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Summary Sheet

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Progress must be accompanied by environmental sustainability, or else it is just a fantasy mankind constructs to shield themselves from the horrors of the future. In response to the need of procuring a bright future for the generations to come, governments have taken the initiative to pass policies aiming at sustainable progress of the society. The ban on single-serving plastic bottled water, as enacted by governments of Concord (MA) and San Francisco(CA), is a great example of such an initiative.

A ban on single-serving plastic bottled water on the surface will decrease plastic consumption and waste within a community, but diving into the issue we see that the ban will result cascade of impacts on not only the environment, but also the local society and economy. We constructed an algorithm accounting for the interconnectedness of the 12 most important variables contributing to the overall impact of the ban, using which not only to provide a comprehensive overview of the effects on society as a whole and track the progress of environmental improvements but also offer valuable insights to government, corporate and individual responses and adjustments towards the prospect of the future.

In our general model concerning the ban, the government is the only active player: after it enacted the ban, various social, economic and environmental impacts will occur. Then the government will adjust the current situation according to the changes in different variables, such as total plastic wastes produced and accessibility of water, mainly through altering and balancing 3 types of government spending: spending on subsidies for producers of substitute goods of single-serving bottled water, on preservation of the environment, or on construction of infrastructure concerning the availability of drinkable water. Based upon our model, ideally the government will react to the impacts brought by the ban to stabilize the social welfare.

Although our model overlooks certain small factors of the ban's impact and is based on ideal assumptions such as the government is able to react swiftly towards changes in society by using fiscal means, we have faith that our model is representative enough to be considered significant.

"IT'S THE WATER BOTTLES' FAULT…"

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2. Assumptions and Justifications

2.1 *Assumptions*

0. Provided by the references in 2019 HIMCM prompt, “single-serving water bottles” refers to all single-serving plastic water bottles, so favored and/or sparkling beverages contained by plastic bottles can still be sold[1].
1. When plastic water bottle ban is enacted, all citizens will strictly comply with it and violation to it seldom occurs to an extent that is negligible.
2. Population within the city remains the same, and migration is negligible.
3.The government is capable of observing societal changes and making response.
4. Consumers’ total demand and quantity demand of drinks stay the same.
5. Water contained in substitutes will replace water contained in plastic bottles.
6. No one in the city reuses a single plastic bottle long enough (about 6 months) to cause severe health damage (like cancer), so the damage to health is negligible.
7. The supply of any kind of drink in the market equals the demand of it.
8. Change in a variable can be predicted by the changes in other variables.
9. A variable’s change over time does not necessarily reflect the actual proportional change, and the growing trend may differ from the exact reality. Nonetheless, it gives us a general sense of how it changes.
10. The existing public infrastructure's role in supplying drinking water is relatively small immediately after the ban; bottled water and/or drinks still remain as the mainstream of daily drinking water supply and consumption.
11. All of the economic variables in the model are only applied to specific industries within the city and does not consider the impact of the ban on foreign economy.

2.2 *Justifications*

1. Governments will strictly enforce the law, which can be referred from their penalties to the violators. Also, towns like concord have their citizens voted for the banning policy, so we assume most citizens tends to comply to the law.
2. Comparing to the majority of the population that stay in city for the majority of the time, migration constitutes an extremely small portion of the city.
3. Most of the governments in the world do not excise a laissez faire economy and attentively involve in economy to guarantee the wellbeing of the society.
4. The consumer's demand of the drinks is stable no matter of the policies taken because water is a necessity of life.
5. Substitutes are extremely influential in demand, as justified by market reaction.
6. The cities that employ the plastic bottle ban policy tends to be highly developed, so we assume the citizens’ health awareness are high enough to an extent to which they can recognize the harm of permanent use of plastic bottle.
7. The supply and demand will self-adjust, in cooperation with regulations by the government, so in the drink city’s market supply equals demand.
8. Most of the variables are interrelated, as represented in figure 4.2.
9. The modeling of relationship between the variables cannot be extremely accurate due to their complexity, but can give an overall trend of change.

10. Initially, the relatively small quantity of existing public water fountains cannot meet the large demand of drinking water, so packaged water remained significant.
11. The city's government should only consider the economic condition within the city instead of economic conditions elsewhere.

3 Possible Impacts of the Ban and Data Collection

3.1 ***Environmental Impacts***

(A) Positive:

1. Decrease in non-degradable materials & their damage to soil
2. Decrease in pollution caused by transportation of single-serving bottled water
3. Decrease in use of fossil fuels that are used to produce single-serving plastic bottles
4. Decrease in wasted unfinished water by eliminating single-serving containers
5. Decrease in garbage on the ground and improvement of city appearance as disposal of used single-serving bottles decrease

(B) Negative:

1. Increase in the exploitation of other natural materials in the production of substitutes to the single-serving plastic bottles, such as tin cans and paper cartons

3.2 ***Social (Health) Impacts***

(A) Positive:

1. Decrease in cancer rate as the intake of potential carcinogenic plastic molecules caused by consumption of single-serving bottled water is reduced
2. Motivation for innovation towards more efficient means of storage and transportation of water as it presents itself as an opportunity in the market
3. Increase in awareness of environmental issues and eco-friendly conducts due to government actions in that direction

(B) Negative:

1. Decrease in rate of emergent response due to the elimination of efficient distribution through single-bottled water
2. Damage to health due to consumers' increased demand for substitute beverages, especially those containing high sugar level
3. Discontent of public towards the inconvenience of purchasing and storing water
4. We did not include "reduction to damage by plastic bottles to health"

3.3 ***Economic Impacts***

(A) Positive:

1. Increase in profit of companies that produce other kinds of drinks like soda as consumers seek substitutes to easily accessed drinks
2. Decrease in government spending on disposing plastic waste and preventing pollution resulting from the plastic bottle waste
3. Increase in demand initially for household water to serve as a substitute to single-serving bottled drinking water
4. Increase in demand of more permanent water-storing containers like glass cups

(B) Negative*:*

1. Decrease in gov't budget as government receives no tax input from single-serving

plastic bottles and must increase spending to maintain more efficient infrastructure for the accessibility of drinking water and balance the aggregate spending of the economy due to decrease in consumer spending as the single-serving water bottles are banned
2. Profit loss of companies that supply single-serving plastic bottles for drinking water
3. Decrease in consumer spending on single-using water bottles

4 Information and Data

We will observe the changes in the following data and information to measure the impacts caused by the ban on single-serving water bottles.

