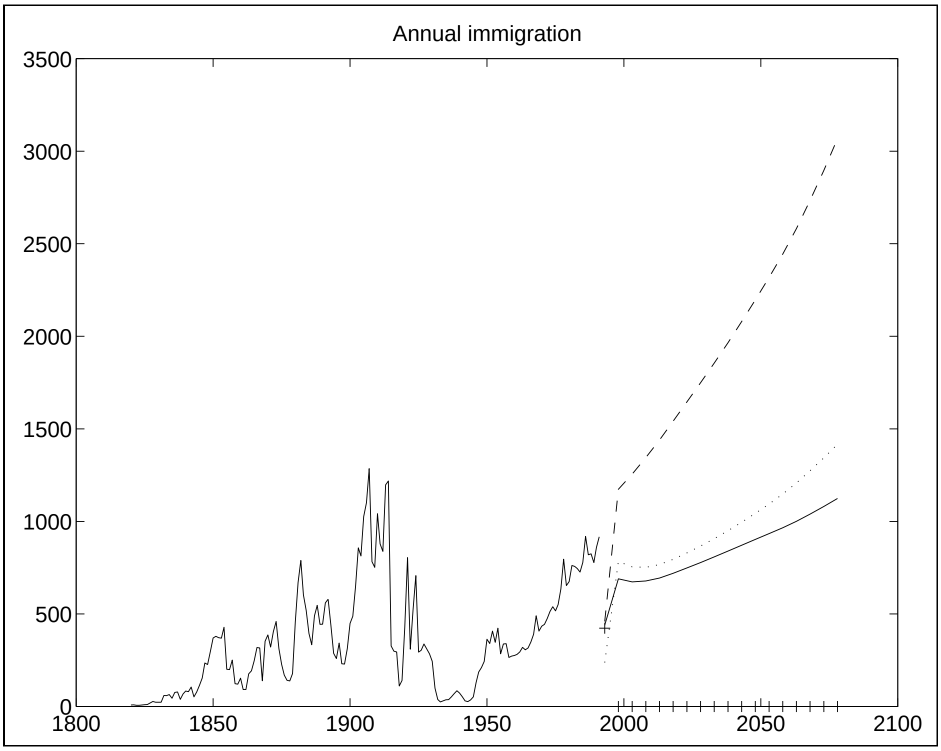

Figure 3.2: Historical immigration 1820 to 1991, and expected immigration under the current immigration policy (solid line), and policy alternatives 1 (on the x axis), 2 (dashed line), and 3 (dotted line). The figures are annual.

The savings rate is projected to fall (relative to the savings rate under the current policy) by 0.5% points immediately after a change to policy alternative 1. Over the next 50 years this difference will increase to about 1.5% points. The intuition for this is that the population is aging faster without immigration. Wages would rise by more than 1% if the immigration policy is changed to policy alternative 1, which would tend to rise savings in the economy. This effect is not enough to offset the effect of the faster aging of the population, though.

A change to policy 2 will induce an instant increase in the savings rate of 0.4%, relative to the savings rate under the current policy. The difference will grow to about 1.4% points by year 2041. A change in the age structure of new immigrants, to policy 3, generates a savings rate slightly below the savings rate under the current policy for the first 30 years. But from year 2021 on, the projected policy 3 savings rate quickly rise 0.8% points above the benchmark savings rate. A child does not work and will not start accumulating capital until, say, age 27. A 37 year old new immigrant starts saving immediately. Allowing only young immigrants

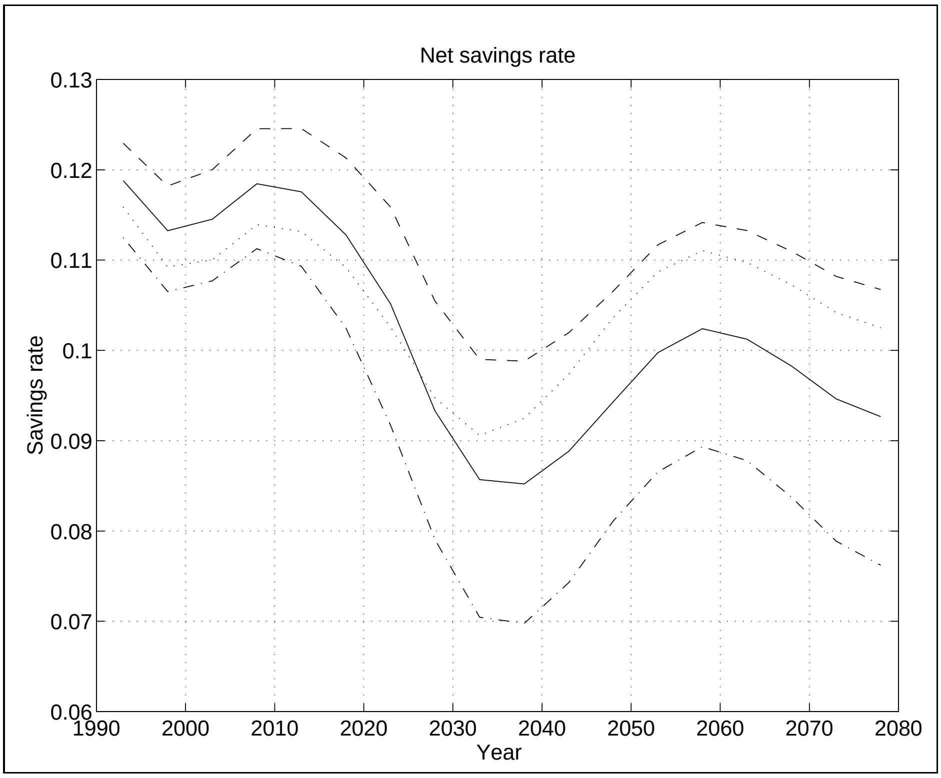

Figure 3.3: Savings rates predicted by the model under the current immigration policy regime (solid line), and policy alternatives 1 (broken dashed line), 2 (dashed line), and 3 (dotted line).

would therefore lower the savings rate in the beginning, and increase it later since the ratio of labor force to retirees is higher than under the current immigration policy.

I find that the results are not sensitive to using the steady state distribution of assets as initial asset distribution instead of the endogenously generated one. The results are also robust to a 10% lower earnings profile for immigrants.

3.4.2 Welfare effects from changing immigration policy

The welfare effects of immigration is an important and politically hot issue: Who gains and who loses? The model in the current chapter can pick up the welfare effects that stem from changes in prices due to a change in immigration policy (i.e. the rise in interest rate and fall in wage rate that accompany a rise in immigration). Figure 5 shows the predicted relative change in interest rate when switching from the current immigration

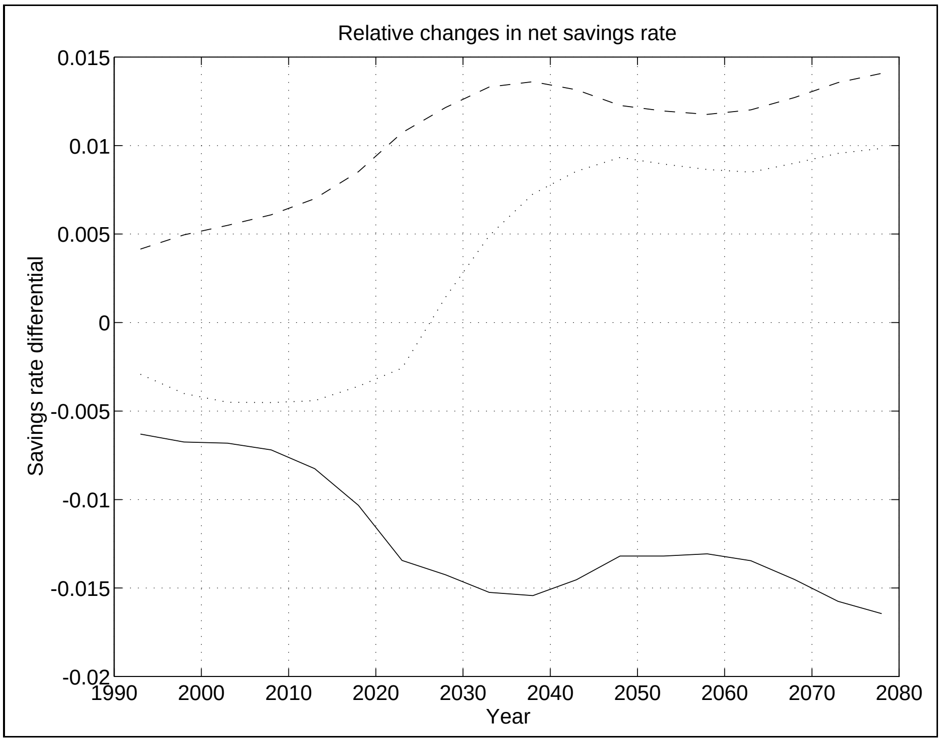

Figure 3.4: Deviation from the savings rate generated by the current immigration policy. Solid line represents zero immigration, dashed line is double immigration, and dotted line is only young immigrants.

regime. There is no government in this chapter, so public finance effects of immigration are dealt with in Chapter 4.

The welfare effects are computed as the additional amount of assets each agent must be endowed with to be indifferent between keeping the current immigration policy and switching to policy alternative 1. The compensation is measured in terms of GNP per capita and is shown in Figure 6. I find that all native adults lose on closing down immigration. Retirees of age 65 suffer the biggest loss: 25% of annual GNP. The intuition is that the increase in wages (from closing down immigration) cannot compensate capital owners for the fall in interest rates. The size of the effects should not surprise. Asset holdings for a newly retired person, for instance, are 12 times annual GNP per capita, so even a small decline in the interest rate is very painful. Note that future generations gain a lot (15% of annual GNP) from the flow of immigrants being shut off today.

