Population Growth and Urban Planning

IMMC18624740

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1 Abstract

Government officials are always looking for ways to tackle demographic transition problems so that they can better coordinate economic growth and social development. [a] This process also plays a critical role in shaping the public policy in a country. Accurately predicting a country's demographic transition is of the utmost importance now. In order to accomplish this, our team endeavor to forecast China's demographic transition in the three decades ahead through mathematical modeling.

To predict the demographic transition, we determined six main factors (mortality rate, fertility rate, sex ratio, the number of emigrants, life expectancy, and the total population in a specific year) which may cause a country's population to shift. Through simplifying the problem by making a few necessary assumptions, collecting and analyzing data, we then designed a mathematical model based on the relations between these parameters and the total population. Afterwards, by using regression analysis on the data collected from various official reports [b], we calculated the formulas for each of the factors and put them together into our model, and tested them against the real demographic data, refining our model along the way, until the establishment of the final model. Using python programming, we estimated the population trends of Mainland China in the next thirty years. Our estimation of the population in that period is around 14.48 billion people. Our model also predicted the population of Beijing in three decades to be 23.059 million.(Appendix 9-4)

This model not only can be applied to accurately predict demographic transition, it can also be used in urban planning. According to our model, Beijing will reach its carrying capacity at around the year 2030. To meet this challenge, we suggested building three satellite cities(Huilongguan, Xianghe, and Langfang) around Beijing, and relocating 3% of Beijing's population these places. We developed a set of policies to curtail the population of Beijing, which will meke it stay safely under the carrying capacity for at least forty years.

Though our model did not fully consider the extent of the evolution of the sex ratio, it is robust against sudden changes in population, can be widely implemented to fit almost any scenario, and can give urban planners a heads-up on the limitations of our demographic growth.

2 Problem Restatement

As a crucial component of economic and social development, population transition has increasingly become a major factor in determining public policies, particularly ones associated with fertility [c]. Mainland China is in its 4th stage in demographic transition, with low birth rates and mortality rates. Up to now, a majority of developed countries have tried to control their population with different policies [d]. To analyze the population transition and the implemented policies, the problem requires us to give a precise prediction so that we can establish further policies. Therefore, we are required to:

𝟙 Give a mathematical model to foresee the demographic transition in thirty years based on data and analysis.

𝟚 In our model, examine population growth, especially fertility rate which dominates the fluctuation.

𝟛 In our model, consider the age distribution of the population.

𝟜 In our model, consider the evolution in sex ratio.

𝟝 Cover other relative factors on population growth and structural dynamics.

𝟞 Analyze the advantages and disadvantages of current policies pertaining to demographic transition.

𝟟 Propose our team's solution on policy wherein optimizing the demographic transition.

3 Assumptions

✓ There are no huge medical breakthroughs in the following thirty years.
Justification: With a relatively small probability of developing reinvigorated medical technology or practices which may turn the fertility rate and mortality rate upside down, it can be seen as a negligible factor.

✓ Major population-crippling disasters will not happen during the time period of our model.

Justification: Major population crippling disasters, such as wars and natural disasters, are likely to affect population significantly. We can't account for this since the probability of these events happening are scant. However, we considered this possibility in our sensitivity analysis.

✓ Emigration from urban areas to rural areas can be ignored.
Justification: Developing rapidly, more and more people from rural area prefer to move to urban areas, and there will be only a few city residents who are willing to move out, and that population is negligible.

✓ The emigrants' change of population per year may be considered as several points in the graph of a linear function.
Justification: Some people are moving out of their home country, and the number of the population changes every year. By fitting the function, we found that the emigrants' change of population per year can be written in form of linear function.

✓ Tourism is an unpredictable and unimportant value, thus is neglected in our model.
Justification: It is unable to have the accurate data of volatile and impermanent value, and it is no need to add it in our model.

✓ The death rates of urban areas and rural areas are the same.
Justification: The differences of death rates between urban area and rural area is lacking in data, and we can only use the data from the whole country, so we assumed that the death rates of these regions are similar or equal.

✓ Young adults' behaviors and dispositions does not change in the next thirty years.
Justification: In predicting the satellite city construction, we may assume young adults act and think as same as today's majority group of young adults, in order to distribute people of different ages to different regions.

✓ The Two-child policy is not considered in this model.
Justification: The Two-child policy[e] in China was established in 2016, and there isn't data on the population changes that year yet. We couldn't get a good result to base off of, so we excluded the small fertility increase due to this policy.

✓ Developed regions have the same amount of resources as undeveloped regions.
Justification: The amount of resources plays an important role in evaluating the city's carrying capacity, so we assumed that regions where humans are consuming resources currently and regions where the resources are natural are the same.

✓ Women in China have their first kid at around 26 years old.
Justification: To simplify the complex moral and social situation where women have births starting at different ages, 26 is a reasonable number to use.

✓ The carrying capacity is only determined by resources in the city but not transported from other regions.
Justification: Our model for carrying capacity only takes the area of the city into account, which we assumed is proportional to the resources contained in that area. However, if we include policies like the South–North Water Transfer Project [f], we are unable to calculate the carrying capacity effectively.

4 Designing The Mathematical Model

Using intuition, we designed a population model, describing the major factors that contribute to the change in population.

4.1 Population Model

In the year of 1979, China started the One-child policy [g] to control its alarmingly increasing population. Thus, according to this policy, we designed a population model, taking the starting population, birth rate, death rate, and emigration into account.
In general, a population model can be written in form of a function, as shown below.

$$P = P_0 + B - D - A$$

where,
- P **is the population of the country**
- P_0 **is the population of the first year**
- B **is the number of new born babies in that year**
- D **is the number of dead in that year**
- A **is the number of emigrants who are no longer citizens**

From the previous equation, we can get that the population 1 year after the starting year will be the population last year times a factor:

$$P = P_0(1 + B_r - D_r) - A$$

Thus, if we decide to calculate the population t **years after the starting year, the function will look like:**

$$\begin{aligned} P(t) &= P_0(1 + B_r 1 - D_r 1)(1 + B_r 2 - D_r 2) \cdots (1 + B_r t - D_r t) - (A_1 + A_2 + A_3 + \cdots + A_t) \\ &= P_0 \prod_{i=1}^{t} (1 + B_r i - D_r i) - \sum_{i=1}^{t} A(i) \end{aligned}$$

To get a more accurate population estimate, we chose to add several variables to our formula, such as mortality, fertility, life expectancy, and sex ratio.

$D_r i$ **is the death rate, and because our data of mortality rate is of 1000 people, we can detail it by** $\frac{1}{1000} m(i)$**.**
$B_r i$ **stands for the birth rate, and since we have the data to predict sex ratio, fertility rate, life expectancy, and average age of birth giving mothers, it can be written in form of** $s_r f(i) \frac{1}{E(i-\beta)}$**.**

We can further derive this equation by considering the effect of aging on the birth rate. The sex ratio s_r multiplied by the population will be the female population, and the fertility rate is for all ages of women, but some very small and very large ages are neglected (0 - 14, 45+). When $E(i - \beta)$ increases, fertility rate goes up, then the total birth rate stays around the same value. But when the fertility rate stays, and the life expectancy increase, the total birth rate drops, and aging starts to become more severe. The Two-child policy is adopted by the Chinese government to solve this problem.