4.1 ***Environmental Impacts***

1. Quantity of raw materials used for producing plastic bottles: information is represented by sampled production costs of single-serving bottles
2. Quantity demanded of substitute goods of single-serving bottled water: data is extrapolated from sampling the quantity of substitutes sold by local vendors bimonthly
3. Government spending on cleaning and disposing plastic waste: data is obtained through the annual report of estimated government spending in said area
4. Average proportion of water wasted: data is hard to obtain
5. Public attitude towards the overall appearance and environment of region: information is obtained through public poll rating the appearance of regions
6. Quantity of fuel used in the transportation of single-serving bottled beverages: information is represented and estimated from the sampling of the quantity of all types of single-serving drinks supplied to local vendors

4.2 ***Social Impacts***

1. Casualties in natural disasters: data (though unrepresentative) is obtained through government records
2. Overweight condition of the population: data is estimated through health records and represented by the local sale of sugar-containing single-serving substitute drinks
3. Public attitude towards the inconvenience caused by the ban: information is obtained through official polls on online media regarding attitudes towards the ban
4. Rate of getting cancer: information is obtained through medical reports but is only useful after decades and unrepresentative of the effect of plastic bottles on health
5.Government subsidy for producers of substitutes of single-serving bottled water: data is obtained from government spending in said area

4.3 ***Economic Impacts***

1. Average volume of water used per household: data will be obtained monthly from utility companies that supply household water
2. Increase in the purchase of permanent water-storing commodities: data will be estimated from sampling the quantity consumed of such containers at local vendors
3. Government revenue: data is obtained through government records
4. Profit of plastic bottle producers: data is obtained from said producers' reports
5. Profit of substitute drink producers: data is obtained from said producers' reports

6. Government subsidy for producers of substitutes of single-serving bottled water: data is obtained from government spending in said area

5 The General Model

It is typically easier to model a societal phenomenon with the use of Big Data. We believe that if we can find detailed, comprehensive data about Concord and San Francisco, our problem will be quite more simplified, which is the case of part (b). But, sadly, we cannot actually do this.

Hence, for part (c), we attempt to model the impacts of banning the sale of single-serving plastic water bottles on a city by a dynamic model based on differential equations and analysis of dimensionless variables. We call this model the "General Model," and it can model the impact of the ban on San Francisco. Please note that it cannot model the impact of the ban only specific types of single-serving plastic bottles, such as in Concord, for which we will use another model (refer to 7.1).

The reason for using dimensionless variables is – it is extremely difficult to relate quantitative data, like gain in profit of companies, with measures that are intrinsically qualitative, like the opinion of people. Also, it is risky to predict the actual amount of change in any variable, like the government spending. Our model simulates the state change of a hypothetical city after the ban on sale of plastic water bottles is enacted. It calculates the growth rate of each variable at a moment and repeats this process through numerous tiny time intervals. The state of the city will gradually stabilize, when we can compare each variable to its original value to figure out the change in proportion.

5.1 *The 12 Variables*

From part (a), we summarize the following 12 variables to represent the state of the city:

1. The proportion of the volume of substitutional bottled water, S_B:

Once the law is enacted, the sale of water stored in cans and glass bottles will grow until it reaches the original proportion of plastic bottle water's volume in the entire drink market before the ban. S_B measures the proportion of water sold among the entire drink market.

2. The proportion of volume of beverages demanded, D_B:

Immediately after the enactment, water companies need some time to convert their production to substitutional bottles, so during this time the demand for beverages (non-pure water drinks) would increase, based on the fact that many are too "lazy" to bring own water outside or prefer those drinks. D_B measures the proportion of beverages sold among the entire drink market.

3. The profit companies who initially benefit from the ban, P_B:

After the ban of single-serving plastic water bottles, the demand of beverages, which is still contained by plastic bottles, will increase suddenly due to its role as the complementary good of water. As a result, the demand of plastic will increase responding to the increase in the demand of beverage bottles. However, the supply of substitutional single-serving water bottle will also increase to cover the loss of convenient plastic bottles, since water is still an indispensable factor of people's life, and make the demand of beverages drop right after its sudden increase, in turn leading to the decline of the demand of plastics. $\boldsymbol{P_B}$ models the profit of plastic and beverage producers and sellers, which two factors are directly proportional to the demand of plastics and beverages, as a function of time starting from the increase in the supply of substitutional bottles of single-serving plastic bottles, which is the point right after the enactment of the ban (because the increase in the demand of both the plastics and beverages take little time, so we directly create the model starting from the point that they begin to decrease).

4. The profit of companies who are initially hurt by the ban, $\boldsymbol{P_W}$:

$\boldsymbol{P_W}$ models the profit of the producers and sellers of mineral water with single-serving bottles like plastic bottles and aluminum bottles and raw materials used to make these bottles (plastic producers are not included as their trend of profit is the opposite of others). Their profits will increase as function of time, in the pattern of a logistic function. The profit of the producers of mineral water with single-serving bottles will decrease largely right after the enactment of the ban within an extremely short time, so we ignore this period, directly creating the model starting from the point where the profit of both kinds of producer begins to increase as people demand substitutional bottles containing single-serving bottled water to cover the loss of convenient single-serving plastic water bottles.

5. The overall healthiness level of all citizens, $\boldsymbol{H}$:

Right after the enactment, the increase in the demand for beverages would lead to health damage to many, since excessively drinking beverages is unhealthy.

6. The condition of the environment, $\boldsymbol{E}$:

If the demand for plastic bottles decrease, plastic garbage formation will drop, so do fossil fuels used to produce plastic and emission of transportation of plastic. The greater $\boldsymbol{E}$ is, the better the environmental condition is.

7. Overall employment level, $\boldsymbol{e}$:

As mentioned before, certain companies will have profits elevated and consequently employ more people, while others will go the other way around. $\boldsymbol{U}$ models the unemployment level by inference from $\boldsymbol{P_W}$ and $\boldsymbol{P_B}$.

8. The public's overall acceptance of the law, or their opinion on it, $\boldsymbol{A}$:

It is expected that some people are going to be favor the law and others will never positively view the law. The great $\boldsymbol{A}$ is, the more people are supporting the law.

9. The ability to deal with disasters and water inaccessibility, $\boldsymbol{D}$:

Initially the supply of substitutional bottled water would be low, so damage due to disasters (fire, earthquake, etc.) and certain areas' inaccessibility to water will be more severe. The greater $\boldsymbol{D}$ is, the better the water supply situation is, and hence the less the damage is.