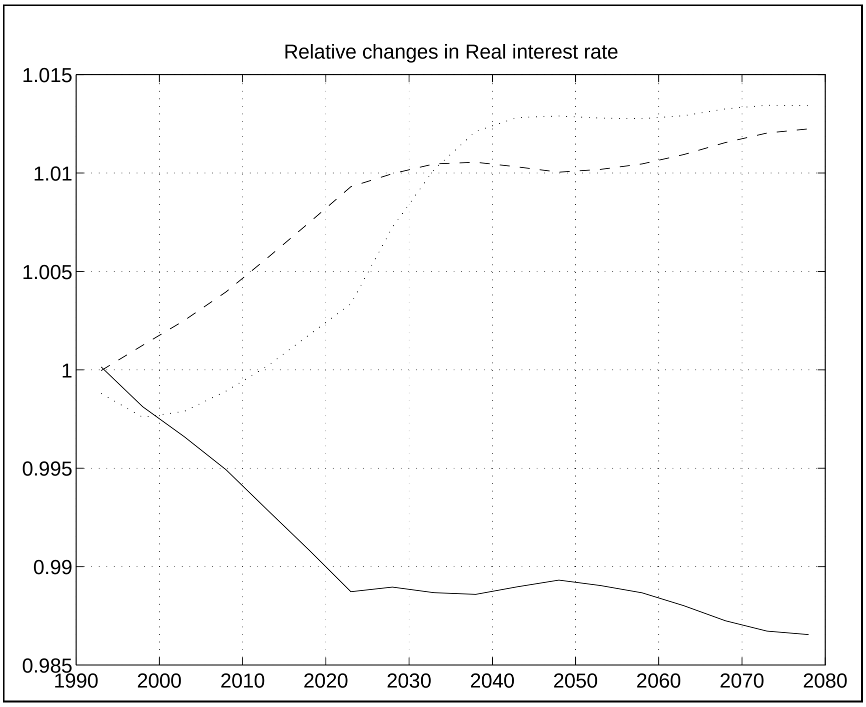

Figure 3.5: Deviation from the interest rate generated by the current immigration policy. Solid line represents zero immigration, dashed line is double immigration, and dotted line is only young immigrants.

3.4.3 Fraction of fluctuations explained by immigration.

To measure what fraction, ν, of the fluctuations in savings rate that can be accounted for by shocks to immigration policy, I follow the same approach as Prescott (1986) uses to find how much of the volatility in output that can be explained by technological shocks. ν is estimated as the ratio of variance in the savings rate for the benchmark economy to the variance in the US savings rate.

The standard deviation and autocorrelations of the US savings rate (5–year averages) during the period 1869 to 1988 is shown in Table 1. I run 4000 samples of the benchmark economy,[7] each of length 24 periods, where shocks to the immigration process is the only source of aggregate uncertainty. Second moments for the savings rate are reported in Table 1. The standard deviations in savings rate for the US economy and the model economy are 4.5% and 0.24%, respectively. Thus, shocks to immigration seem to account for $\frac{0.24}{4.5} = 5.3\%$ of the fluctuations in 5-year savings rates. The model economy exhibits a somewhat higher autocorrelation of

[7] The time period used to estimate the immigration process here is 1869 to 1992, as opposed to 1965 to 1992 for the rest of the paper.

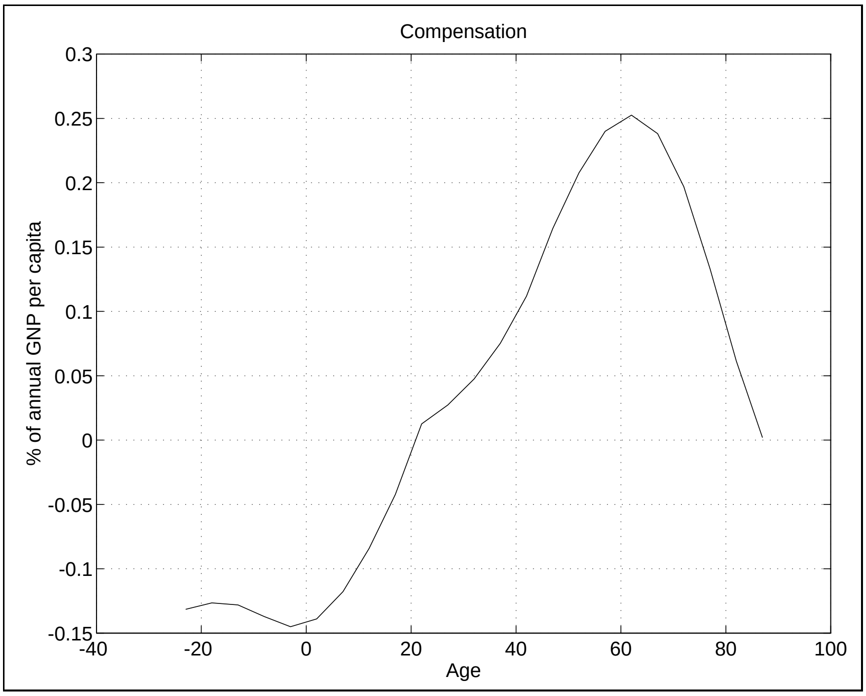

Figure 3.6: Compensation (measured in terms of annual GNP per capita) needed to make each agent indifferent when switching from current immigration policy to policy alternative 1 (closing down all immigration).

savings rates than the U.S. economy when shocks to immigration is the only source of uncertainty. The first order autocorrelation in the U.S. economy is 0.42, while it is 0.78 for the benchmark economy.

3.5 Summary

This paper investigates the link between the immigration policy and the national savings rate. I included immigration explicitly in a (general equilibrium) overlapping generations framework, and could thus give a projection of the future US savings rate consistent with the current immigration policy. This approach also allowed me to address whether immigration is a quantitatively important determinant of the savings rate or not. The results indicate that reasonable changes in the immigration policy can have a quite big effect on the aggregate savings rate, and that shocks to the immigration process may explain about 5% of the fluctuations in the savings rate.

Two possible extensions of the paper are to include a government sector, and to include a "neighbor country" in the model, that emit immigrants and can borrow and lend from the "home country".

3.6 Appendix

3.6.1 Numerical algorithm for computing individual decision rules

The purpose of the following algorithm is to compute numerically the competitive equilibrium of the model economy.

The aggregate state of the economy, S, is given by $S = (\mu, z, K) \in \mathbf{R}^N \times \mathcal{Z} \times \mathbf{R}^N$, where N is the number of agents, μ is the distribution of agents, K is the distribution of capital, and z is lagged values of the immigration and fertility processes. The state variable for an agent is then (S, a) where a is the capital held by the agent. Each period the agent makes a decision $d = (a', n)$, where a' is assets next period and n is labor supply in the current period. The law of motion for the population, Γ, is a linear function of μ and z. The law of motion for the distribution of capital is $K' = G(S)$ and the distribution of labor is $N = H(S)$.

Preferences and technology are known, and so is Γ. The functions G and H are not known, however, and the algorithm below describes how to find them. A necessary and sufficient condition for a pair of functions $(G^*, H^*) \in \mathcal{A}$ to equal (G, H) is that (G^*, H^*) are consistent with individual behavior[8] (i.e. when the agents take H^* and G^* as given then in state S the realized labor supply and law of motion for capital will be exactly $H^*(S)$ and $G^*(S)$). A mapping $\phi : \mathcal{A} \to \mathcal{A}$ is defined as follows: $\phi(\hat{G}, \hat{H})$ are the laws of motion for capital and the labor supply (as a function of S) that would occur in the economy if the agents believe that (G, H) are given by $(\hat{G}, \hat{H})$. By construction a fixed point of the mapping ϕ satisfies the consistency condition above, and it is found by iterating on ϕ.

The Algorithm.

First, compute the steady state of the economy in a standard way. The first order and market clearing conditions give an equation in the capital to output ratio which is solved numerically.

Second, for all types (i, m), make a quadratic approximation of the instantaneous utility $u(c, n)$ of agent (i, m) around his steady state allocation (where c is substituted with the agent's budget constraint). Recall that subscript $i \in \{1, .., I\}$ represents age and subscript $m \in M$ represents age at time of immigration ($m = 0$ indicates native born). The approximation can be expressed by a square matrix $R_{i,m}$ as $(S, a, N, d)\ R_{i,m}\ (S, a, N, d)^T$ (where S from now on includes a constant, $S = (1, \mu, K)$).

[8] $\mathcal{A}$ is the set of functions f such that f maps $R^{2I} \to R^{2I}$, e.g. if $f = (G, H)$ then $f(S) = (K', N)$.

Third, iterate on ϕ to find a fixed point consistent with individual behavior. An iteration on ϕ is given by the 4-step procedure below:

Step 1 Start with a guess of G and H as linear functions of S, i.e. $K' = G * S$ and $N = H * S$.

Step 2 Find the value function and the optimal labor supply for the oldest agents in the economy, imposing the restriction that $a' = n = 0$ (they are retired and cannot die indebted). Thus,

$$V_{I,m}(S,a) \quad = \quad (S,a,N,0,0)R_{I,m} \begin{pmatrix} S \\ a \\ N \\ 0 \\ 0 \end{pmatrix}$$

Since H by construction is linear in S, the vector (S,a,d) can be converted to (S,a,N,d) by a linear transformation B_H: $B_H * (S,a,d)^T = (S,a,N,d)^T$. Thus,

$$V_{I,m}(S,a) \quad = \quad (S,a,0,0)B_H^T\ R_{I,m}\ B_H \begin{pmatrix} S \\ a \\ 0 \\ 0 \end{pmatrix}$$

Note that the value function $V_{I,m}$ is quadratic in the state variables, i.e. $V_{I,m}(S,a) = (S,a) * V_{I,m} * (S,a)^T$.

Step 3 Taking $V_{I,m}$, G, and H as given (and imposing $n = 0$ if the agent is retired), $V_{I-1,m}$ is then computed as

$$V_{I-1,m}(S,a) \quad = \quad \max_d \left\{ (S,a,N,d)R_{I-1,m} \begin{pmatrix} S \\ a \\ N \\ d \end{pmatrix} + \beta(S',a')V_{I,m} \begin{pmatrix} S' \\ a' \end{pmatrix} \right\}$$

The laws of motion Γ and G are linear in S, so the vector (S,a,d) can be converted to (S', a') (the state variable tomorrow) by a linear transformation
$C_G : C_G * (S,a,d)^T = (S',a')^T$. Thus,

$$\begin{aligned} V_{I-1,m}(S,a) &= \max_d \{ \quad (S,a,d) B_H^T \, R_{I-1,m} \, B_H \begin{pmatrix} S \\ a \\ d \end{pmatrix} + \\ & \qquad \beta (S,a,d) C_G^T \, V_{I,m} \, C_G \begin{pmatrix} S \\ a \\ d \end{pmatrix} \} \\ &= \max_d \{ \quad (S,a,d) \left[B_H^T \, R_{I-1,m} \, B_H + \beta C_G^T \, V_{I,m} \, C_G \right] \begin{pmatrix} S \\ a \\ d \end{pmatrix} \} \end{aligned}$$

Note that now the objective function is quadratic in (S,a,d). Thus the optimal decision $d_{I-1,m}$ must be linear in (S,a) and hence $V_{I-1,m}$ must be quadratic in (S,a), i.e. $V_{I-1,m}(S,a) = (S,a)V_{I-1,m}(S,a)^T$. Roll backwards to compute $V_{i,m}$ and $d_{i,m}$ in the same way for $i \in \{m,..,I-2\}$. By a recursive argument $d_{i,m}$ is linear in (S,a) for all i.