Thus we get:

$$P(t) = P(\alpha)\prod_{i=\alpha}^{t}\left(1 - \frac{1}{1000}m(i) + s_r f(i)\frac{1}{E(i-\beta)}\right) - \sum_{i=\alpha}^{t} A(t)$$

where

- P **is the population of the country as a function of time**
- t **is the number of the year**
- α **is the start of the calculation (from 1979, for mainland China)**
- m **is the mortality rate per 1000 people**
- s_r **is the sex ratio**
- f **is the fertility rate per women**
- E **is the life expectancy**
- β **is the average age of birth giving mothers (suppose it is 26)**
- A **is the emigrant amount**

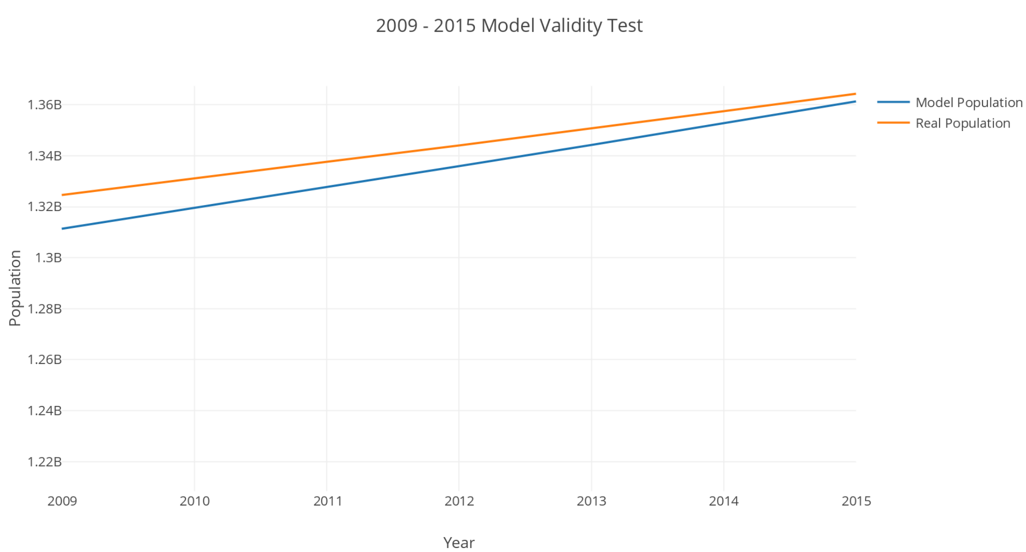


Figure 1: The model-predicted population in relation with the real population

We firstly used the data from 1979 to 2008 to get a regression-based model, then used that model to compare with the actual population. Figure 1 shows our validity test results.

The difference between the real data points and our model is not very large, and might be caused by unquantifiable parameters. Thus, we conclude that our model is relatively accurate and precise, so we can use results from our model to estimate the real population in our further analysis.

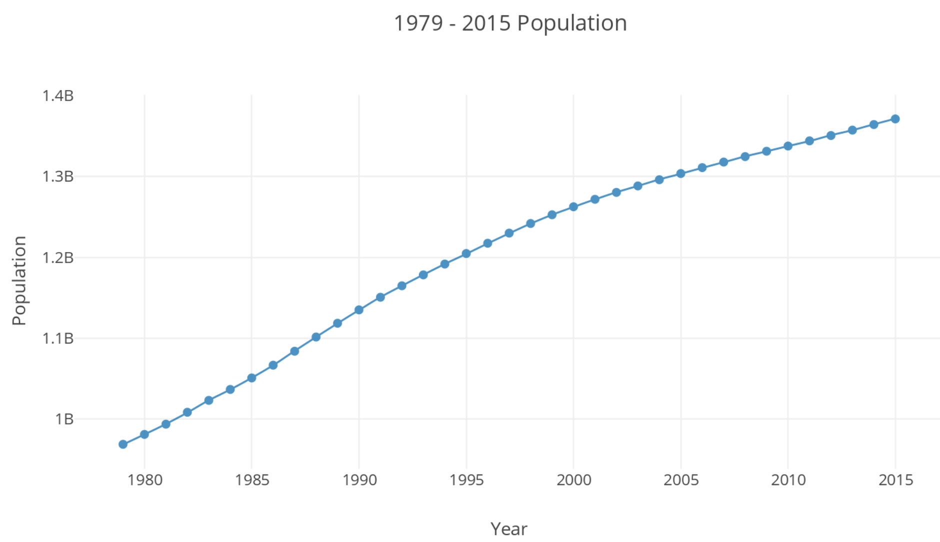


Figure 2: The population data of Mainland China from 1979 to 2015

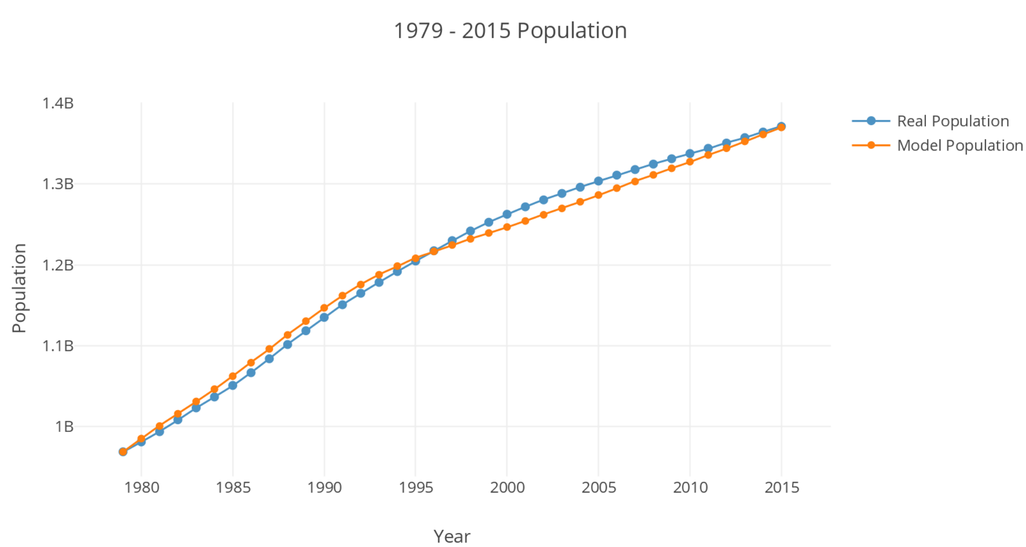


Figure 3: A comparison of the model-predicted population and the real population

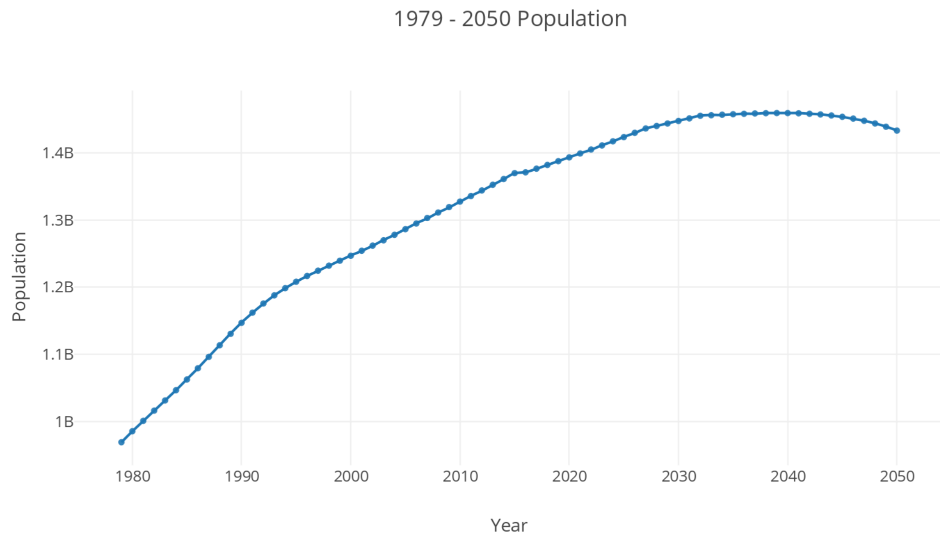


Figure 4: The model-predicted population of Mainland China from 1979 to 2050

We used data from the World Bank [b] to predict future fertility, mortality, and emigration rates, and created regression models to fit the data, and predicted these rates thirty years into the future. (Appendix 9-2)

4.2 Model Analysis

4.2.1 Is the model sensible?

We analyzed the graphs with common sense, and then with real data to validate our result to see if they make sense or not. From Figure-4, we can see a significant decrease in population starting from the late-2030s. This is the aging effect. The average life expectancy is around 80 years old, so then we realize that it represents the major percentage of the Chinese population in the 1950s and 1960s, when high fertility rates are applauded by the government.