10. The government spending, $\boldsymbol{G}$:

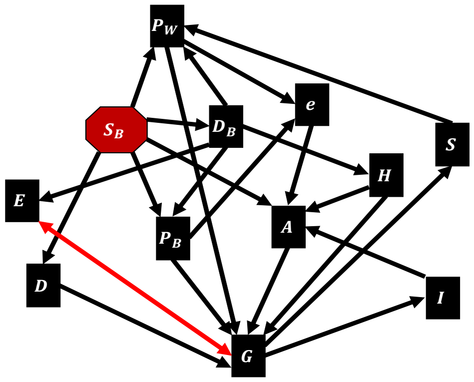
Since the government observes the conditions of the city and receives opinions of citizens, it will decide how urgent it is to spend money and how much to spend. The higher $\boldsymbol{G}$ is, the government is expected to spend more money the city.

11. The subsidy given by government to the companies with great losses, $\boldsymbol{S}$:

Hopefully, the government feels obliged to aid the companies that face miserable losses, because of the ban is the government's decision. A great $\boldsymbol{S}$ means a greater amount of financial aid to those companies.

12. Amount of public infrastructure build that provide free drinking water, *I*:

Due to the ban, the government would probably create a certain amount of free water sources, like a water bar in a department store.



5.2 *The Interrelationship of the Variables*

As mentioned before, the General Model calculates changes to each variable for numerous tiny time steps, which helps reveal the trend of overall condition of the city. After scrupulous consideration, we conclude the interconnection of all variables in the figure (5.2) to the left. An arrow from X to Y (X→Y) means X affects Y, and notice that the red arrow is double-sided.

5.3 *The Starting Variable*

A dilemma appears: it is impossible to identity one single independent variable that accounts for the changes of all the others, because the relationship of all variables is not in the form of a CHAIN but a WEB instead. We believe that a variable that is most independent from the others is $\boldsymbol{S_B}$, the supply of water not sold in single-serving plastic bottles (we call it *substitutional bottled water*). Our reasoning for this is: based on the assumption that the total volume of drinks demanded is conserved (Assumption 5), the sale of water in single-serving plastic bottle will be replaced by sale of substitutional bottled water which is in cans or glass bottles. This process is expected to be inevitable and resistant to other variables. Hence, we call $\boldsymbol{S_B}$ the *starting variable*. The General Model begins immediately after the ban of single serving plastic bottle is enacted.

5.4 *The Model: Step-Simulation Procedures*

Step 1:

We speculate that water companies will gradually restructure themselves for production of substitutional bottled water, thus the proportion of the volume of substitutional bottles in the drink market gradually reaches the proportion of single-serving plastic bottles before the ban; so, $\boldsymbol{S_{B_f}}$, the final value of $\boldsymbol{S_B}$, equals the percentage of those banned before the enactment. At the beginning of restructuring, the companies would face a lot of difficulties due to inexperience and furious competition, thus the supply will grow slowly; but later, as they are more experienced, the process will be faster. This trend fits quite well with a *logistic regression*, in which the growth rate is directly proportionate to the product the progress (how much completed) and the distance from completion (how much left to do). That is to say,

$$\frac{dS_B}{dt} = kS_B\left(S_{B_f} - S_B\right) \Rightarrow dS_B = kS_B\left(S_{B_f} - S_B\right)dt$$

But keep in mind, this equation only describes the volume percentage of substitutional bottled water out of the drink market but NOT their volume, because the total volume of drinks supplied in the market in not constant. We assume that the supply of all single-serving plastic bottles is 0 at the very beginning. That is, the total volume of drinks supplied becomes $(\boldsymbol{1-S_{B_i}})$ of before. We expect the total volume to grow until it reaches the total volume before the ban, following the logistic pattern similar to $\boldsymbol{S_B}$, and the percentage of current total volume to final total volume supplied in drink market is: $\boldsymbol{V(S_B)=\left(1-S_{B_f}+S_B\right)}$, where $\left(\boldsymbol{1-S_{B_f}}\right)$ is the initial value, and adding $\boldsymbol{S_B}$ to it makes it growth toward 1, when $\boldsymbol{S_B}$ approaches $\boldsymbol{S_{B_f}}$. We consider $\boldsymbol{V}$ as a temporary variable, so it is not included in the variable list. At any time, the product $\boldsymbol{S_B V}$ gives the proportion of actual volume of substitutional water supplied in the final total volume in drink market.

To find $\boldsymbol{S_{B_f}}$, we looked for the production makeup by volume of the entire drink market. The best data we can find is the market composition in 2016: bottled market made up 19.7% of the market, so $\boldsymbol{S_{B_f}=0.197}$, and the remaining 80.3% is beverage [2]. We also need the initially value of $\boldsymbol{S_{B_i}}$, but we can find nothing about the sale of water in can or glass bottle, as we find that canned water is only used as a water supply during emergency[3]. We can only give our best guess: let it be $\boldsymbol{0.1\%}$.

The first step of the simulation described above directly calculates new value of $\boldsymbol{S_B}$ using the Euler's Method: multiplying the rate of change of $\boldsymbol{S_B}$ with a tiny time duration yields $\boldsymbol{dS_B}$, which approximates the value of change in $\boldsymbol{S_B}$, and then we refresh $\boldsymbol{S_B}$ by adding $\boldsymbol{dS_B}$ to it. Starting from the second step, the model uses other variables according to the causal relationships described in the table below. The idea is the same: using other variables to calculate the change in one variable, and refresh the variable by adding the change to it. The table below paraphrases the information already represented in figure in 5.2, and in addition specifies the chronological order of the effect on each variable will be calculated in the model.

	$\boldsymbol{S_B}$	$\boldsymbol{D_B}$	$\boldsymbol{P_B}$	$\boldsymbol{P_W}$	$\boldsymbol{H}$	$\boldsymbol{E}$	$\boldsymbol{e}$	$\boldsymbol{A}$	$\boldsymbol{D}$	$\boldsymbol{G}$	$\boldsymbol{S}$	$\boldsymbol{I}$
$\boldsymbol{S_B}$		2		5	4		6	8	9			
$\boldsymbol{D_B}$			3			7	6					
$\boldsymbol{P_B}$										10		
$\boldsymbol{P_W}$										10		
$\boldsymbol{H}$								8		10		
$\boldsymbol{E}$										10		
$\boldsymbol{e}$								8				
$\boldsymbol{A}$										10		
$\boldsymbol{D}$										10		
$\boldsymbol{G}$						11					13	12
$\boldsymbol{S}$				14								
$\boldsymbol{I}$				14				15				

(The yellow column are causes; the blue row are effects; an "6" at $\boldsymbol{H}$ row and $\boldsymbol{A}$ column means that at the sixth step, $\boldsymbol{H}$ affects $\boldsymbol{A}$; the black boxes are useless because a variable does not affect itself; crossed-out boxes are useless because none of the variables cause change on the *starting variable*.)