Step 4 Impose the representative agent condition (i.e. that individual assets for agent (i,m) equals $K(i,m)$) by transforming the linear decision rule of agent (i,m): add the coefficient of individual assets to the coefficient of $K(i,m)$. Then the decision rules can be written as linear functions of the aggregate state only. These decision rules constitute the new choices of $G(S)$ and $H(S)$ and complete the iteration (note that the new G and H are linear in S).

The iteration process terminates when the new choices of (G,H) are sufficiently close (in an Euclidean sense) to the (G,H) in step 1. I use 10^{-8} as a stopping criteria (i.e. stop iterating when the maximum change in (G,H) is less than 10^{-8}).

3.6.2 Estimating the Process of Immigration.

The time t inflow of age k immigrants, $b_{k,t}$, is modelled as

$$b_{k,t} = \sum_{i,m} \eta_{k,i,m} \mu_{i,m,t} \; + d_{k,t}$$

where $\eta_{k,i,m}$ is the number of new age k immigrants per type im agent at time t, and $\mu_{i,m,t}$ is a measure of type im agents, and $d_{k,t}$ is the (stationary) deviation from trend. The task of this section is to estimate the parameters $\eta_{k,i.m}$, and the process of d for the current (status quo) immigration policy.

Data

By immigration to the US I mean legal plus illegal immigration. The data on the number of legal immigrants and their age are published annually by the Immigration and Naturalization Service. Data on illegal immigrants are not easily available, however. I estimate the number of illegal immigrants in a given year as a fixed fraction of illegal aliens required to leave the US. This is of course an imperfect measure since the number of detected illegal aliens depends heavily on the effort made by the INS, and since illegal aliens often make new attempts to enter if they are caught. I set this fraction to 20%, the ratio of illegal immigrants residing in the US in 1986 (roughly 4 million, according to Passel (1986)) to the number of illegal immigrants required to depart since 1941 (20 million). This is probably a low estimate, since some of illegal aliens who entered during this period are dead and some have returned to their home countries.

The immigration policy has changed a lot over the last 170 years (see figure 1). To estimate the *current* immigration policy, I sample the period 1965–1992, because the last significant change was in 1965 (see Borjas (1992)). To evaluate the time series properties of the savings rate, I estimate the immigration policy using data from 1869–1992, the years that I have data on the savings rate.

The Process

To reduce the number of parameters to estimate, I restrict the contribution to immigration to be the same for every type, i.e. $\eta_{k,i,m} = \eta_k$ for each type im. Ideally, I would like to estimate a process for each age group k. However, estimating the age of illegal immigrants is very hard. For simplicity I therefore assume that the future age distribution of new immigrants is the same as the 1988 distribution. The age distribution of legal immigrants is plotted in figure 5. The immigration of age k immigrants in period t is then $b_{k,t} = \omega_k(\eta \sum_{i,m} \mu_{i,m} + d_t)$ where ω_k represents the age k share of immigration.

η is then estimated as the average ratio of new immigrants to total population, which is 0.28% and 0.51% for the periods 1965–1992 and 1869–1992 respectively.

Using population and immigration data and the estimated η, annual series for d_t are generated. I estimated the d_t process for the period 1965–92 to be:

$$d_t = 0.87\, d_{t-1} + \epsilon_t$$

with ϵ_t iid and $\sim N(0, 0.0003^2)$ (with a population of 250,000,000 the standard deviation corresponds to 75,000 immigrants). The R^2 of the regression is 0.75. For the period 1869–1992 the estimate is

$$d_t = 0.88\, d_{t-1} + \epsilon_t$$

with ϵ_t iid and $\sim N(0, 0.002^2)$. The R^2 is 0.78.

One period in the model economy is 5 years while the estimated process is annual. I therefore approximate the annual process with a 5-year process. This is done by simulating long series of the annual process, convert it to a 5-year process, and then estimate the new process as an ARMA(p,q) process.

Using this procedure for the annual $\{d\}$ process above yields

$$z_\tau = 0.55\, z_{\tau-1} + \epsilon_\tau$$

where z_τ is the converted 5 year process.

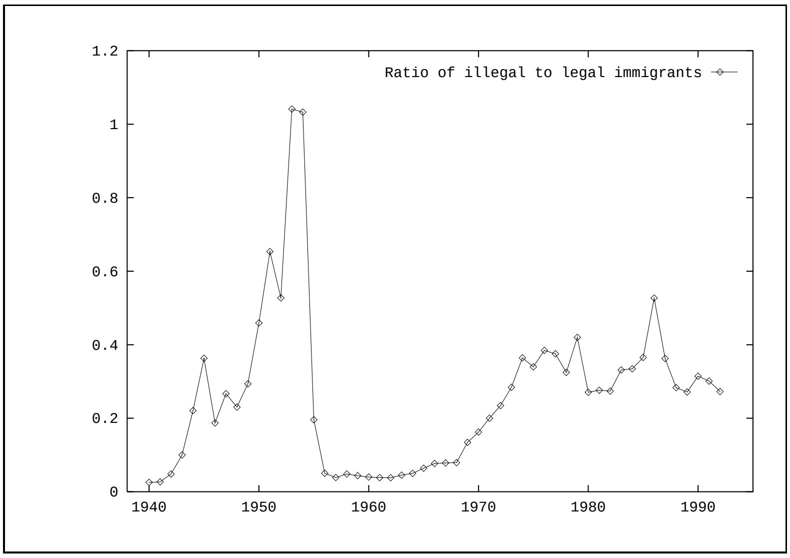

Figure 3.7: Ratio of illegal immigrants (estimated as 20% of aliens required to depart) to legal immigrants, 1940 to 1992.

	Standard deviation	Autocorrelation 1	2	3	4
US 1869-1988	4.5%	0.42	0.27	-0.22	0.20
Model economy	0.24% (.08%)	0.78 (.32)	0.55 (.27)	0.36 (.22)	0.16 (.13)

Table 3.1: Cyclical properties of the savings rate in the model economy and in the US economy, 1869–1988 (5–year averages). (Numbers in parenthesis denote standard deviations of the observations.

Chapter 4

Sustaining Fiscal Policy Through Immigration

4.1 Abstract

It is widely perceived that the U.S. government cannot sustain its current level of public expenditures without increasing taxes at some time in the future. This perceived problem is compounded by the decreasing income tax base and increasing social security obligations that will accompany an aging population. An alternative to adjusting fiscal policy is changing immigration policy. On average immigrants are younger than natives and therefore change the age structure of the population. A general equilibrium model is constructed to investigate the possibility of using immigration policy to sustain current U.S. fiscal policy. I show that such policies exist and are characterized by modest changes from the current immigration policy. One particular policy involves admitting 2.4-2.8 million young immigrants into the U.S. annually until the year 2030 and approximately 0.44% of the population thereafter. For comparison, annual immigration to the U.S. is 1.1 million.

4.2 Introduction

Many economists believe that maintaining public expenditures at current levels with no increase in taxes is not a feasible policy for the U.S. government. Social security, which is an important part of fiscal policy, transfers wealth from the young to the old. Given the aging of the U.S. population, future social security payments will represent a significant liability for the government (see e.g. Aaron, Bosworth, & Burtless (1989)). Combining this future liability with the current budget deficit, a future with higher taxes and/or fewer public services might seem inevitable.

However, the ability to sustain fiscal policy cannot be disentangled from choice of immigration policy. Immigration policy determines the number and composition of new immigrants. If a policy specified that only young immigrants would be accepted, it would change the domestic age distribution, which could alleviate some problems associated with an aging population.[1] The purpose of this chapter is to investigate whether immigration policies exist that would make current fiscal policy feasible. I find that such policies exist and are characterized by modest changes from the current immigration policy. A particular implementation of one of these policies is to admit 2.4-2.8 million immigrants annually until the year 2030 and revert to the current number of immigrants thereafter. Annual immigration to the U.S. is currently 1.1 million, or 0.44% of the population.

These findings are driven by the following results: Under the current fiscal policy and the immigration policy above, the discounted value of future tax receipts less government expenditures for an additional newborn native is -$ 50,000. The net present value gain for the U.S. government of an additional immigrant (who arrives at age 27) is $ 60,000, taking into account the cost of the immigrant's future offspring.

An inflow of young, working age immigrants affects the government budget through several channels. At first, per capita tax revenues rise and per capita government expenditures fall. Also, debt per capita falls. When the immigrants retire, the impacts on tax revenues and expenditures are reversed. The government budget is also affected through changes in prices due to a rise in the labor-capital ratio. Higher interest rates increase the cost of servicing the public debt, and a fall in wages lowers tax revenues (ceteris paribus), since most of the tax revenues are collected from labor. Quantifying the relative strengths of these effects requires a general equilibrium analysis in an overlapping generations framework.

[1] Currently, new legal immigrants are on average 5 years younger than natives.

The model setting is a dynamic equilibrium model of population transition, of the same type as in Ríos-Rull (1992b). The population distribution adjusts due to changes in immigration and fertility. Fertility follows an exogenous process, while mortality is taken to be constant. Immigration is given by an immigration policy determining age and annual inflow of new immigrants as a function of debt, population variables and asset holdings. Natives and immigrants in the model economy differ in age and skills. Immigrants are, in addition, differentiated by age at time of immigration. Fiscal policy is exogenously given and consists of a payroll tax, a tax rate on income, a transfer system that closely resembles Social Security, and a set of age-specific public consumption rules (proportional to GNP). The role for government is to determine an immigration policy such that the exogenous fiscal policy is feasible. Feasibility means that the government does not default on its debt in any state of the world. Evaluating whether an immigration policy makes the fiscal policy feasible involves solving for the decision rules of all agents.

Despite the strong implications of immigration for public finance, surprisingly few studies address the cost-benefit aspect of immigration. Two noteworthy exceptions are Huddle (1994) and Passel (1994) who aim at measuring the annual net gain of immigration for the U.S. These studies are static accounting exercises, and do not incorporate any endogenous behavior or impact through changes in prices.

This chapter is also related to the dynamic fiscal policy literature, see Auerbach & Kotlikoff (1987), Auerbach et al. (1989) and others. For given exogenous spending policies and population processes, these studies compute feasible future tax policies in a general equilibrium overlapping generations framework. Auerbach et al. (1989) include immigration as part of an exogenous demographic process, but immigrants are not distinguished from natives, and no attempts are made to explore the impact of changing the immigration policy.