Also, we looked at government census data, and found the population growth rate starting from the early-2010s dropped significantly, and is shown in figure 4.

4.2.2 The Aging Factor

We considered the major effect aging does to a whole population. [Tea] More elders means more tax money set aside to care for them, fertility rate drops, the labor force shrinks, and the whole GDP will decrease because of this as well.

To realistically model the aging effect, we increased our mortality rate by different amounts in different times. The first wave of aging will come in around 2025, and a larger wave will come around 2030. We increased our mortality rate by 30% in the first wave, then another 30% in the second wave of aging. Using data from previous census, it is evident that aging is now a problem. This can be graphically seen in figure 5

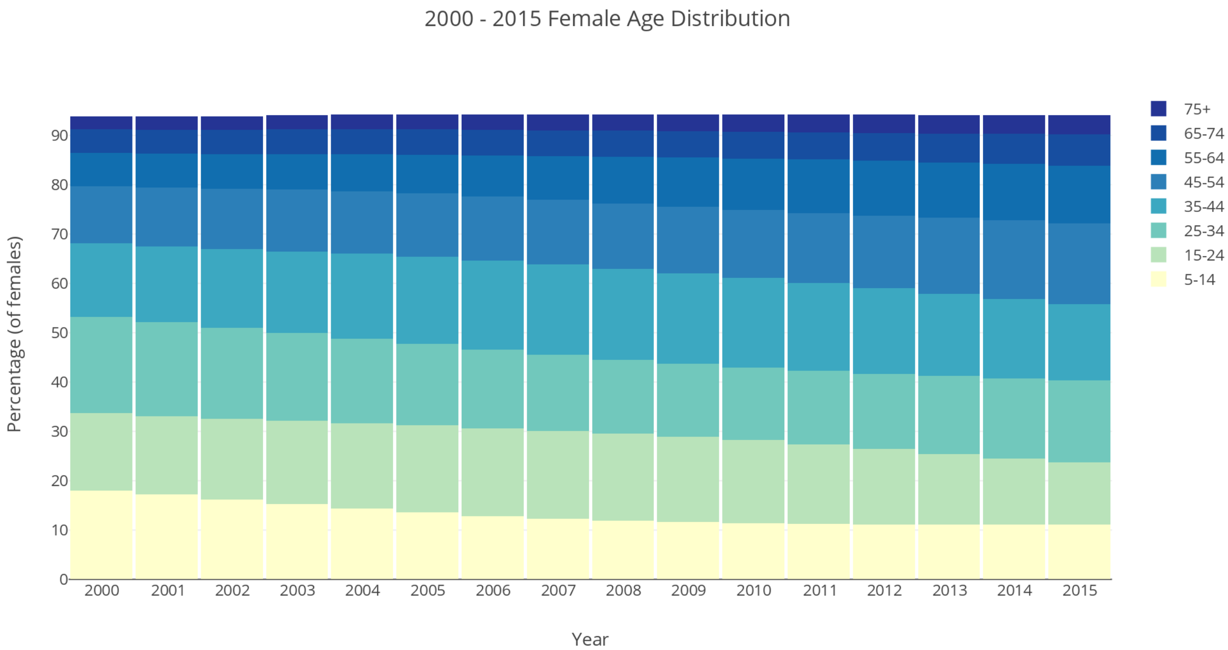


Figure 5: The female age distribution from 2000 - 2015

4.3 Sensitivity Analysis

Our model has covered several main factors; however, there are still a few uncontrollable factors that are likely to affect the outcome of our model. In order to handle uncertainty, we have to analyze the sensitivity of our model, based on a sensitive comprehensive evaluation result.

To analyze the sensitivity, we ran our model with a different set of parameters, and analyzed the result to see if it is valid.

We tested our model with a population crippling disaster - an epidemic - resulting in a sudden mortality rate drop. We supposed that a disaster was to hit Mainland China in 2014, and thus increased the mortality rate of 2015 by 2.35%, a rate we calculated from the Spanish Flu in 1917, and found that the epidemic will decrease the population by 2%.

We also calculated an F-Test on the Population Model, and the results indicate that, with a relatively high p-value, it is very accurate and fitting to the real population data [b], and our initial model of Population Model is capable of adapting random events and different circumstances, effectively.(Appendix 9-3)

5 Models of Urbanization

Based on our Population Model, we developed an Urbanization-Dependent Model, for the sake of predicting population of urban area within a country. As we know, the logistic

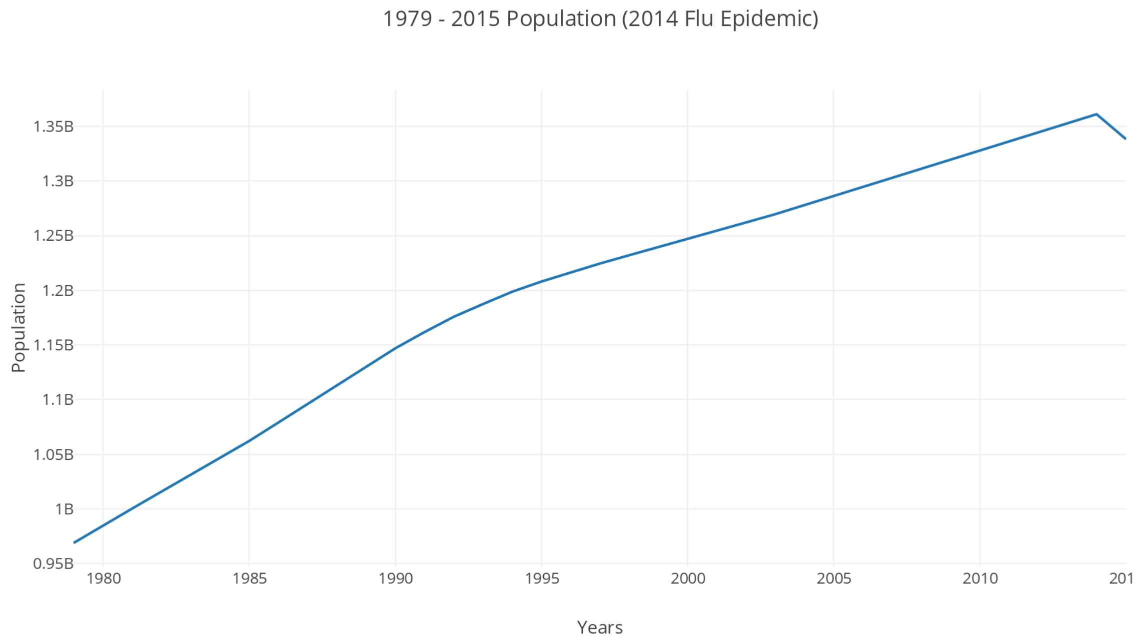


Figure 6: The model-predicted populations if there were a large epidemic in 2015

model roughly fits in population models. So we compared these two models, and used a computer program to simulate the time when the city will reach its carrying capacity. When our two population models intersect, and the intersection population is very close to the carrying capacity, we will call this situation as when the population will reach its carrying capacity.