Step 2:

As mentioned before, we assume that total volume of drinks demanded is constant, so the proportion of volume of beverages supplied and that of substitutional bottled water always add up to 100%, a.k.a. $\boldsymbol{S_B + D_B = 1 \Rightarrow D_B = 1 - S_B}$, by which we calculate the value of $\boldsymbol{D_B}$.

The initial value of $\boldsymbol{D_B}$ is set to $\boldsymbol{1 - S_{B_i} = 1 - 0.001 = 0.999}$ because right after the ban only *substitutional bottled water* exists.

Step 3:

The model keeps $\boldsymbol{P_B}$ a real number and set its initial value to be 1. We use the value of $\boldsymbol{D_B}$ to calculate the increase in profit of the beneficiary companies (such as can companies). Instead of calculating the real profit change, we use the proportion change in the former two variables to calculate the change in $\boldsymbol{P_B}$:

$$\boldsymbol{dP_B = \frac{D'_B V(S'_B) - D_B V(S_B)}{D_B V(S_B)}}$$

where $\boldsymbol{D'_B}$ denotes the new $\boldsymbol{D_B}$ value. (Likewise, the same notation applies to all below.) Because $\boldsymbol{D_B}$ does not show the actual volume, in the equation the numerator subtracts the percentage of old total volume of beverage supplied out of the total volume supply of the drink market before the ban from the new one, while the denominator is the old volume's percentage. The change in $\boldsymbol{P_B}$ equals the change in total volume of the beverages. When total beverage volume decreases, its proportion of change is negative and decreases $\boldsymbol{P_B}$, as beverage and plastic companies' profit will decrease.

The purpose of not using the product the ratios of the new values to old values, respectively, is to ensure that both volume demand changes unbiasedly affect $\boldsymbol{P_B}$; the product may "favor" one of the multipliers.

Step 4:

This step calculates the change to the general health level of all citizens, $\boldsymbol{H}$. The model keeps $\boldsymbol{H}$ a real number between 0 and 1, with 0 being the worst health state and 1 being the best health state, since health cannot just increase or decrease without boundary. The model initializes the value of $\boldsymbol{H}$ as 0.5 – this does not mean that the overall health level is in in the middle – we just intuitively take the mean of 0 and 1 for convenience, and this is fine because we only need to see trend of how the value changes.

Since drinking too much beverages, especially soft drinks or alcohol, would damage health, we calculate the change to $\boldsymbol{H}$ by:

$$\boldsymbol{dH = (1 - |2H - 1|)\frac{D_B V(S_B) - D'_B V(S'_B)}{D_B V(S_B)}}$$

When $\boldsymbol{D_B}$ decreases, health level would increase, so $\boldsymbol{(D_B V(S_B) - D'_B V(S'_B))}$ serves to make $\boldsymbol{dH}$ positive. The factor of $\boldsymbol{(1 - |2H - 1|)}$ applies the same intuition of the logistic model: when $\boldsymbol{H}$ is 0.5, this factor is 1; and this factor moves toward to 0 when $\boldsymbol{H}$ move away from 0.5, no matter toward 1 or 0. When the health level is abnormal (too high or too low), we make it less sensitive to change in $\boldsymbol{D_B}$. We do this based on the consideration that $\boldsymbol{H}$ is not proportionate to real health level, which is difficult to measure. This ensures that $\boldsymbol{H}$ is between 0 and 1. We admit that $\boldsymbol{H}$ is reality may not behave like this, but here this method allows us to control $\boldsymbol{H}$ and observe a clearer pattern. Based on Assumption 9, we believe the use of this factor will not affect the overall pattern. For the other three variables that are kept between 0 and 1, we use the same factor as well.

By the way, we do not consider the damage to health by the plastic bottle itself, because only after a long time of reusing the same bottle will cause significant damage.

Step 5:

$\boldsymbol{P_W}$ is kept a real number and initialized as 1. The higher $\boldsymbol{P_W}$ is, the greater the profits of sellers and producers of substitutes are, so it is only affected by $\boldsymbol{S_B}$:

$$\boldsymbol{dP_W = \frac{S'_B V(S'_B) - S_B V(S_B)}{S_B V(S_B)}}$$

When the volume of substitutional bottled water increases, its proportion of change is positive and increases $\boldsymbol{P_W}$, because these sellers and producers will gain profit (purchase increases when supply increases).

Step 6

The employment level, $\boldsymbol{e}$, is kept a positive real number and has an initial value of 1. It does not have an upper bound because employment level can be large. (Again, it does not reflect the actual proportion.) We believe that a company's profit increase causes increase in its number of employees, and vice versa holds true as well.

$$\boldsymbol{de = r_e\left(\frac{P_B{}' - P_B}{P_B} + \frac{P_W{}' - P_W}{P_W}\right), r_e = \begin{cases} 1 \; if \; e \geq 1 \\ e \; if \; e < 1 \end{cases}}$$

Therefore, the adding proportions of changes of $\boldsymbol{P_W}$ and $\boldsymbol{P_B}$ would represent the change in employment level. To prevent $\boldsymbol{e}$ from dropping below 0, when it is smaller than 1, the closer it is to 0, we make it more insensitive to the net proportion change.

Step 7:

The decrease in $\boldsymbol{D_B}$ means that fewer plastic bottles are going to be produced, bought, and thrown away. Since plastic bottles damage soil, and their production and transportation use fossil fuels that pollute air, the environment quality, $\boldsymbol{E}$, increases by:

$$\boldsymbol{dE = (1 - |2E - 1|)\frac{D_B V(S_B) - D_B{}' V(S'_B)}{D_B V(S_B)}}$$

The model keeps $\boldsymbol{E}$ between 0 and 1, and the factor $\boldsymbol{(1 - |2E - 1|)}$ serves to shrink the effect of change in $\boldsymbol{D_B}$ when $\boldsymbol{E}$ is close to 1 or 0. We reuse the reasoning in **Step 4** here. The second part in the equation is positive when $\boldsymbol{D_B}$ is decreasing.

Step 8:

The overall attitude of citizens, $\boldsymbol{A}$, is kept between 0 and 1 and initialized as 0.5 for convenience. Again, 0.5 does not mean half of the people would support the ban, but rather it serves as a standard for comparison to future values.

We reason that $\boldsymbol{A}$ depends on $\boldsymbol{S_B}$, $\boldsymbol{H}$, and $\boldsymbol{e}$. A higher volume of substitutional bottled water means it is easier for citizens to buy substitutional bottled water, so their dislike to the ban will be mitigated. The health level directly reflects the living standards and well-being of the citizens, so a higher $\boldsymbol{H}$ means a better popular opinion on the ban. Likewise, a higher employment level makes people feel better about the ban.