There has been a recent debate in border states such as California, Texas and Florida concerning the desirability of limiting immigration. These states shoulder a significant portion of the cost of immigration without necessarily receiving the offsetting benefits, and immigrants (illegal ones in particular) are perceived to be a net financial burden on state and local government. My findings do not consider the validity of this view since this chapter addresses public finance on an aggregate level. The paper demonstrates that, for the nation as a whole, young immigrants represent a net public gain, and the government's budget deficit could be significantly reduced with even moderate changes in immigration policy.

4.3 The model

The model setting is equivalent to the framework in Chapter 3, with the inclusion of a government. For completeness, I review the key elements of the model setting here.

4.3.1 Law of motion for the population

The economy is populated by agents that live up to I periods. Agents of age i differ in national origin (domestic or foreign), and, if immigrant, age at time of immigration. The "type" of an agent in the economy is denoted by im, where i is age and m is the age at time of immigration ($m = 0$ indicates native-born). The key difference between immigrants and natives in the model is in the labor productivity. Children of immigrants (born after their parents immigrated) are assumed to be identical to natives.

Agents face longevity uncertainty. Conditional on being alive at age i, the probability of surviving to age $i+1$ for a type im agent is $s_{i,m}$. The measure of type i,m agents in period t is $\mu_{i,m,t}$. The number of births at time t, $\mu_{1,0,t}$ are given by the type-specific fertility rates $\phi_{i,m,t}$. Following Lee (1974) and Ríos-Rull (1992b), the birth process can be approximated by $\mu_{1,0,t} = \sum_m \sum_i \phi_{i,m}\mu_{i,m,t} + y_t$, where $\phi_{i,m}$ are average fertility rates and y_t is a deterministic error term.

An immigration policy determines the number and age composition of new immigrants as a function ψ of the state of the economy.[2] There are numerous ways to specify the possibilities. I focus on a very simple class of policies where inflow of each age category is linear in the state variables. The immigration policy is chosen by the government at the beginning of time.

4.3.2 Preferences and technology

Agents derive utility from consumption of a standard good. Preferences are time separable. The instantaneous utility takes the form $u(c, n)$, where c is the current consumption, n is time spent working in the market, and $u(.)$ is strictly concave and increasing. Agents younger than age ζ are defined as children. Children make no economic decisions in the model economy, and do not consume. Furthermore, agents do not care about their

[2] The model economy has a recursive representation, and the *state* of the economy can by expressed as a finite set of state variables S.

children and have no bequest motives. At a certain age all agents take retirement. Immigrants and natives are assumed to have the same preferences. A type m agent maximizes his expected lifetime utility, given by

$$\max_{\{c_t,n_t\}} \mathrm{E}_{\max\{m,\zeta\}} \left\{\beta^t u(c_t, n_t)\right\} = \sum_{t=\max\{m,\zeta\}}^{I} \beta^t \pi_{t,m} u(c_t, n_t)$$

subject to the intertemporal budget constraints. $\pi_{t,m}$ is the probability for an agent of type m to be alive at age t (so $\pi_{t,m} \equiv \prod_{j=\max\{m,\zeta\}}^{t-1} s_{j,m}$). Agents get zero utility when dead.

Production in period t is given by a standard constant return to scale production function $z_t f(K_t, N_t)$ with labor N_t and capital K_t as inputs and z_t as the level of technological progress. Growth in z is deterministic. The good produced is used for consumption and investment in new capital. The labor productivity of an agent is measured in equally productive efficiency units. The aggregate labor input in period t, N_t, is the sum of efficiency units supplied, i.e. $\sum_{i,m} e_{i,m} n_{i,m,t} \mu_{i,m,t}$, where $n_{i,m,t}$ is time spent working and $e_{i,m}$ is the number of labor efficiency units for agents of type im in period t. Firms rent labor and capital on spot markets at given wage rate W_t and net rental rate R_t. The firms solve

$$\max_{K,L} \left\{z_t f(K, N) - (R_t + \delta)K - W_t N\right\}$$

where δ is the depreciation rate.

4.3.3 Government and market structure

Fiscal policy is given exogenously and consists of a tax rule, a public spending rule, and a transfer rule that closely resembles social security. The tax rule specifies a constant payroll tax rate τ_S, and a constant tax rate τ on income (net of payrolls tax). The public consumption rule determines government purchases of goods and services as a function of output and population:

$$G_t = \sum_{i,m} g_{i,m} \mu_{i,m,t} \cdot \frac{z_t f(K_t, N_t)}{\sum_{i,m} \mu_{i,m,t}}$$

where $g_{i,m}$ is agent-specific government cost, expressed as a fraction of GNP per capita (e.g. schools, military, etc.).

The social security benefits paid by the government to respective agents consist of old age insurance (OAI), survivors' insurance (SI), disability insurance (DI), hospital insurance (HI), and supplementary medical insurance (SMI). OAI benefits are paid to retired agents only. An individual's OAI transfers are a function $h(.)$ of his average indexed monthly earnings (AIME) from when he was in the work force. I model the SI, DI and HI benefits as agent-specific transfers $\xi_{i,m}$, proportional to GNP. The SMI program receives large subsidies from the federal government, and the subsidy part of SMI benefits is modelled as a part of $\xi_{i,m}$. The aggregate social security benefits in period t are then

$$T_t = \sum_{i,m} \mu_{i,m,t} \left(\xi_{i,m} + h(D_{i,m,t})\right)$$

where $D_{i,m,t}$ is the AIME of a agent i, m in period t. Government debt B_t is held by agents, and aggregate private wealth is given by $A_t = K_t + B_t$. Half of the social security benefits are subject to income taxation. The government's budget constraint is then

$$B_{t+1} = B_t(1 + R_t) + \tau_S W_t L_t + \tau((1 - \tau_S)W_t L_t + R_t A_t) - G_t - (1 - \frac{\tau}{2})T_t$$

While an individual agent faces longevity uncertainty, there is no aggregate uncertainty about deaths.[3] The risk for an agent of dying with non-zero wealth is hedged on perfect annuities markets. One way to implement these markets is to let agents write contracts with members of their own type, where the surviving agents share the wealth of those who died. The recursive budget constraint for agent im is then

$$\begin{aligned} c + s_{i,m} a' \quad \leq \quad & W e_{i,m} n(1 - \tau_S)(1 - \tau) + (1 - \frac{\tau}{2}) \left(\xi_{i,m} + h(d_{i,m})\right) + \\ & (1 + (1 - \tau)R)a \end{aligned}$$

where a and a' are the agent's asset holdings this and next period, respectively, and $d_{i,m}$ is individual's private accumulated AIME.

4.3.4 State variables and equilibrium definition

The aggregate state of the economy is given by

1. The distribution of population $\mu \in \mathbf{R}_+^M \times \mathcal{Y}$, where M is the number of different agents. For notational convenience the error term in the birth process, $y \in \mathcal{Y}$, is expressed as a part of μ.

[3] Recall that the probability of surviving till next period for a type i, m agent is $s_{i,m}$. Since there is a continuum of agents, this fraction of type i, m agents will survive.

2. The distribution of wealth: $A \in \mathbf{R}^M$.

3. The distribution of agents' average indexed monthly earnings (AIME): $D \in \mathbf{R}_+^M$.

4. Total government debt: $B \in \mathbf{R}$.

The aggregate state variables are abbreviated $x \in \mathcal{X}$, The individual specific state variable is the agent's private wealth, $a \in \mathbf{R}$, and his accumulation of AIME, $d \in \mathbf{R}_+$.

A government *policy* consists of a fiscal policy $\nu(x) \equiv \{G(x), T(x), \tau, \tau_S\}$, and an immigration policy $\psi(x)$. The law of motion for population is a function of the immigration policy, and is denoted $\hat{\Gamma}_\psi(x)$. I assume that the policy $\{\psi, \nu\}$ is such that a non-zero steady state of the population exists. Let $\eta - 1$ be the steady state growth in population, and normalize the law of motion to make the population stable in steady state: $\Gamma_\psi(x) = \frac{1}{\eta}\hat{\Gamma}_\psi(x)$.

Given a policy $\{\psi, \nu\}$ a recursive equilibrium is defined as

1. Price functions $W(x) \in \mathbf{R}$ and $R(x) \in \mathbf{R}$ that compute the wage rate, and the rate of return on savings, and functions computing aggregate labor and capital, $N(x) \in \mathbf{R}_+$, and $K(x) \in \mathbf{R}_+$.

2. A set of individual decision rules for how much to save $a_{i,m}(x, a, d)' \in \mathbf{R}$, and how much to work $n_{i,m}(x, a, d) \in [0, 1]$,

3. A set of value functions $v_{i,m}(x, a, d) \in \mathbf{R}$.

4. A law of motion for the distribution of wealth, $H_A(x) \in \mathbf{R}^M$, a rule describing agents' work effort $H_N(x) \in [0, 1]^M$, a law of motion for agents' AIME, $H_D(x) \in \mathbf{R}^M$, and a law of motion for government debt, $H_B(x) \in \mathbf{R}$.

such that for all $(x, a, d) \in \mathcal{X} \times \mathbf{R} \times \mathbf{R}_+$ the following holds:

a) The rental prices for labor and savings, W and R, clear the markets for capital and labor (prices equal marginal productivities).

$$\begin{aligned} \frac{\partial zf(K(x), N(x))}{\partial K} &= W(x) \\ \frac{\partial zf(K(x), N(x))}{\partial N} &= R(x) + \delta \end{aligned}$$

where δ is the rate of depreciation.