5.1 Urbanization-Dependent Model

When we derived the function of population of a country(see 4.1-Population Model), we used a similar function(Emigration) when evaluating a country's population. However, it differs: when we calculate a city's population, we can neglect the small emigration amount, but have to include urbanization. During the process of urbanization, people move from rural areas to urban areas. So, we decide to add a variable, U, into the function, shown by,

$$P(t) = P(t-\alpha)\prod_{i=t-\alpha}^{t}\left(1-\frac{1}{1000}m(i)+s_r f(i)\frac{1}{E(i-\beta)}\right)+U(t)$$

where,
♠ U is the population change between urban areas and rural areas as a function of time (All the other symbols remain the same definition as it is in 4.1-Population Model)

The Urbanization-Dependent Model has a greater possibility to be accurate and show a clearer evolution of population changes of modern urban areas than rural areas.

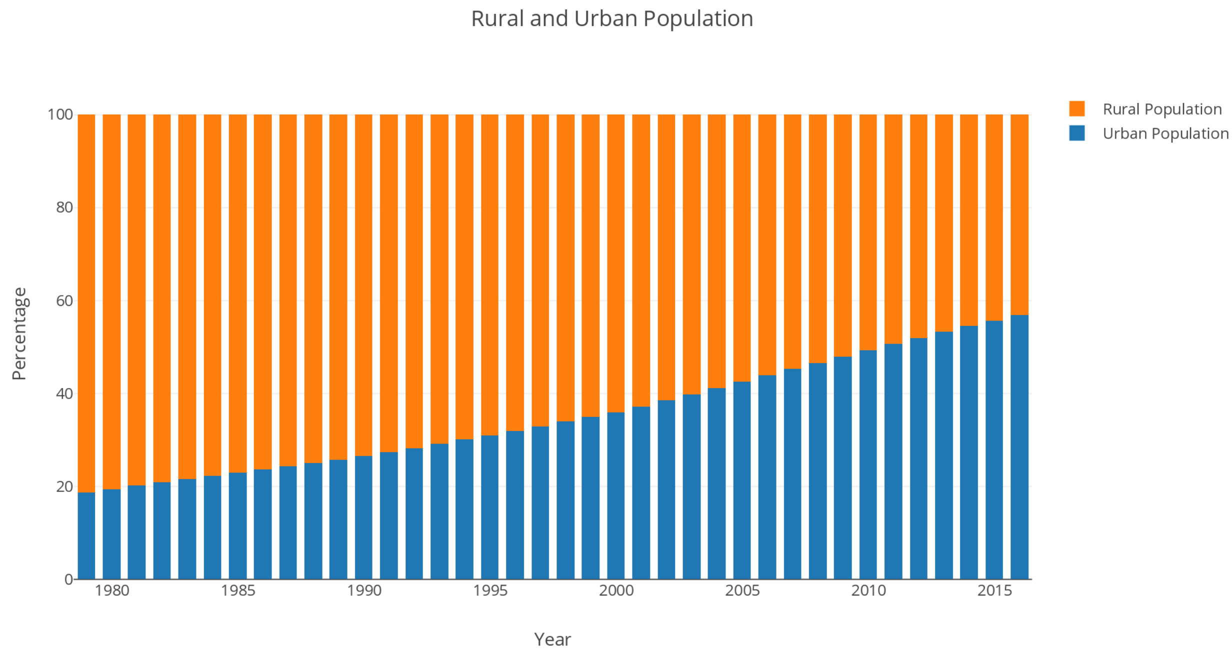


Figure 7: The rise of urbanization, shown graphically

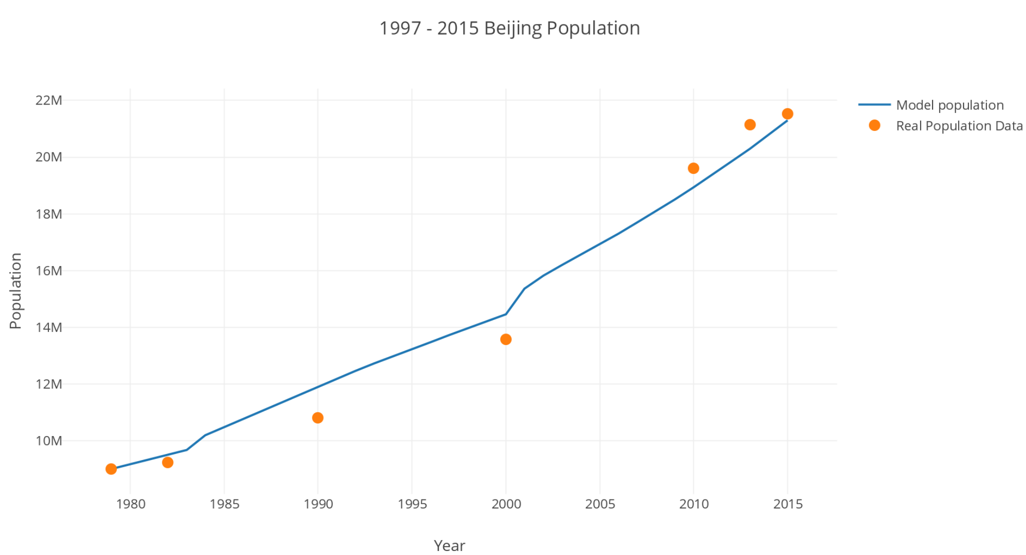


Figure 8: Prediction of population of Beijing from 1979 to 2015, compared with the real data.

Shown in figure 8: Using the real population data from several Beijing census, we used our model to compare with the real population data of Beijing. The recorded population of Beijing in 2015 is 21.52 million, and our model predicted 21.29 million, a very close prediction.

5.2 Logistics Model

According to Pierre François Verhulst's differential equation [n] describing population growth: $\frac{dP}{dt} = rP\left(1 - \frac{P}{K}\right)$, which takes into account the rate of reproduction of a region, the amount of resources available in that region, and the existing population. Solving the differential equation, we wrote it in the form of logistic function, shown by:

$$P(t) = \frac{K \cdot P_0 \cdot e^{rt}}{K + P_0 \cdot (e^{rt} - 1)}$$

where
- P **is the population of a city as a function of time**
- t **is the year**
- K **is the carrying capacity of the city**
- P_0 **is the cardinality of the population of the city, and for this model, we use 1979**
- r **is the reproductive capacity, which is the product of sex ratio and the probability of females who have higher fertility(15-44) getting pregnant that year; and we calculated that the value of** r **is a constant: 0.075**

This function was made up theoretically, and it derived to describe a biological population growth. Thus, we may use it as an "ideal" function of predicting human population.

The logistics function represents how the population of a city changes, in consideration of carrying capacity, sex ratio and age distribution. Therefore, we may compare and contrast the two functions shown in 5-Models of Urbanization, and compute the population of some typical cities in Mainland China, to confirm that our Urbanization-Dependent Model is accurate in a certain period of time.

5.3 Real-World City Analysis

Comparing the Urbanization-Dependent Model that we have made and the logistic model that scholars have made, there is a great possibility of differences' presence. Therefore, in order to develop our further model, we have to analyze our model by placing it into operation, to solve real demographic issues that is happening today.