However, a variable's value may not have a linear relationship to its impact on $\boldsymbol{A}$. People are more worried when health level and employment level are especially low; but when they are high, people are generally happy, so small increases in them would have small impacts. We adjust the values of the three factors by:

$$\boldsymbol{S_{B_{adj}}} = \frac{\boldsymbol{S'_B - S_{B_i}}}{\boldsymbol{S_{B_f} - S_{B_i}}}, \boldsymbol{H_{adj} = 1 - H'}, \boldsymbol{e_{adj} = 1 - e'}$$

Because $\boldsymbol{S_B}$ is always between $\boldsymbol{S_{B_i}}$ and $\boldsymbol{S_{B_f}}$, $(\boldsymbol{S'_B - S_{B_i}})$ calculates how much $\boldsymbol{S_B}$ has travelled, and $(\boldsymbol{S_{B_f} - S_{B_i}})$ calculates the total length of the path $\boldsymbol{S_B}$ travels, so the ratio of the above two terms represents what percentage of the entire progress is completed. Because $\boldsymbol{H}$ and $\boldsymbol{e}$ are kept between 0 and 1, citizens will be especially concerned when they are small, so we subtract each one from 1 to measure the severity felt by people. The methods we use to adjust the variables ensure that each of the adjusted values are between 0 and 1. The weight on each variable, represented by X, in calculating its impact on $\boldsymbol{A}$ is given by:

$$\boldsymbol{w_X} = \frac{\boldsymbol{X_{adj}}}{\sum(adjusted\ values)}$$

And finally,

$$\boldsymbol{dA} = (\boldsymbol{1} - |\boldsymbol{2A - 1}|)\sum_{\boldsymbol{X}}\left(\boldsymbol{w_X} \cdot (proportion\ change\ in\ \boldsymbol{X})\right)$$

$$= (\boldsymbol{1} - |\boldsymbol{2A - 1}|)\frac{\frac{\boldsymbol{S_B}'\boldsymbol{V(S'_B) - S_B V(S_B)}}{\boldsymbol{S_B V(S_B)}}\boldsymbol{S_{B_{adj}}} + \frac{\boldsymbol{H' - H}}{\boldsymbol{H}}\boldsymbol{H_{adj}} + \frac{\boldsymbol{e' - e}}{\boldsymbol{e}}\boldsymbol{e_{adj}}}{\sum(adjusted\ values)}$$

We reuse the reasoning in **Step 4** to include the factor of $(\boldsymbol{1} - |\boldsymbol{2A - 1}|)$ in the equation. Here we also use the proportion of change in the volume of substitutional bottled water. The increase in volume supplied, $\boldsymbol{H}$, and $\boldsymbol{D}$ all would make people more relaxed about this ban and more likely to embrace it, so we subtract the old values from the new values.

Step 9:

The measure of how well the city deals with natural disasters, $\boldsymbol{D}$, is kept between 0 and 1, because we assume that there is an upper bound of the city's ability to combat disasters' damages, where $\boldsymbol{D}$ is 1, and a lower bound. The change in $\boldsymbol{D}$ is given by:

$$\boldsymbol{dD} = (\boldsymbol{1} - |\boldsymbol{2D - 1}|)\frac{\boldsymbol{S'_B V(S'_B) - S_B V(S_B)}}{\boldsymbol{S_B V(S_B)}}$$

The factor $(\boldsymbol{1} - |\boldsymbol{2D - 1}|)$ aims at decreasing the impact on $\boldsymbol{D}$ when $\boldsymbol{D}$ is too big or small based on the reasoning in **Step 4**. The second part in the equation measures the proportion change in total volume of substitutional bottled water.

Step 10:

The government spends more money to when it is more concerned with the problems of the city. We suppose it is concerned with $\boldsymbol{A}$, $\boldsymbol{H}$, $\boldsymbol{D}$, $\boldsymbol{P}$, and $\boldsymbol{E}$, and each of them have different strength at affecting government spending, $\boldsymbol{G}$. We adjust each variable by it as below:

$$A_{adj} = \frac{1}{A'}, H_{adj} = \frac{1}{H'}, D_{adj} = \frac{1}{D'}, P_{B_{adj}} = |P_B'|, P_{W_{adj}} = |P_W'|, E_{adj} = \frac{1}{E'}$$

A, H, D, and E all are kept between 0 and 1, and the lower they are, the more the people are worried. Thu, taking one variable's reciprocal dramatically enlarges it effect when it is small. Since P_B and P_W are positive real numbers, all adjusted values are positive real numbers.

To calculate the combined effect of all 5 variables, we calculate each variable's weight and proportion change. The weight of each variable, represented by X, is given by the proportion of its adjusted value out of the sum of all adjusted values:

$$w_X = \frac{X_{adj}}{\sum(adjusted\ values)}$$

And finally,

$$dG = \sum_X \left(w_X \cdot (proportion\ change\ in\ X)\right)$$

$$= \frac{\frac{A-A'}{A}A_{adj} + \frac{H-H'}{H}H_{adj} + \frac{D-D'}{D}D_{adj} + \frac{P_B-P_B'}{P_B}P_{B_{adj}} + \frac{P_W-P_W'}{P_W}P_{W_{adj}} + \frac{E-E'}{E}E_{adj}}{\sum(adjusted\ values)}$$

The increase in each of A, H, D, P_B, P_W, and E will decrease G because the increase means a better social situation, and thus the government will be less concerned and lower its spending. Thus, we subtract the new values from old values.

Step 11, 12, and 13:

These three steps calculate the government spending on improving environment, establishment of water infrastructure, and subsidy to companies losing money. Since we cannot anticipate how the government will distribute its money among these three categories, we set three parameters, E_r, I_r, and S_r, which respectively represent the proportion of the spending on one variable in the total spending on all three variables. That is, $E_r + I_r + S_r = 1$. For convenience, we set $E_r = I_r = S_r = \frac{1}{3}$ at first. In 7.4, we are going to examine the impact of changing these parameters on the city. Since increasing government spending increases each of these, we subtract the old values from new values:

$$dE = \frac{G' - G}{G} \cdot E_r, dI = \frac{G' - G}{G} \cdot I_r, dS = \frac{G' - G}{G} \cdot S_r$$

Step 14:

Increasing infrastructure encourages more people to drink at public fountains, who in turn buy less drink. Therefore, the profits of substitutional bottled water will decrease, so we subtract the new value of I from the new. We do not consider the beverages because they still attract people when there are free water, while substitutional bottled water taste same as free water and will then attract people less. Besides, higher subsidies increase substitutional bottled water's profits, so we subtract the old value from the new; the total change in P_W is given by:

$$dP_W = \frac{I - I'}{I} + \frac{S' - S}{S}$$

Step 15:

When more infrastructure is built, citizens' inconvenience of obtaining water decreases, so they will feel better about the ban. Hence, we subtract the old value from the new, and A increases by:

$$dA = \frac{I' - I}{I}$$

5.5 *Brief Summary of all Variables*

The tables below summarize the initial value and range of possible future values of each variable, and the values of the parameters (constants), from the detailed description above.