b) The goods market clears

$$zf(K(x), N(x)) + (1-\delta)K(x) = \sum_{i,m} \mu_{i,m} c_{i,m}(x, A_{i,m}, D_{i,m}) + K(x') + G(x)$$

where $x' = (\mu', A', D', B') = (\Gamma_\psi(x), H_A(x), H_D(x), H_B(x))$, and $c_{i,m}$ is agent i, m's consumption:

$$\begin{aligned} c_{i,m}(x, A_{i,m}, D_{i,m}) &= W(x) e_{i,m} n_{i,m}(x, A_{i,m}, D_{i,m})(1-\tau_S)(1-\tau) \\ &+ (R(x)-1)A_{i,m}(1-\tau) + A_{i,m} \\ &- s_{i,m} a'_{i+1,m}(x, A_{i,m}, D_{i,m}) + (1-\frac{\tau}{2})\,(\xi_{i,m} + h(D_{i,m})) \end{aligned}$$

c) Given the price functions and value functions, the decision rules $a'_{i+1,m}(x, a, d)$ and $n_{i,m}(x, a, d)$, solve agent (i, m)'s objective function,

$$\max_{a',n} \{u_{i,m}(c) + \beta s_{i,m} v_{i+1,m}(\Gamma_\psi(x), H_A(x), H_B(x), a', d')\}$$

subject to $d' = d + e_{i,m} n$ and

$$\begin{aligned} c + s_{i,m} a' &= W(x) e_{i,m} n (1-\tau_S)(1-\tau) + ((R(x)-1)(1-\tau)+1)a \\ &+ (1-\frac{\tau}{2})\,(\xi_{i,m} + h(d)) \end{aligned}$$

d) The agents are using appropriate value functions. Thus, given price functions, decision rules and aggregate laws of motion for population, wealth and government debt, for any state variables $(x, a, d) \in \mathcal{X} \times \mathbf{R} \times \mathbf{R}_+$ the following holds:

$$\begin{aligned} v_{i,m}(x, a, d) &= u_{i,m}(c_{i,m}(x, a, d)) + \\ \beta s_{i,m} v_{i+1,m} &\left(\Gamma_\psi(x), H_A(x), H_D(x), H_B(x), a'_{i+1,m}(x, a, d), d + e_{i,m} n_{i,m}(x, a, d)\right) \end{aligned}$$

e) The law of motion for the distribution of wealth is consistent with individual decision rules, i.e. for each m

$$H_{A,m,m}(x) = 0$$

$$H_{A,i,m}(x) = a'_{i,m}(x, A_{i-1,m}, D_{i-1,m}) \qquad i \in \{m+1, \ldots, I\}$$

where $H_A(x) = (H_{A,1,0}(x), \ldots, H_{A,I,I}(x))$.

f) The rule for agents' work effort is consistent with individual decision rules, i.e. for each m

$$H_{N,i,m}(x) = n_{i,m}(x, A_{i,m}, D_{i,m}) \qquad i \in \{m, \ldots, I\}$$

where $H_N(x) = (H_{N,1,0}(x), \ldots, H_{N,I,I}(x))$.

g) The law of motion for agents' AIME is consistent with the rule for agents' work effort, i.e. for each m

$$H_{D,i,m}(x) = D_{i,m} + e_{i,m} H_{N,i.m}(x) \qquad i \in \{m, \ldots, I\}$$

where $H_D(x) = (H_{D,1,0}(x), \ldots, H_{D,I,I}(x))$.

h) The law of motion for government debt is consistent with the government's short term budget constraint:

$$\begin{aligned} H_B(x) &= R(x)B + G(x) + (1 - \frac{\tau}{2})T(x) - \\ &\quad (\tau(1-\tau_S) + \tau_S) W(x)N(x) - \tau(R(x) - 1)\mu^T A \end{aligned}$$

where T denotes transposed.

i) The government government policy (ψ, ν) is feasible, i.e. the government does not default in any state of the world. A sufficient set of conditions[4] to ensure feasibility is

- The state space $\mathcal{X}$ is compact, and
- The image of $\mathcal{X}$ under the composite mapping $\{\Gamma_\psi, H_A, H_D, H_B\}$ is a subset of $\mathcal{X}$.

j) Aggregate functions K and N are generated by population, debt, wealth distribution, and the rule for agents' work effort:

$$\begin{aligned} K(x) &= \sum_m \sum_i \mu_{i,m} A_{i,m} - B \\ N(x) &= \sum_m \sum_i \mu_{i,m} e_{i,m} H_{N,i,m}(x) \end{aligned}$$

4.4 Numerical solution

Solving numerically for the equilibrium poses two challenges:

[4] In a recursive setting these conditions ensure that debt is bounded

1. Find a law of motion for asset holdings, $H_A(x)$, and a rule for agents' work effort, $H_N(x)$, that are consistent with individual behavior.

2. Ensure that a candidate government policy, $\{\psi, \nu\}$, is feasible.

The numerical approximation strategy for dealing with the first issue is based on Ríos-Rull (1992a, 1992b, 1994). The equilibrium rules $H_A(x)$ and $H_N(x)$ are found by iterating on the agents' expectations: For an initial set of expectations of $H_A(x)$ and $H_N(x)$, compute the optimal decisions of each agent. Use the new individual decision rules as a new guess of agents' expectations. A fixed point of this mapping is a set of rational expectations, i.e. aggregate rules consistent with individual behavior.

I make linear-quadratic approximations of the agents' utility functions, make a linear approximation of the law of motion for government debt, H_B, and restrict the law of motion of population, $\Gamma_\psi(x)$, to be linear in the state variables. Agents' optimal decision rules are then linear, and each iteration can be reduced to linear algebra. I demonstrate in the appendix that the law of motion for the approximated economy is linear in the fixed point. Finding the fixed point, given a government policy, takes about 3 hours on an HP 715.

The part of the computational procedure that is not standard is to ensure that a candidate government policy, $\{\psi, \nu\}$, is feasible. The following theorem provides a method to implement equilibrium condition i) for the approximated economy.

Theorem 1 *A sufficient set of conditions for equilibrium condition i) to hold is:*

(a) The law of motion for the economy, $\{\Gamma_\psi, H_A, H_D, H_B\}$, is linear, and can thus be expressed as $x' = \hat{\Omega} \cdot x + x_0$ where $\hat{\Omega}$ is a matrix and x_0 is a constant vector. For simplicity, rewrite this as

$$\begin{pmatrix} 1 \\ x' \end{pmatrix} = \begin{bmatrix} 1 & 0 & \dots & 0 \\ x_0 & & \hat{\Omega} & \end{bmatrix} \cdot \begin{pmatrix} 1 \\ x' \end{pmatrix} \equiv \Omega \cdot \begin{pmatrix} 1 \\ x \end{pmatrix}$$

(b) All eigenvalues of Ω are less than or equal to 1 in absolute value.

(c) Any degenerate eigenvalue[5] *of Ω is strictly less than 1 in absolute value.*

Proof: See the appendix. □

[5] An eigenvalue of a matrix is said to be degenerate if the eigenvalue has strictly smaller geometric than algebraic multiplicity.

For a given fiscal policy the problem is to identify the set of immigration policies (possibly empty) for which a recursive equilibrium exists. The computational algorithm identifies this menu of immigration policies for a given fiscal policy ν. It is described in detail in the appendix.

4.5 Parameterization of the model economy

Population parameters, preferences, and technology are calibrated as in Chapter 3. Below I quickly review the parameter choices.

4.5.1 Population parameters and preferences

One period in the model is taken to be 5 years, and each agent can live up to 18 periods and retires after period 13 (i.e. agents retire at age 65 and die before 90). Natives and immigrants are assumed to have identical mortality rates, fixed at the 1988 U.S. levels.

Fertility for immigrant women is estimated to be about 50% higher than for natives. Recall that the birth process is modelled as

$$\mu_{1,0,t} = \sum_m \sum_i \phi_{i,m} \mu_{i,m,t} + y_t$$

The age-specific average fertility rates for native women $\phi_{i,0}$ are estimated by averaging over the 1960-89 time period. The y_t process is estimated as an AR(2) process and the resulting coefficients are $\rho_1 = 1.28$ and $\rho_2 = -0.65$. In the simulations y_t follows the deterministic version of this process.

Preferences are standard. The instantaneous utility of any agent takes the form

$$u(c,n) = \frac{(c^\alpha (1-n)^{1-\alpha})^{1-\rho}}{1-\rho}$$

with $\alpha = 0.33$, $\rho = 4$, and the time preference parameter $\beta = 1.011$.

4.5.2 Technology and efficiency unit profiles

Accounting for the differences in labor productivity between natives and immigrants is crucial when quantifying the effects of immigration. Estimates of the wage profiles of natives and of immigrants (of different ages at time of immigration) are reported in Chapter 2. The estimated wage profile of immigrants who come at age 27 implies that these immigrants earn on average 3.5% less than natives over their remaining lifetime. Borjas (1990) and others find the difference in earnings to be bigger. Since the public finance implications of immigration is sensitive to wage income of natives, I also try with an alternative earnings profile where immigrants earn 20% less than natives.

Technology is standard. A neoclassical Cobb-Douglas production function takes labor and capital as inputs. Capital's share of output is set to 0.40 (see Chapter 3 for justification) and the annual depreciation rate δ, is set to 7.8%. The average annual growth in US GNP per capita has been 1.5% over the last two decades. The rate of growth in the level of technology, z, is set to match this figure in steady state.

4.5.3 Government

The payrolls tax, τ_S, is set to 15.3% of labor income. Total federal, state and local tax revenues were on average 28.9% of GNP during the 1980–91 period. I set the income tax rate to 25.8% to match this figure in steady state.

Recall that government consumption is modelled as $G = \sum_{i,m} g_{i,m}\mu_{i,m} \cdot \frac{zf(K,N)}{\sum_{i,m}\mu_{i,m}}$. (interpret $g_{i,m}$ as government spending for an agent of type i, m as a fraction of GNP per capita). Using population data and the Auerbach et al. (1989) estimates of age specific government spending in 1980, $g_{i,m}$ are computed to be 24.6%, 13.4%, and 23.2% for the age groups 1–24, 25–64, and ≥ 65, respectively.

I assume that all workers are enrolled in social security. The Old Age Insurance (OAI) formula is a function $h(.)$ of average indexed monthly earnings (AIME). h is piecewise linear with two "bend points". The bend points are set to 20% and 122% of monthly GNP per capita based on data from the annual actuary reports. The replacement rates (i.e. slope of h) within brackets 1, 2, and 3 are 90%, 32%, and 15%, respectively. Recall that the benefits from survivors' insurance (SI), disability insurance (DI), and hospital insurance (HI), plus the subsidy part of supplementary medical insurance (SMI) are modelled as an age dependent lump sum transfer $\xi_{i,m}$. I assume that immigrants and natives enjoy the same benefits. I used unpublished data[6] from the Social Security Administration to estimate the lump sum transfers (as a fraction of GNP per capita), and the results are reported in Figure 6.

[6] Thanks to Netty Barrick, Steve McKay, and John Wandishin for providing the information I needed.

4.5.4 Initial conditions

I use the 1992 distribution of natives and immigrants as initial condition for the population. The initial government debt is set to 47.6% of GNP. The initial distribution of assets is the steady state distribution of assets scaled so that the initial capital output ratio is 2. Agents then hold 25% more wealth than in steady state.