5.3.1 Beijing Population Model

We first draw the graphs of our model and logistics model:

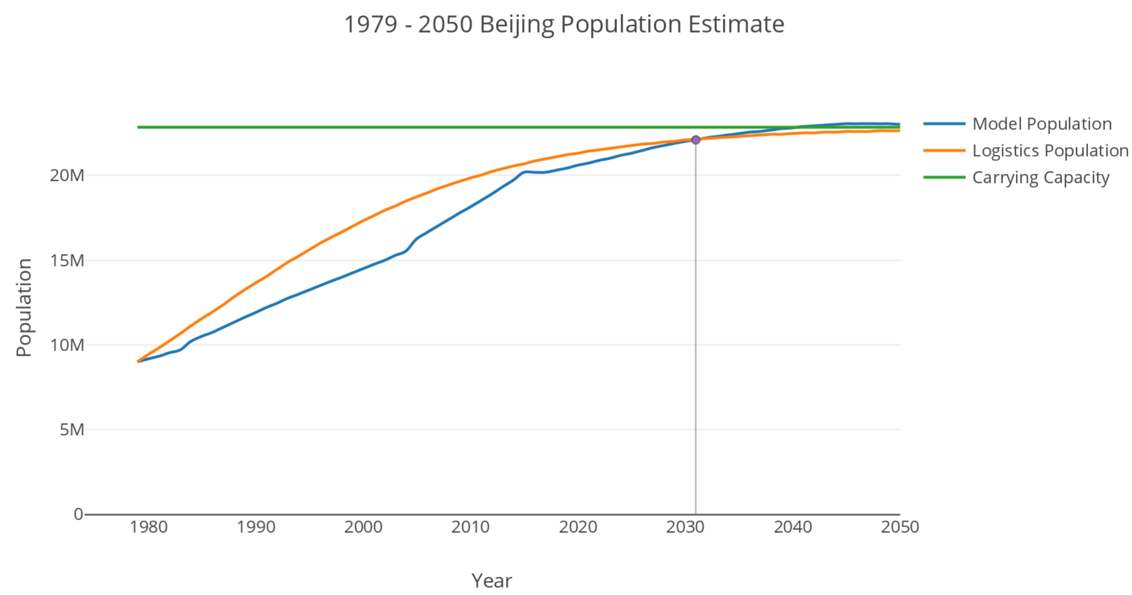


Figure 9: A comparison of the logistics model and our population model, predicting the population of Beijing from 1979 to 2050

Since we have considered many variables, which make our prediction clearer, the model population tends to be different from the logistics population. Our model fits more with the actual population growth, thus we mainly used the logistics equation as a reference, and to determine the time when the population reaches the carrying capacity.

The graph of our model and logistics model has an intersection in the year of 2031, as the vertical line shows in the figure. After two curves meet, they keep increasing and our model population shows a faster average speed of increase.

5.3.2 Carrying Capacity Analysis

The area of a city is constant, but its population keeps changing, and eventually the resources within the city region will not be able to supply the large population.

In ecological terms, the carrying capacity of a biological species in an environment is the maximum population size of the species that the environment can sustain indefinitely, given the food, habitat, water, and other necessities available in the environment. [h] Basically, the carrying capacity is the maximum population that a region is able to hold.

We looked at cities with a high urban population, and according to their population dispersion, we found that the carrying capacity depends on the urban area of the city, not the whole metropolitan area.

Analyzing various cities, we realized that the carrying capacity(K) does not increase as urban area increases, instead, it decreases. Although a city might have an expansive

urban area, its resources might not be keep up with its population demand. Taking this into account, we devised a model:

$$K = \begin{cases} cityUrbanArea * 16500 & cityUrbanArea < 2000 \\ cityUrbanArea * 9800 & cityUrbanArea \geq 2000 \end{cases}$$

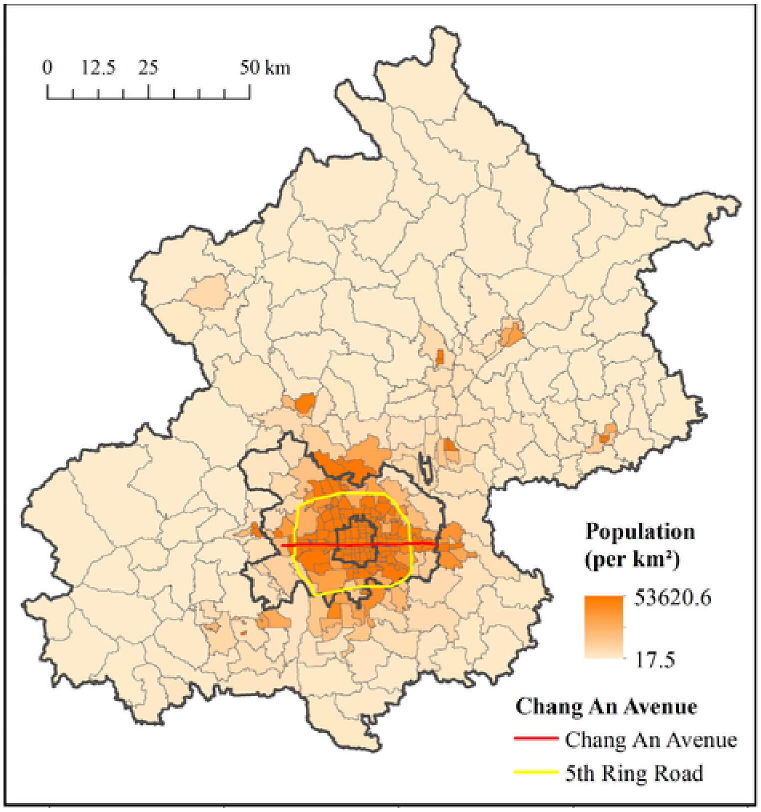


Figure 10: The population density of Beijing

By this model, Beijing, with an urban area of around $1350km^2$, has a carrying capacity of 22.8 million.

6 Satellite City Construction

6.1 Overpopulation

Owing to continuous development, a large number of cities and countries now has to cope with the growth of population. By definition, overpopulation refers to an unfavorable condition where the number of population exceeds the carrying capacity of a city or a country. Specifically, our team takes aim at the overpopulation problem in Beijing.