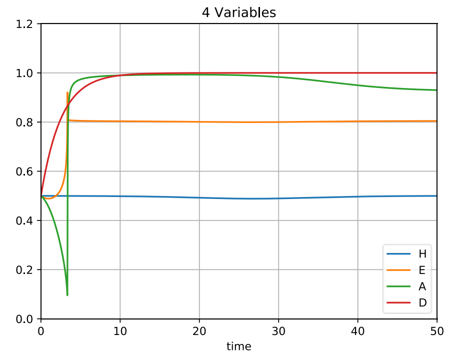
No.	Variable (Constant)	Initial Value	Range
1	S_B	0.001	$[0.001, 0.197)$
2	D_B	0.999	$(0.203, 0.999]$
3	P_B	1	$(-\infty, +\infty)$
4	P_W	1	$(-\infty, +\infty)$
5	H	0.5	$(0, 1)$
6	E	0.5	$(0, 1)$
7	e	1	$(0, +\infty)$
8	A	0.5	$(0, 1)$
9	D	0.5	$(0, 1)$
10	G	1	$(0, +\infty)$
11	S	1	$(0, +\infty)$
12	I	1	$(0, +\infty)$

Table: Information of all variables

Parameter	Value
dt	0.01
S_{B_i}	$0.1\% = 0.001$
S_{B_f}	$19.7\% = 0.197$
E_r	$1/3$
I_r	$1/3$
S_r	$1/3$

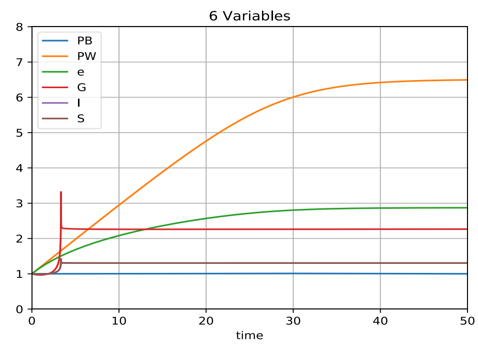
5.6 Results and Analysis of the General Model

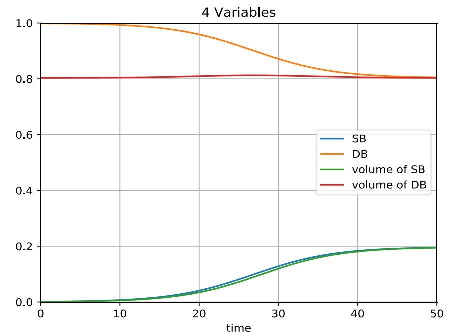
We made several graphs to illustrate how each variable evolve over time. The plot shown on the top of next page shows the growth of the 4 variables whose values are kept between 0 and 1. All variables stabilizes when time reaches 40. Remarkably, D reaches nearly 1 because of the growth of S_B. A experiences a huge valley at time of



about 1, but then it quickly rises and slightly drops after some time. The sudden change of $\boldsymbol{A}$ at time of about 1 is accompanied by a huge jump in $\boldsymbol{E}$, due to a significant increase in government spending. But unlike the others, $\boldsymbol{H}$ increased fairly slowly and stably and is the variable that experienced the least change, so the ban in San Francisco does not improve health much.

The graph to the right shows the growth of other variables except $\boldsymbol{S_B}$ and $\boldsymbol{D_B}$. The huge growth of $\boldsymbol{P_B}$ and $\boldsymbol{e}$ surprises us, so does the great increase in $\boldsymbol{P_B}$. But the level of government spending is always above 1, meaning that there is constant need for government to spend money. Like the plot above, there is an abrupt change at about time of 1.





The graph to the left shows the market proportion $\boldsymbol{S_B}$ and $\boldsymbol{D_B}$, and their actual volume share. The total volume of beverages changes quite little during the entire period, which account for the consistent value of $\boldsymbol{H}$. As mentioned before, we did not include any realistic numerical values into the model, and thus time does not have a unit. But we can infer that in the short term, people's objection toward the ban is going to increase, while the government needs to significantly increase its spending; however, in the long term, many of the variables will demonstrate dramatic improvements, such as better health, more optimistic opinion on the ban, higher employment level, and more profit gained by some companies.

The above analysis only discusses individual variables, and to reflect the overall welfare of the city, we define a score using five variables, $\boldsymbol{H}$, $\boldsymbol{E}$, $\boldsymbol{e}$, $\boldsymbol{A}$, and $\boldsymbol{G}$. They respectively measure health level, environmental condition, employment level, people's support to the law, and pressure experience by the government. Since not all have the same domain and initial value, we use this equation to calculate the score:

$$\boldsymbol{Score} = \frac{\frac{1}{1-H} + \frac{1}{1-E} + e + \frac{1}{1-A} + \frac{1}{G}}{5}$$

Since $\boldsymbol{H}$, $\boldsymbol{E}$, and $\boldsymbol{A}$ are between 0 and 1, subtracting each from 1 yields its distance from 1, and because a small distance from 1 means a great condition, the reciprocal of the distance reflects the welfare. As $\boldsymbol{e}$ is already a positive real number, it is unchanged. $\boldsymbol{G}$ is different from others: the smaller $\boldsymbol{G}$ is, the less pressure the government feels,

and the better the condition is, so we use its reciprocal to represent
the welfare. Now, each variable has been adjusted into a positive real number, and then we simply take the arithmetic mean of them. The initial score is $\frac{8}{5}$.The figure to the left shows the score of the city. Surprisingly, it first significantly increases and then shrinks–which closely assembles the total energy change in an endothermic reaction–and exemplifies a sociological antithesis of the distant domain of chemistry. But still, the score greatly dropped after it reaches its peak surprises us, and we speculate it is the increasing employment and profits that release the pressure on government and let it decrease its spending.