4.6 Findings

The aim of the numerical experiments is to investigate if the current U.S. fiscal policy could be sustained by changing the immigration policy only. Given the calibrated economy and fiscal policy, I explored a class of immigration policies satisfying the following criteria:

- The number of new immigrants in steady state (as a fraction of the population) is the same as in 1992 (0.44%).
- Only immigrants of age 27 are admitted.
- Immigration is linear in debt, aggregate capital, retired population and non-retired population.

  $$\psi(x) = \psi_B B + \psi_K K(x) + \psi_{\mu,1} \sum_m \sum_{i \leq 13} \mu_{i,m} + \psi_{\mu,2} \sum_m \sum_{i \geq 14} \mu_{i,m}$$

  where $\psi(x)$ is the number of new immigrants of age 27.

The set of policies in this class that are feasible (i.e. generate recursive equilibria) is not empty.[7] In choosing among the feasible policies I searched for the one with the lowest coefficient on debt ψ_B.[8] This approach was followed for both productivity profiles, and the resulting immigration policies are plotted in Figure 1 (as % of population) and Figure 2 (in absolute numbers).

The policy prescribes an initial annual immigration of almost 0.9% of the population (or twice the current level). In absolute numbers this corresponds to less than 2.8 million annually. The number of immigrants falls gradually to 0.2% of the population in year 2075 and returns to the steady state level thereafter (0.44%).

[7] At first I tried with age 17 immigrants only, but I was not able to show existence of any feasible immigration policies in this case.

[8] Note that one of the policy parameters $(\psi_B, \psi_K, \psi_{\mu,1}, \psi_{\mu,2})$ is fixed once the steady state growth rate and age distribution of new immigrants are fixed.

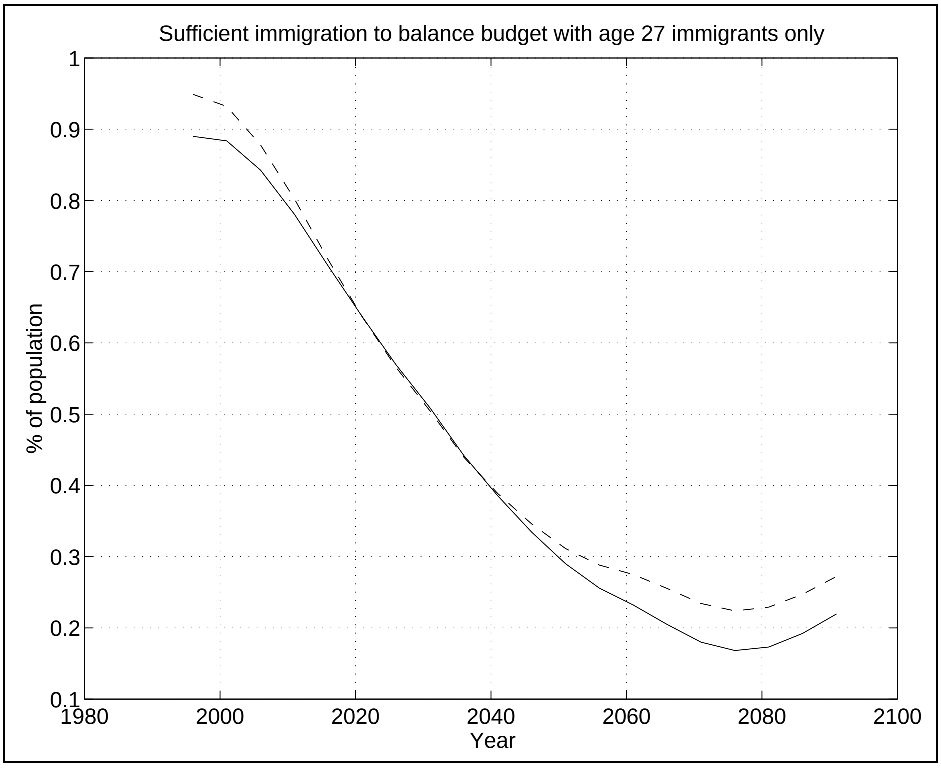

Figure 4.1: Number of age 27 immigrants needed to sustain current fiscal policy. Solid line: Case of estimated earnings profile for immigrants, dotted line: Case of alternative (lower) earnings profile.

Under the alternative profile less than 200,000 more immigrants are needed to make the policy feasible. So, with immigrants earning 10% less than in the benchmark case, approximately 5% more immigrants are needed to balance the budget.

The projected debt-output ratios are displayed in Figure 3. After 45 years (following the prescribed immigration policy) government debt is reduced to zero. This finding highlights the impact of immigration on fiscal policy.

To get some intuition of what drives the results, I computed the net present value of future tax payments less future government expenditures (including Social Security) for an additional native newborn and an additional immigrant. This was done using the future path of interest rates, wage rates and output per capita projected by the model. The net present value for a U.S. newborn is -$50,000, see Figure 4, and ranges from -$100,000 for an immigrant of age 65 to $85,000 for an immigrant of age 27. The spike in net present value after age 55 is due to the fact that 10 years of participation in Social Security is required to receive full benefits. After arrival, however, immigrants may have children. Discounting this additional cost to society

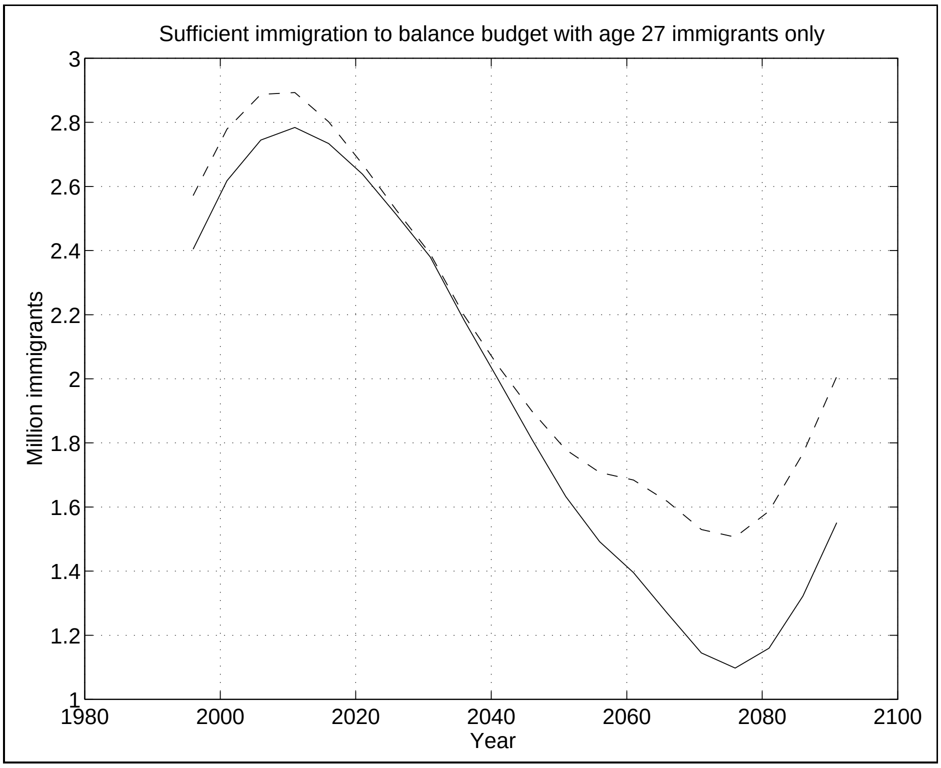

Figure 4.2: Number of age 27 immigrants needed to sustain current fiscal policy (absolute numbers). Solid line: Case of estimated earnings profile for immigrants, dotted line: Case of alternative (lower) earnings profile.

and charging it to the immigrant, lowers the estimated discounted gain to society to \$60,000 for an age 27 immigrant, see Figure 5. Including the cost of future offspring for natives, lowers the gain of a newborn native to -\$70,000. These findings are quite sensitive to the fertility of immigrants after arrival.

4.7 Conclusion

This chapter investigates the implications of immigration for fiscal policy. Immigration to the U.S. has surged over the last two decades, and immigrants are viewed by many as a financial burden on society, at least at the state level. Since immigrants are much younger than natives, the rise in immigration will have dramatic effects on the U.S. age structure. Demographic changes affect fiscal policy because a big chunk of public expenditures are age dependent (e.g. schooling and Social Security) and because most of the tax revenues are collected from the working age population.

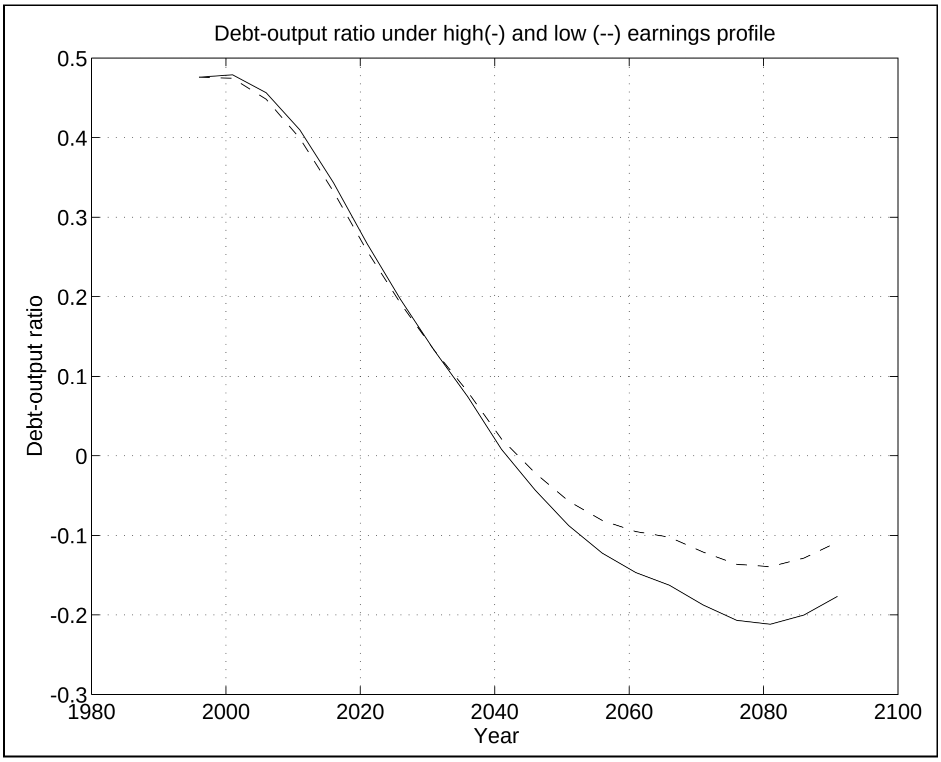

Figure 4.3: Debt to output ratio under current fiscal policy and the two computed immigration policies.