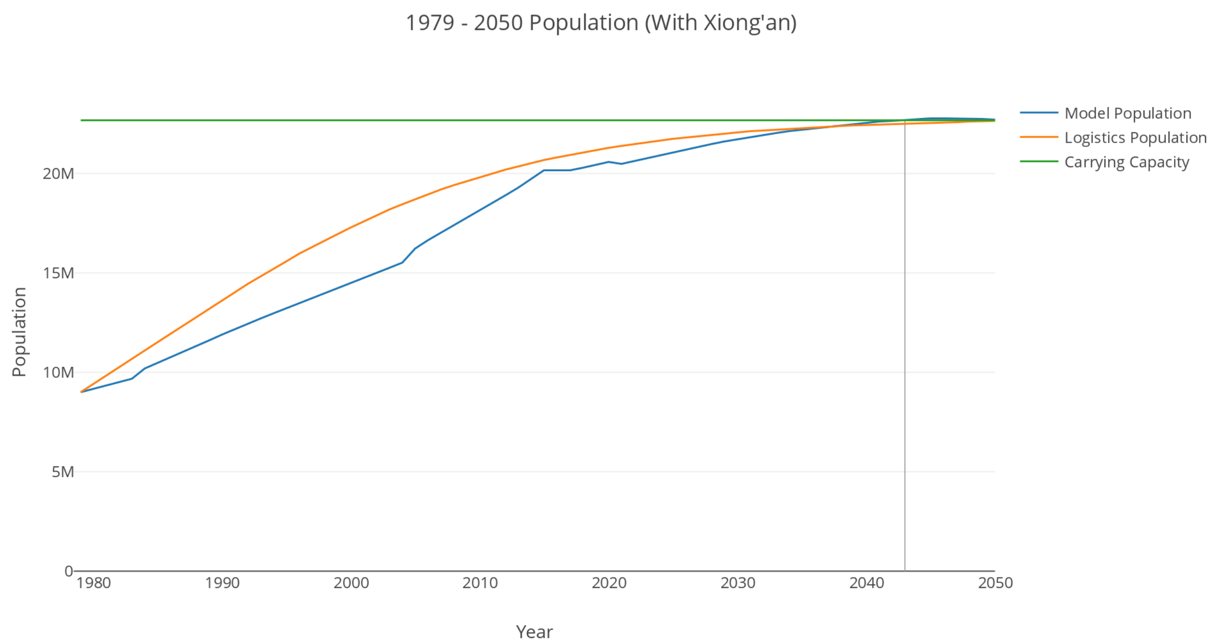
According to our population model for Beijing, we anticipated that the population of Beijing will exceed the carrying capacity by 2031.

Concerning the problem, in 2016, the Chinese government strives to disperse the dense population in Beijing (22 million) by means of relocating people to Xiong'an, a new developed area south of the megalopolis. According to the data available, 500 thousand people will be transferred to Xiong'an in around 2019. [i]

6.1.1 Problems

We used our urbanization-dependent model and logistics model to approximate the population trend of Beijing within 30 years of the relocation. Due to the estimated data from our model, the population under the policy will grow safely beneath the carrying capacity (P(t) max) before 2030. Yet, Beijing's population will still exceed the carrying capacity in 2041. In this case, government's proposal fails to work out the overpopulation problem thoroughly.

6.1.2 Data



6.2 Our Solution

6.2.1 Definition of Satellite City

To solve the overpopulation Problem, we came up with our own solution. We recommend transferring a scant amount of the total population out of the central city through building satellite cities. In urban planning, a satellite city, or satellite town, is a term referring to a smaller city system usually located near to, but mostly independent to a metropolis. Building satellite cities can share responsibility for some of functional module of a metropolis, such as population, industry, real estate etc. In our model, we defined a satellite city to be a minimum of 20 km from the city center, and at most a distance of 80 km, so that the satellite city would be partly connected to the city, while still maintaining its quasi-independent status.

6.2.2 Location of Satellite City

The government has planned to build satellite city since 1957; however, after developing in 60 years, only one "city" is successfully established, Shunyi.

Figure 11: The location of satellite cities around Beijing
[k]

In order to solve the overpopulation problem in Beijing, we selected three ideal locations of the new satellite city. [j]
①**Huilongguan**
Huilongguan is chosen because of its adequate real estate resources. Some of the blue collars is not able to afford the high house price, so they need a place with low housing price. Huilongguan, where is only 18.9 kilometers far from the center of Beijing, become a perfect choice.
②**Xianghe**
A good satellite city should have advantages of connecting metropolises and developing its own industry; Xianghe has both two advantages, thus we choose this area.
③**Langfang**
We chose this area because it is a transportation hub for Beijing, and can disperse the heavy traffic pressurized on Urban Beijing. A satellite city stationed at this area can effectively become a center of railway stations, airports, bus hubs, and more.

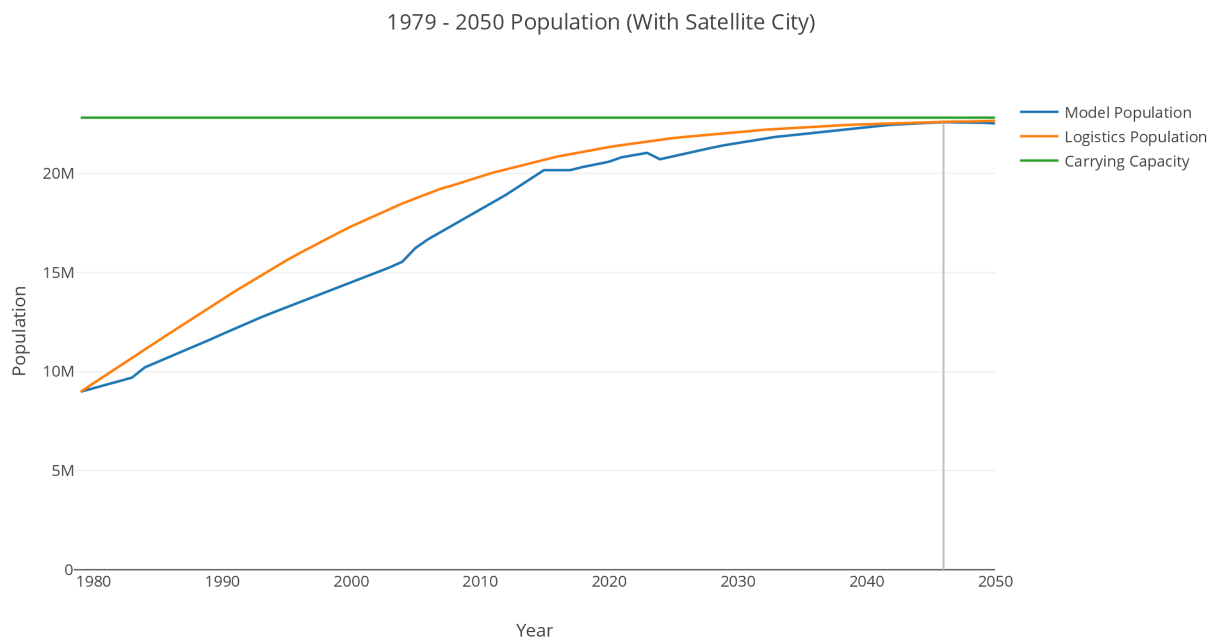
6.2.3 Policy Solution

Using our model, we found an optimal solution to this overpopulation crisis. We decided that smaller, closer satellite cities are the way to go. We chose three locations: Huilongguan, Xianghe, and Langfang, and want to relocate specific businesses and residents to these areas.

Our policy is a gradual relocation process, taking up three years. Based on current observations and common sense, we deduced that a one-year relocation plan would be insensible. It is impossible to move such a large amount of people and get them settling

down in one year, and a one-year relocation will only make it not overpopulated for a short period of time. Thus, we propose that Beijing relocate 1% of its population on the first year, 1.2% on the second year, and 1.4% in the last year. This can lead to steady population growth in both Beijing and the three satellite cities we chose.

We also gave a plan on who to relocate:
First, some major businesses associated with the satellite cities would be moved first, and we associated Xianghe for joint venture, Langfang for companies heavily relying on complex transportation connections.
Second, we considered the age issues. We assumed that relatively young people would not change their dispositions in the future, thus we can assume that most young people are more willing to accept change, face hardships, and see things in a new light. These people are perfect for relocating into farther areas.
Third, since young people are planned to move to farther areas, they need to work to be affordable with his living necessities; labor force, therefore, become one of our considerations. With a large working population, Huilongguan, where has adequate real estate with affordable prices, will evolve into a center for young workers in Beijing.