6 Airport Model and Change

6.1 ***Changes to the General Model:***

(A) Variables Included:

1. $\boldsymbol{S_B}$: Substitute of bottle in airport is similar to the trend of substitute bottles in San Francisco city, as restaurants, bookstores, cafes, supermarket, and retail stores sell similar goods in the airport. It will also increase logistically, first slowly and later more quickly, eventually reaching a stable level, due to increasing water supplying infrastructure.
2. $\boldsymbol{D_B}$: Demand of beverage will initially increase due to the policy but will eventually decrease because of the gradual replacement of substitute water that is contained other coverages. This factor is similar to its counterpart in the general model, but considering that most people in airport aim at travelling, the intensity of change might differ.
3. $\boldsymbol{A}$: Attitude of people will be measure through sampling. Since most people only stay in airport for a short time, and the security check in airport prohibit most of plastic bottles, and price of bottled water, the intensity of discontent or inconvenience of citizens is projected to be lower than its counterpart in the general model.
4. $\boldsymbol{G}$: In the airport, gov't spending is mostly on building water stations and maintaining them. In short term the cost will be mostly setting up the infrastructure, but the cost will decrease in long run as cost is reduced to maintaining the infrastructure. Also, the gov't only need to subsidize little for the airport restaurants for recycled containers.
5. $\boldsymbol{I}$: The amount and quality of airport infrastructure including water station and water fountains will increase and reach a stable level.

(B) Variables NOT Included:

1. $\boldsymbol{S}$: Subsidies should not be included because there are no companies that require the subsidy from the government as all those companies are severely affected by the new policy, and demand subsidies from the government are not a part of the airport.
2. $\boldsymbol{P_B}$: This factor should not be included in the airport model because plastic and beverage producers are not a part of the airport while the sellers like restaurants will not be affected because they do not use plastic bottles.
3. $\boldsymbol{P_W}$: This factor should not be included because producers of single-serving bottled water and materials used to make substitutional bottles are not a part of the airport while sellers like restaurants will not be affected due to the reason mentioned in 2. Also, water

fountains in the airport means that single-serving plastic bottled water is not dominant product in the airport, so the ban won't affect airport's economy by much.
4. $\boldsymbol{H}$: Health should not be considered because passengers travelled to airport comes from various places, so it is impossible to have a stable population to be measured.
5: $\boldsymbol{E}$: Unlike the San Francisco city, the airport's effort is difficult to measure in precise number, and its impact is negligible as compared to the overall effort of the entire city. In fact, airport itself cannot be considered as a part of environment.
6: $\boldsymbol{e}$: Outside companies or local industries are affected by the policy, but they are not parts of airport. Also, companies in the airport like cafes and restaurants will not really be affected because they can simply replace plastic bottles with paper or glass ones.
7. $\boldsymbol{D}$: Airport itself is well connected to the emergency agencies and has storage of emergency materials, meaning $\boldsymbol{D}$ shall not be considered in airport model as loss of single-serving water bottle will not change its ability to deal with emergency.

6.2 *Similar and Different Impacts Compared to the Ban in a City*

(A) Similarities:

1. The demand for beverages will increase because they are substitute goods of water.
2. The supply of substitute bottles for single-serving plastic water bottle will increase in places like restaurant and cafe to cover the loss of single-serving plastic water bottle.
3. The amount of infrastructure providing free water resources will increase to cover the loss of convenience due to the ban of single-serving plastic water bottle.
4. The attitude of passengers toward the convenience of the airport will change because they cannot buy water sources that can be brought with them easily.
5. The water usage will increase because people are more relied upon drinking fountain.

(B) Differences:

1. The economy of the businesses inside the airport likes shops, cafes, and restaurants will not be severely affected by the new policy because people spend little time in airport, so beverages can become a substitute for the single-serving water. Moreover, businesses can just substitute plastic bottle with paper cups or steel containers.
2. The negative effect of the banning of the single-serving water bottle is not as strong as that in San Francisco because passengers can buy beverages as they only spend short time in airport, while there are free water fountains for them to use. In contrast, citizens in San Francisco daily demand water, so the impact of the policy on SF is stronger

7 The New Model for Concord

The General Model above models the impacts of banning all single-serving plastic water bottles, and it is suitable for simulating the impacts on San Francisco. But because Concord only bans those single-serving plastic bottles below 1 liter, we need to consider a new set of variables and develop a new model could the Concord Model. Below are the description and discussion of the Concord Model.

7.1 *Variables and Comparison*

1. $\boldsymbol{S_B}$: The $\boldsymbol{S_B}$ in concord will be lower compared to the one in San Francisco because only single-serving bottle that has a volume smaller than 1 liter is banned, meaning that people can still consume those of higher volume. Thus, the supply of substitute bottle

will be less than San Francisco who bans all of the single-serving plastic bottle.
2. $\boldsymbol{S_L}$: This is a new variable, which represents the proportion of the volume of single-serving plastic bottled water over 1 liter. Though water bottles below 1 liter are banned, those over 1 liter are still allowed.
3. $\boldsymbol{D_B}$: Change in $\boldsymbol{D_B}$ will also be less than San Francisco because people can still consume single-serving water bottle. Although they may consume other drinks, but water will still be the first choice, making the change in $\boldsymbol{D_B}$ less than that in SF.
4. $\boldsymbol{P_B}$: It will have the same trend as in the General Model, but it will have less change because only single-serving plastic water bottles with volume less than 1 liter are banned, meaning that the demand in beverages will increase to a level less than that of the Genera Model(not considered in this period), so the later drop in profit caused by the increase in the supply of substitutes will be less than that of the General Model.
5. $\boldsymbol{P_W}$: It will have the same trend as in the General Model, which decreases dramatically once the ban is enacted (not considered by the model), and then it will recover and reach a stable level. However, it will experience smaller changes because only single-serving plastic bottled water below 1 liter are banned, meaning that single-serving plastic bottled water producers and sellers will have less loss at first, and that their later recovery of profits will also be less than those of industries in San Francisco.
6. $\boldsymbol{H}$: Health of people will be better compared to that of people in SF because people in Concord consume less beverages as they can buy bottled water over 1 liter.
7. $\boldsymbol{E}$: Environment protection will be less because plastic bottles with volume less than 1L are available so there are more fossil fuel and also non-degradable waste in concord.
8. $\boldsymbol{e}$: It will change with the same level since $\boldsymbol{P_B}$ and $\boldsymbol{P_W}$ are both smaller in Concord.
9. $\boldsymbol{A}$: Citizen's attitude will be better at the start of the ban because they can consume large volume bottled water(>1L). The attitude function will change slower as Concord is a small town, as it has less ability to overcome the problem as easy as SF. Moreover, because there are still single-serving bottles, government may spend less on subsidizing industries to produce substitutes, so people need more time to habituate to new law.
10. $\boldsymbol{G}$: Gov't spending in theory will be less than that of SF because the change in Sb is less, meaning that the gov't needs not spend so much subsidizing companies for creation of other substitute bottles. Gov't will spend less money on $\mathbf{I}$ because people can still buy bottled water. Although the gov't in Concord need to spend more on environmental protection than gov't of SF, in total it spends less due to less I&S.
11. $\boldsymbol{S}$: Subsidy will be less than that of San Francisco because the loss companies in Concord are less than those in San Francisco.
12. $\boldsymbol{I}$: There will be less infrastructure because people still have single-serving plastic water bottle to buy so that the government does not need to build free water resources.