The U.S. population is aging as the "baby-boomers" approach retirement. Many economists believe that maintaining public expenditures at current levels with no increase in taxes is not a feasible policy for the U.S. government, because of the shrinking tax base and large Social Security obligations that accompany an aging population. To illuminate the quantitative implications of immigration policy for fiscal policy, I explored in this chapter if an immigration policy could be constructed that would sustain the current fiscal policy.

Using a general equilibrium overlapping generations model calibrated to U.S. data, I found that such policies do exist and are characterized by modest changes from the current immigration policy. A particular implementation of one of these policies is to increase the annual number of age 27 immigrants to 0.7-0.9% of the population until year 2020, and revert to the current level of immigrants thereafter (0.44% of the population). These findings are robust to changes in the earnings-profile of immigrants.

The chapter demonstrates that immigration policy has strong quantitative implications for fiscal policy, and that immigration policy should be viewed as an important part of fiscal policy (in addition to tax policy and spending policy). In particular, a case is made that age at time of arrival and fertility after immigration

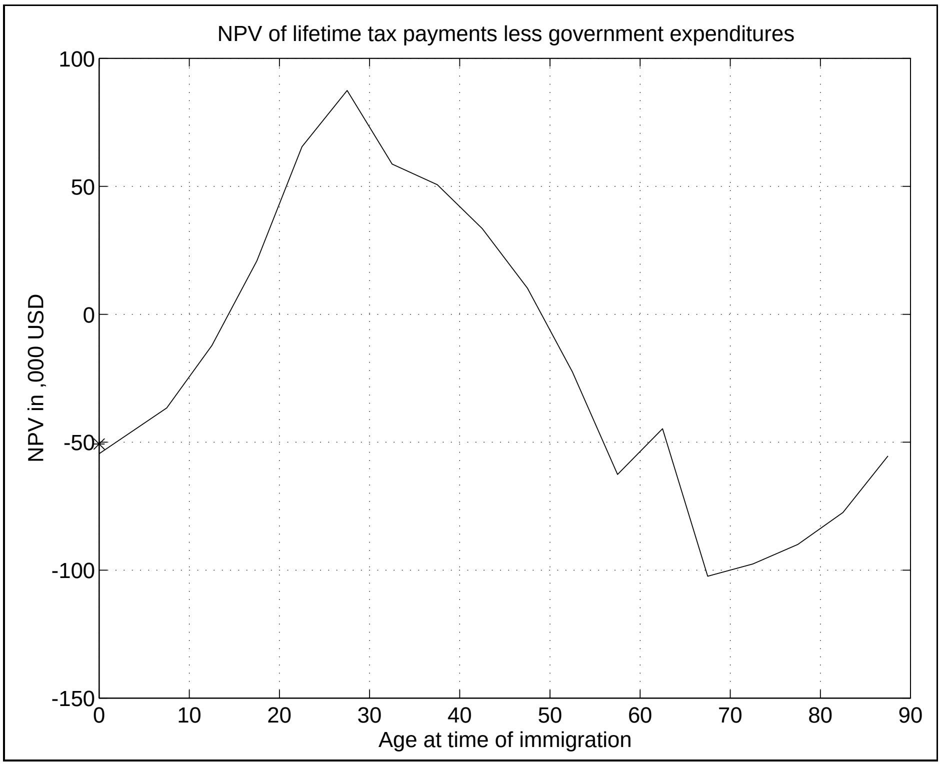

Figure 4.4: Net present value of future tax payments less government expenditures for additional immigrants (solid line) and newborn natives (marked by *).

matter a lot for the cost-benefit calculation of new immigrants. This work could be used to design an optimal "point system" for allocating visas to prospective immigrants, resembling the immigration policy in Canada.

4.8 Appendix

4.8.1 Proof of Theorem 1

Express Ω in Jordan form: $\Omega = MJM^{-1}$. The Jordan matrix J is

$$J = \begin{bmatrix} J_1 & & 0 \\ & \ddots & \\ 0 & & J_s \end{bmatrix}$$

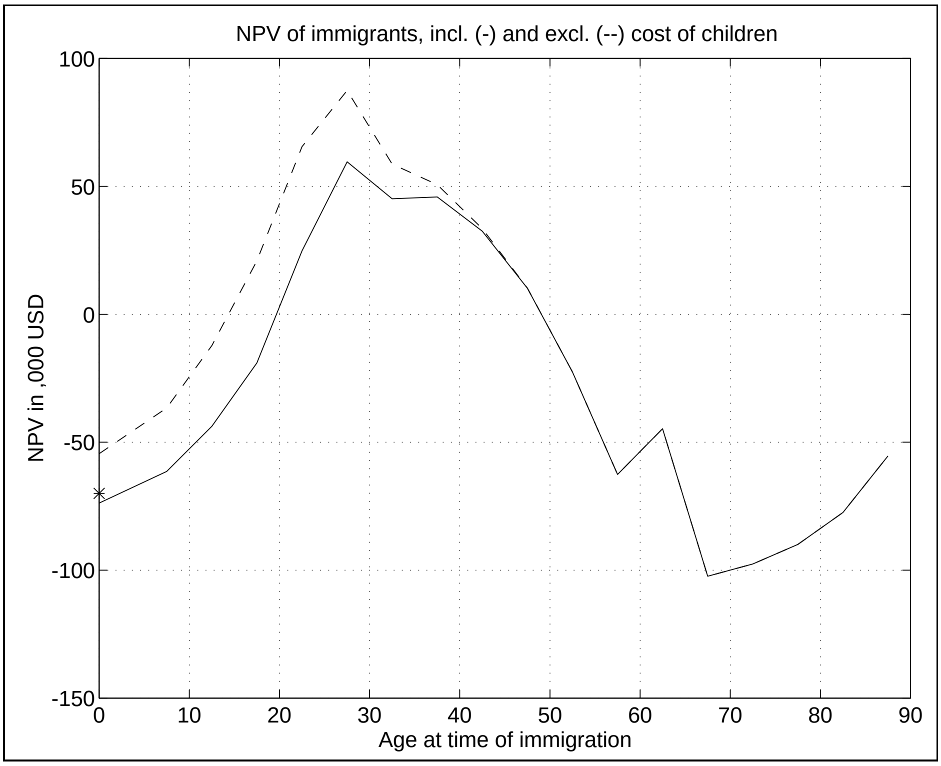

Figure 4.5: Net public gain (including the cost of future offspring) of additional immigrants (solid line) and newborn natives (*).

If the eigenvalue λ_i is degenerate the Jordan block in J_i is

$$J_i = \begin{bmatrix} \lambda_i & 1 & & 0 \\ & \ddots & \ddots & \\ & & \lambda_i & 1 \\ 0 & & & \lambda_i \end{bmatrix}$$

The number of rows of J_i, D_i, is 1 plus the algebraic multiplicity less the geometric multiplicity of λ_i. If the eigenvalue is not degenerate, $J_i = \lambda_i$. Label the columns of M as $M = [M_{1,1}, \ldots, M_{1,D_1}, \ldots, M_{s,1}, \ldots, M_{s,D_s}]$. Then $\Omega \cdot M_{i,1} = M_{i,1}\lambda_i$, and for $j \geq 2$, $\Omega \cdot M_{i,j} = M_{i,j-1} + M_{i,j}\lambda_i$. Note that the column vectors of M span $\mathbf{R}^{m+1}$ since M is invertible. Then $\exists$ weights $\alpha_{1,1}, \ldots, \alpha_{s,D_s} \in \mathbf{C}$ such that $(1, 0, \ldots, 0) = \sum_{i=1}^{s} \sum_{j=1}^{D_i} \alpha_{i,j} M_{i,j}$. Define the constant $r_0 = \max_{i,j}\{|\alpha_{i,j}|\}$.

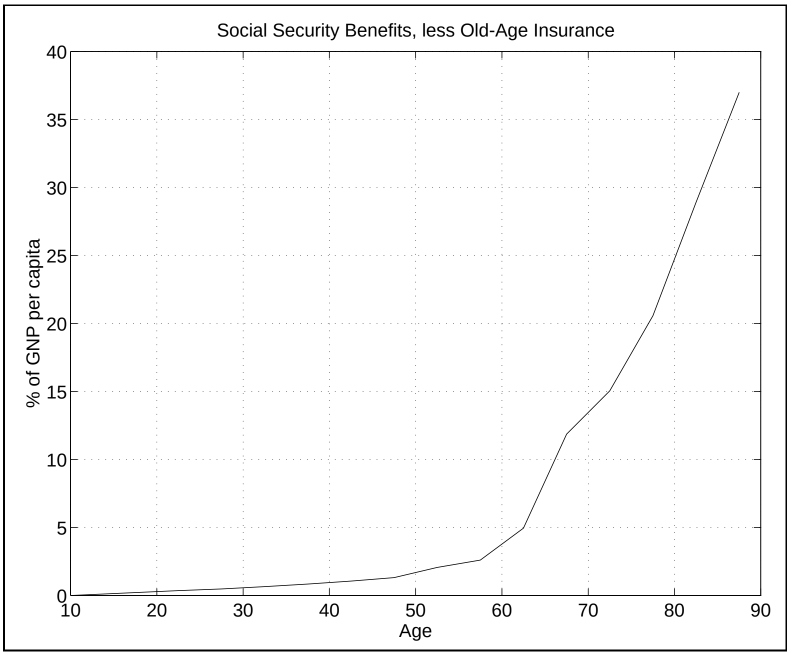

Figure 4.6: Average benefits from Survivors' Insurance, Disability Insurance, and Hospital Insurance plus subsidy part of Supplemental Medical Insurance, expressed as a fraction of GNP per capita.

Then for some $r > r_0$ the state space is defined as

$$\begin{aligned}\mathcal{X} \quad = \quad \{z \in \{1\} \times \mathbf{R}^m \quad | \quad & z = \textstyle\sum_{i=1}^{s} \sum_{j=1}^{D_i} \alpha_{i,j} M_{i,j} \text{ where } |\alpha_{i,1}| \leq r \text{ if } \lambda_i \text{ is not} \\ & \text{degenerate, and } |\alpha_{i,j}| \leq r(1 - |\lambda_i|)^{j-D_i} \text{ if } \lambda_i \text{ is degenerate}\}\end{aligned}$$

$\mathcal{X} \subset \{1\} \times \mathbf{R}^m$ is closed and bounded since the coefficients on the basis vectors are chosen from closed and bounded sets. Thus, $\mathcal{X}$ is compact by the Heine-Borel theorem. $\mathcal{X}$ is full dimensional since $r > r_0$.