7 Strengths and Weaknesses

7.1 Strengths of Our Model

1 We used a combination of past data and regression models to develop our population estimate, which is very accurate. Our model only uses a starting population, which is very easy to come by.
2 We used statistics from authoritative sites, for example: National Bureau of statistics of China [l], The World Bank DATA [b], UNdata [m], etc, so our data used is reliable.
3 Our model was based on our own inspirations and ideas, and fully authentic. Thus, no copyright issues are involved.

4 **Our model can be applied to both estimating national population and regional population, giving the model a wider usage.**
5 **Our model can effective predict the population trends if a major event made sudden changes to the population.**
6 **Our model is flexible, and can predict the population trends of any country, given the past data.**

7.2 Weaknesses of Our Model

1 **The model cannot calculate population growth prior to 1979 or after 30 years from now.**
2 **During our derivation of our model, we eliminated some outlier points, making a few estimations relatively unreliable.**
3 **We do not find the theoretical value for any of the variables in our model, so these data that we predicted can only approximate the true values.**
4 **We do not other variables that might have effects to the value of population, like women labor force and education level.**
5 **We can not analyze the evolution of sex ratio with our model.**

8 Conclusion

In conclusion, we developed two models, the Population Model and Urbanization-Dependent Model, to predict the population of any country or any city provided that a few data points are given. As with China and Beijing, we estimated that there will be 1,448,051,116 and 23,059,377 people three decades ahead, respectively. By further analyzing, we validated that our model is not sensitive to changes in parameters, which means that the model can be used if real situations like population-crippling accidents, such as epidemics or wars.

Then we referred to Pierre François Verhulst's logistics population model [n], to further predict the population of real world cities, by comparing our model and the published model. As shown in figure 7, we can see that the population of Beijing tend to reach Beijing's carrying capacity of the roughly estimated 22.8 million, which brings about the problem of overpopulation.

Furthermore, we found out that the establishment of satellite cities can solve overpopulation. Although the government had made steps to solve this immediate problem with Xiong'an, according to our calculations, it may only delay the threat of reaching the capacity. Thus, we put forward our own solution, which can solve the problem thoroughly and permanently.

We chose three regions near Beijing and separated them by giving different practical uses — for joint ventures, working class residents, and transportation. Using our solution policy, we estimated that the population in Beijing will be a roughly 22,573,200 by 2047.

If the data we used to derive the model were accurate and precise, then we can conclude that we can effectively model the future population trends in three decades, can help urban cities plan for overpopulation, if that occurs.

Given more time, we can add more factors that can change population, such as labor force, medical advancements, higher education levels, etc, into our model, which can make it more precise.

9 Appendix

9.1 Factors That Could Affect Demographic Transition

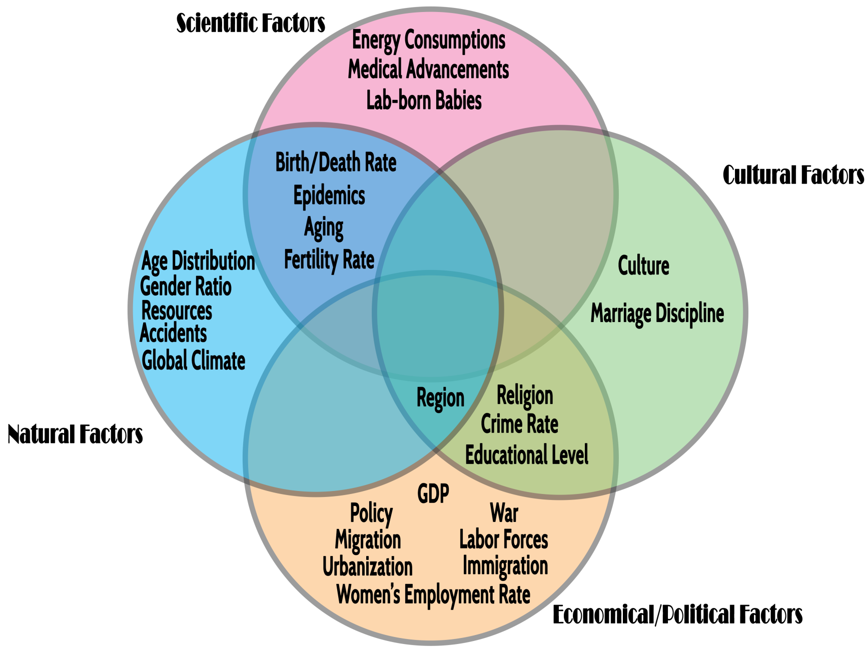


Figure 12: Factors That Could Affect Demographic Transition

9.2 Parameters of the Population Model

The regression analysis function of the mortality rate: $m(x) = \| -2.72x + 4546.81\| + 637.98$ **(See Figure 14)**

The regression analysis function of the fertility rate: $f(x) = -1.7467 \cdot 10^{-9}x^5 + 5.25 \cdot 10^{-7}x^3 + 1.500051 \cdot 10^{-3}x^2 - 9.10526 \cdot 10^{2}x + 2.9377$ **(See Figure 15)**

The regression analysis function of the life expectancy: $E(x) = 0.142x - 210.013$ **(See Figure 16)**

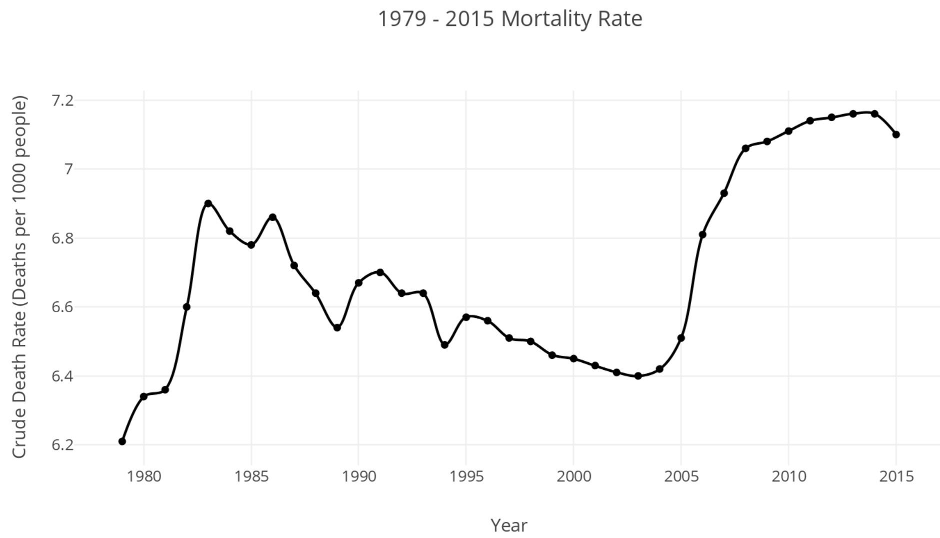
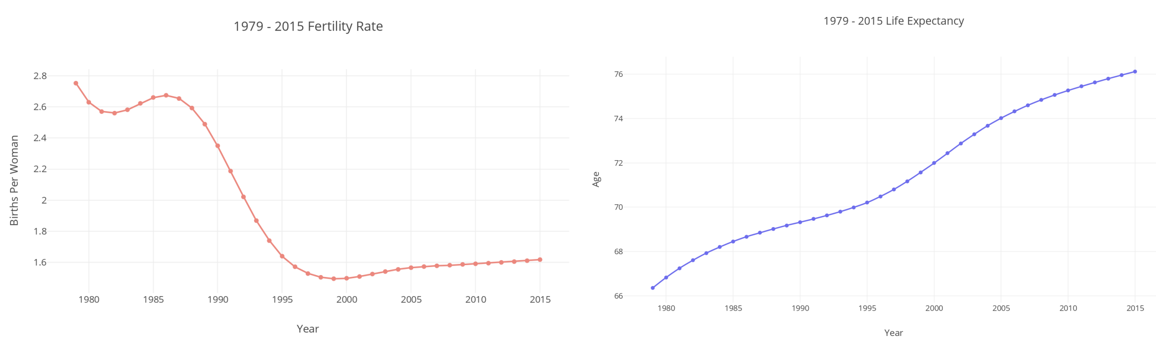