For a given $z \in \mathcal{X}$, pick $\alpha_{1,1}, \ldots, \alpha_{s,D_s} \in \mathbf{C}$ such that $z = \sum_{i=1}^{s} \sum_{j=1}^{D_i} \alpha_{i,j} M_{i,j}$. Then

$$\Omega \cdot z \quad = \quad \sum_{i=1}^{s} \sum_{j=1}^{D_i} \alpha_{i,j} \Omega M_{i,j} = \sum_{i=1}^{s} \left(\sum_{j=1}^{D_i - 1} (\alpha_{i,j} \lambda_i + \alpha_{i,j+1}) M_{i,j} + \alpha_{i,D_i} \lambda_i M_{i,D_i} \right)$$

For $j = D_i$, $|\alpha_{i,D_i} \lambda_i| \leq |\alpha_{i,D_i}| \leq r$ (recall that $D_i = 1$ if λ_i is not degenerate). If λ_i is degenerate, for $1 \leq j < D_i - 1$

$$\begin{aligned}|\alpha_{i,j} \lambda_i + \alpha_{i,j+1}| \quad & \leq \quad |\alpha_{i,j}| \cdot |\lambda_i| + |\alpha_{i,j+1}| \\ & \leq \quad r(1 - |\lambda_i|)^{j-D_i} |\lambda_i| + r(1 - |\lambda_i|)^{j+1-D_i} \quad = \quad r(1 - |\lambda_i|)^{j-D_i}\end{aligned}$$

Furthermore, $\Omega \cdot z \in \{1\} \times \mathbf{R}^m$ since both Ω and z are real valued, and since the first element in the vector $\Omega \cdot z$ is 1 by construction of Ω. Thus, $\Omega \cdot z \in \mathcal{X}$.

Note that Ω^n explodes as $n \to \infty$ if a degenerate eigenvalue is equal to 1 because the upper right corner of the Jacobian block of the eigenvalue grows without bounds. $\Box$

4.8.2 Computational algorithm

The aim of the computational algorithm is to identify a menu of immigration policies, given fiscal policy ν, such that the government policy $\{\psi, \nu\}$ is feasible.

I restrict my attention to immigration policies that are linear in the state variables. If all new immigrants were of the same age, the normalized law of motion for population would be

$$\mu' = \Gamma(\psi)\begin{pmatrix} \mu \\ A \\ D \\ B \end{pmatrix} = \frac{1}{\eta}\begin{bmatrix} \phi_{1,1} & \dots & \phi_{I,I} & 0 \\ S_1 & 0 & & 0 \\ & \psi_\mu & & \psi_{A,D,B} \\ 0 & S_2 & & 0 \end{bmatrix}\begin{pmatrix} \mu \\ A \\ D \\ B \end{pmatrix}$$

where S_1 and S_2 are survival matrixes for natives and immigrants, respectively, $\phi_{i,m}$ are average fertilities, and the vector $(\psi_\mu, \psi_{A,D,B})$ represents the immigration policy.

Let Q_ν be the set of possible steady states for the economy, given a fiscal policy ν, and allowing any immigration policy. A steady state is characterized by a rate of growth of population η, an age distribution of new immigrants, distributions of population, assets, and AIME, μ^*, A^*, and D^*, and a government debt B^*. For each element $q \in Q_\nu$, define $\Psi(q)$ as the set of immigration policies that (given ν) is consistent with q as a steady state.

For a given $q \in Q_\nu$ I want to find a subset $\hat{\Psi}(q) \subset \Psi(q)$ such that for $\psi \in \hat{\Psi}(q)$, the policy (ψ, ν) is feasible, and for each element in $\hat{\Psi}(q)$ I will compute the corresponding recursive equilibrium. Methodology: Select some candidate immigration policies from $\Psi(q)$ and for each candidate ψ do:

1. Compute the rule for work effort H_N, and the law of motion for individual wealth H_A, and the law of motion for government debt H_B, given policy (ψ, ν).
2. Verify if equilibrium condition i) is satisfied by checking the conditions of theorem 1.

Algorithm for computing $H_A(x)$, $H_B(x)$, and $H_N(x)$ given (ψ, ν) and q

The law of motion for government debt, $H_B(x)$, is approximated by making a first order Taylor approximation around the steady state q. The result is a vector H_B such that $H_B(x) \approx H_B \cdot (1, \mu, A, D, B)^T$ (where T signifies transposed, and the aggregate state variable x from now on includes a constant, $x = (1, \mu, A, D, B)$).

A necessary and sufficient condition for functions $H_A^*, H_N^* \in \mathcal{A}$ to equal the law of motion for wealth H_A, and agents' work effort rule H_N, is that H_A^* and H_N^* are consistent with individual decision rules[9] (i.e. when the agents take H_A^* and H_N^* as given, then in state x the realized law of motion for wealth will be exactly $H_A^*(x)$ and the realized work effort will be H_N^*). A mapping $\phi : \mathcal{A} \times \mathcal{A} \rightarrow \mathcal{A} \times \mathcal{A}$ is defined as follows: $\phi(\hat{H}_A, \hat{H}_N)$ are the law of motion for wealth and the work effort that would occur in the economy if the agents believe that H_A and H_N are given by $\hat{H}_A$ and $\hat{H}_N$. By construction a fixed point of the mapping ϕ would be an equilibrium law of motion for wealth, and an equilibrium work effort rule. A fixed point is found using the following algorithm:

First, for all types (i, m), make a second order Taylor approximation of the instantaneous utility $u(c)$ of agent (i, m) around his steady state allocation (where c is substituted with the agent's budget constraint). Recall that subscript $i \in \{1, .., I\}$ represents age and subscript m represents age at time of immigration. The approximation can be expressed by a square matrix $R_{i,m}$ as $u_{i,m}(x, a, d) \approx (x, a, d, a', n)\ R_{i,m}\ (x, a, d, a', n)^T$.

Second, iterate on ϕ to find a fixed point consistent with individual behavior. An iteration on ϕ is described by the 4-step procedure below:

Step 1 Start with a guess of H_A and H_N as linear functions of x, i.e. $H_A(x) = H_A \cdot x$ and $H_N(x) = H_N \cdot x$.

Step 2 Find the value functions for the oldest agents in the economy, imposing the restriction that $a' = 0$ and $n = 0$ (they cannot die indebted and are retired). Thus, $V_{I,m}(x, a, d) = (x, a, d, 0) R_{I,m}(x, a, d, 0)^T$. Note that the value function $V_{I,m}$ is quadratic in the state variables.

Step 3 Taking $V_{I,m}$, H_A, H_D, H_B, H_N, and Γ_ψ as given, $V_{I-1,m}$ is then computed as

$$\begin{aligned} V_{I-1,m}(x, a, d) &= \max_{a', n} \{\ (x, a, d, a', n) R_{I-1,m}(x, a, d, a', n)^T + \\ &\quad \beta s_{I-1,m}\ (x', a') V_{I,m}(x', a')^T\ \} \end{aligned}$$

[9] $\mathcal{A}$ is the set of linear functions f such that f maps $\mathcal{X} \rightarrow R^M$, where $\mathcal{X}$ is the state space and M is the number of different agents in the economy.

where $x' = (1, \mu', A', D', B')^T = (1, \Gamma_\psi(x), H_A(x), H_D(x), H_B(x))^T$. H_N and the laws of motion H_A, H_D, H_B, and Γ_ψ are linear in x, so the vector (x, a, d, a', n) can be converted to (x', a', d') (the state variable tomorrow) by a linear transformation C: $C \cdot (x, a, d, a', n)^T = (x', a')^T$. Thus,

$$\begin{aligned} V_{I-1,m}(x,a,d) &= \max_{a',n}\{ \quad (x,a,d,a',n) R_{I-1,m}(x,a,d,a',n)^T + \\ &\qquad\qquad \beta s_{I-1,m} \ (x,a,d,a',n) C^T \ V_{I,m} \ C(x,a,d,a',n)^T \ \} \\ &= \max_{a',n}\{(x,a,d,a',n) \left[R_{I-1,m} + \beta s_{I-1,m} \ C^T \ V_{I,m} \ C\right](x,a,d,a',n)^T \ \} \end{aligned}$$

Note that now the objective function is quadratic in (x, a, d, a', n). Then the optimal decision (a'^*, n^*) must be linear in (x, a, d) and hence $V_{I-1,m}$ must be quadratic in (x, a, d), i.e. $V_{I-1,m}(x, a, d) = (x, a, d)V_{I-1,m}(x, a, d)^T$. Roll backwards to compute $V_{i,m}$ and $(a'^*_{i+1,m}, n^*_{i,m})$ in the same way for $i \in \{m, .., I-2\}$. By a recursive argument $a'^*_{i+1,m}$ and $n^*_{i,m}$ are linear in (x, a, d) $\forall\, i$.

Step 4 Impose the representative agent condition (i.e. that individual wealth for agent (i, m) equals $A_{i,m}$ and individual AIME is $D_{i,m}$) by transforming the linear decision rule of agent (i, m): Add the coefficient on the individual's own assets and AIME to the coefficient on $A_{i,m}$ and $D_{i,m}$, respectively. Then the decision rules can be written as linear functions of the aggregate state only. These decision rules constitute the new linear guesses of $H_A(x)$ and $H_N(x)$, completing the iteration.

The iteration process terminates when the new choices of H_A and H_N are sufficiently close to the H_A and H_N in step 1. I use 10^{-8} as a stopping criteria (i.e. stop iterating when the maximum change in H_A and H_N is less than 10^{-8}).

Verify if equilibrium condition i) is satisfied

Equilibrium condition i) is verified by checking the conditions for theorem 1. Given H_A and H_B computed above, the normalized law of motion for the economy is linear and can be expressed in matrix notation as

$$\begin{pmatrix} 1 \\ \mu' \\ A' \\ D' \\ B' \end{pmatrix} = \begin{bmatrix} 1 & 0 & \dots & 0 \\ 0 & \Gamma_\psi & & \\ & H_A & & \\ & H_D & & \\ & H_B & & \end{bmatrix} \cdot \begin{pmatrix} 1 \\ \mu \\ A \\ D \\ B \end{pmatrix} \equiv \Omega \cdot \begin{pmatrix} 1 \\ \mu \\ A \\ D \\ B \end{pmatrix}$$

Check condition (ii) of theorem 1 by computing the eigenvalues of Ω. Condition (iii) is verified by computing the eigenvectors of Ω corresponding to the eigenvectors of length 1. If these vectors are linearly independent, then all eigenvalues of length 1 are non degenerate.

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