Figure 13: Mortality Rate

9.3 F-Test of the Population Model

$$statistic = 0.0051791669112102113$$
$$pvalue = 0.94282816249558166$$



(a) Fertility Rate

(b) Life Expectancy

Figure 14: Fertility Rate and Life Expectancy

9.4 Code

9.4.1 Population of Mainland China

Listing 1: Population of Mainland China

```
import csv
import math
import matplotlib.pyplot as plt
import scipy.stats as stats
import matplotlib.style as style
import numpy as np

fertRate, mortRate, popEachYear, realPopEachYear = ([], [], [], [])
mortalityArray, fertilityArray = ([], [])


# Calculating the fertility and mortality rates in the future
def fertility(t):
	return -1.7467 * math.pow(t, 5) + 525 * math.pow(t, 3) + 1500510 * math.pow(
	    ↪ t, 2) - 91052600 * t + 2937700000


def mortality(t):
	return abs(-2.27 * t + 4546.81) + 637.98


for i in range(2016, 2051):
	mortalityArray.append(mortality(i))
	fertilityArray.append(0.000000001 * (fertility(i - 1979)))

# Result due to aging
for i in range(0, 35):
	if 10 < i <= 15:
		mortalityArray[i] *= 1.3
	if i > 15:
		mortalityArray[i] *= 1.6

# Reading currently available data
with open('FertilityRate.csv', 'rb') as csvfile:
	fertReader = csv.reader(csvfile, delimiter='\t', quotechar='|')
	for row in fertReader:
		for letter in row:
			fertRate.append(letter)
with open('MortalityRate.csv', 'rb') as csvfile1:
	mortReader = csv.reader(csvfile1, delimiter='\t', quotechar='|')
	for row in mortReader:
		for letter in row:
			mortRate.append(letter)
with open('PopulationData.csv', 'rb') as csvfile2:
	popReader = csv.reader(csvfile2, delimiter='\t', quotechar='|')
	for row in popReader:
		for letter in row:
```

```
                    realPopEachYear.append(int(letter))

# Using our model to calculate the past population trends
for a in range(37):
        factor = 1.00
        for i in range(len(fertRate) - (37 - a)):
                factor *= (1 - float(mortRate[i]) / 1000 + float(fertRate[i]) /
                    ↪ (114.0))
        total = factor * 969005000.00 - 1019429 * a

        popEachYear.append(int(math.ceil(total)))


# Using our model to predict future population trends
for a in range(35):
        factor = 1.00
        for i in range(a):
                factor *= (1 - mortalityArray[i] / 100000 + fertilityArray[i] /
                    ↪ 134.0)
        total = factor * 1371220000 - 1019429 * a
        popEachYear.append(int(math.ceil(total)))
```

9.4.2 Beijing Population with Satellite Cities

Listing 2: Beijing Population with Satellite Cities

```
import csv
import math
import matplotlib.pyplot as plt
import numpy as np
import matplotlib.style as style

fertRate, mortRate, popEachYear, realPopEachYear = ([], [], [], [])
mortalityArray, fertilityArray = ([], [])

#Self-controlled variables
startingCalcYear = 1979
endCalcYear = 2050
cityStartPop = 9000000 #1979 Population
cityUrbanArea = 1630

#Dependent variables
yearsAfter15 = endCalcYear - 2015
yearsAfter79 = startingCalcYear - 1979
cityMetArea = 3460
if cityUrbanArea < 2000:
        cityCarryCap = cityUrbanArea * 16500
elif cityUrbanArea >= 2000:
        cityCarryCap = cityUrbanArea * 9800
```

```
# Calculating the fertility and mortality rates in the future
def fertility(t):
       return -1.7467 * math.pow(t, 5) + 525 * math.pow(t, 3) + 1500510 * math.pow(
          t, 2) - 91052600 * t + 2937700000


def mortality(t):
       return abs(-2.27 * t + 4546.81) + 637.98


def futLogPop(t, startPop, carryCap, rateChange):
       return float(startPop*carryCap*math.exp(rateChange*t))/float((float(carryCap
          )+float(startPop)*(math.exp(rateChange*t) - 1)))


for i in range(2016, endCalcYear+1):
       mortalityArray.append(mortality(i))
       fertilityArray.append(0.000000001 * (fertility(i - startingCalcYear)))

# Result due to aging
for i in range(yearsAfter15):
       if 10 < i <= 15:
              mortalityArray[i] *= 1.3
       elif i > 15:
              mortalityArray[i] *= 1.6
       elif i >= 27 :
              mortalityArray[i] *= 0.97

# Reading currently available data
with open('FertilityRate.csv', 'rb') as csvfile:
       fertReader = csv.reader(csvfile, delimiter='\t', quotechar='|')
       for row in fertReader:
              for letter in row:
                     fertRate.append(letter)
with open('MortalityRate.csv', 'rb') as csvfile1:
       mortReader = csv.reader(csvfile1, delimiter='\t', quotechar='|')
       for row in mortReader:
              for letter in row:
                     mortRate.append(letter)
with open('PopulationData.csv', 'rb') as csvfile2:
       popReader = csv.reader(csvfile2, delimiter='\t', quotechar='|')
       for row in popReader:
              for letter in row:
                     realPopEachYear.append(int(letter))

# Using our model to calculate the past population trends
for a in range(37):
       factor = 1.00
       for i in range(a):
              factor *= (1 - float(mortRate[i]) / 1000.00 + float(fertRate[i]) /
                 (114.0))
```

```
        total = 0
        if popEachYear != []:
                if a > 21:
                        total = factor * cityStartPop + popEachYear[-1] * 0.011 * a
                elif 5 <= a <= 21:
                        total = factor * cityStartPop + popEachYear[-1] * 0.009 * a
                else:
                        total = factor * cityStartPop + popEachYear[-1] * 0.0015 * a
        else:
                total = cityStartPop

        popEachYear.append(int(math.ceil(total)))

# Using our model to predict future population trends
for a in range(yearsAfter15):
        factor = 1.00
        for i in range(1, a):
                factor *= (1 - mortalityArray[i] / 100000 + fertilityArray[i] /
                    ↪ 114.0)
        total = factor * popEachYear[36]
        popEachYear.append(int(math.ceil(total)))

nriArray = []
for i in range(len(fertilityArray)):
        nriArray.append(1 + (float(fertilityArray[i]) / float(popEachYear[i]) *
            ↪ 1000.0 / 114.0 - mortalityArray[i] / 1000))
for eachElement in nriArray:
        if eachElement >= 0:
                eachElement = 1 - eachElement


futureLogArray = []
for i in range(endCalcYear - startingCalcYear + 1):
        futureLogArray.append(futLogPop(i, cityStartPop, cityCarryCap, 0.075))


a = []
for t in range(len(popEachYear)):
        a.append([abs(int(cityCarryCap * 0.92 - popEachYear[t])), t])
smallest = [a[0][0], 0]
for i in range(len(a)):
        if a[i][0] < smallest[0]:
                smallest[0] = a[i][0]
                smallest[1] = i
print smallest[1] + startingCalcYear
```

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