7.2 *The Steps of the Concord Model*

The steps of the Concord Model are quite similar to those of the General Model. For convenience, we describe the modifications to the General Model below.

After the ban, single-serving plastic bottled water over 1 liter still can be sold, so we assume that the volume ratio of such water to beverages to be constant. The volume proportions of beverages and such water in the drink market are going to decrease as that of substitutional bottled water increases. $\boldsymbol{S_{B_f}}$ is going to be the volume percentage of single-serving bottled water **under 1 liter** before the ban. To find $\boldsymbol{S_{B_f}}$, we went to a local 7-eleven store because it would most universally reflect the proportion we want. We sample all water (non-beverage) in the refrigerator, and 5500 out of 512251 mL of the water are contained in bottles no smaller than 1 liter. Therefore, $\boldsymbol{r = \frac{5500}{512251} \approx 1.07\%}$ of water are still supplied. Thus, $\boldsymbol{S_{B_f}}$ is $\boldsymbol{19.7\%(1-r) \approx 19.49\%}$. There volume percentage of water above 1 liter in the entire drink market is $\boldsymbol{r_L = 19.7\% \cdot r \approx 0.212\%}$, and that of beverages is $\boldsymbol{r_B = 1 - 19.7\% = 80.3\%}$, so at any time, $\boldsymbol{S_L = (1 - S'_B)\frac{r_L}{r_L + r_B}}$ and $\boldsymbol{S_B = (1 - S'_B)\frac{r_B}{r_L + r_B}}$, while we reuse the differential equation in Step 1 of the General Model to calculate $\boldsymbol{S_B}$. The New Model uses the same formula to calculate $\boldsymbol{V(S_B)}$.

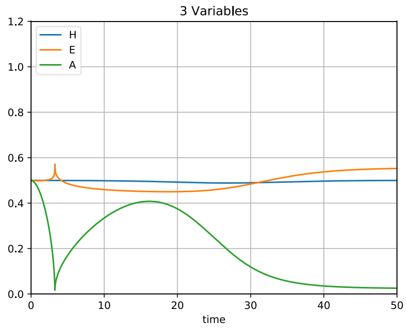
Step 1 uses the same formula as the General Model but a different $\boldsymbol{S_{B_f}}$; Step 2 calculates $\boldsymbol{S_L}$ and $\boldsymbol{S_B}$ according to the equations above; and Step 3 uses the equation below because the bottled water above 1 liter and the beverages follow the same trend, and companies producing them originally benefited from the ban, so the evolution of the volumes of these drinks should affect $\boldsymbol{P_B}$. Steps 4 to 6 are the same; Step 7's equation is replaced by the following, because both beverages and water bottles above 1 liter contain plastic and may damage the environment. Step 9 of the General Model is skipped; and Step 10 omits variable $\boldsymbol{D}$ and use the equation below.

$$step\ 3\text{: } \boldsymbol{dP_B = \frac{(S'_L + D'_S)V(S'_B)}{(S_L + D_S)V(S_B)} - 1},\ step\ 7\text{: } \boldsymbol{dE = (1 - |2E - 1|)\left(1 - \frac{(D_B{}' + S_L{}')V(S'_B)}{(D_B + S_L)V(S_B)}\right)},$$

$$step\ 9\text{: } \frac{\frac{A-A'}{A}A_{adj} + \frac{H-H'}{H}H_{adj} + \frac{P_B - P_B{}'}{P_B}P_{B\,adj} + \frac{P_W - P_W{}'}{P_W}P_{W\,adj} + \frac{E-E'}{E}E_{adj}}{\sum(adjusted\ values)}$$

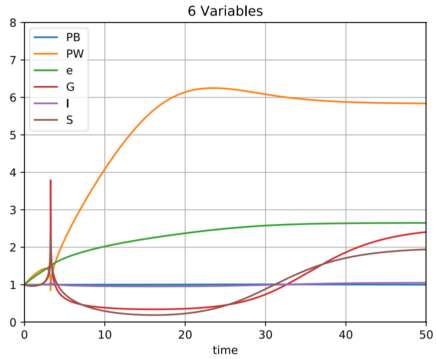
Where all variables are adjusted in the same way, but denominator does not sum $\boldsymbol{D_{adj}}$. We make this change simply because $\boldsymbol{D}$ is not considered for concord, as the bottled water can serve as emergency supply and the city's ability to deal with disasters and inaccessibility of water is constant.

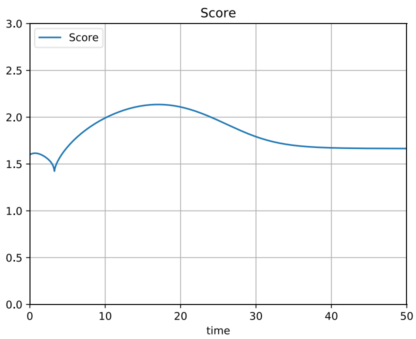
7.3 ***Analysis of the Concord Model:*** We originally believed that the allowance of single-serving plastic water bottles over 1 liter will make the condition of Concord better than that of San Francisco, but we are astounded by the fact that the ban quite undesirable and yields far worse outcomes than those in San Francisco. The graph in variables show 3 variables that are between 0 and 1: the health level stays almost the same and the condition of the environment barely changes because only single-serving plastic bottles that are less than 1L are banned, meaning that the use of plastic, however, is still large as people will buy more large bottles, creating even more pollution at the beginning of the ban. Although this negative effect can be covered by the increase in the supply substitutional bottles, the ban does not really reach its aim of better



protecting the environment. The worst aspect of this policy is illustrated by the change in the public attitude. In the left graph, the public attitude of people toward the ban in the long run is approaching 0. That is to say, people mostly dislike the ban. This is probably because the ban favors neither the people who want to protect the environment nor the group who favors the use of single-serving plastic water bottles as the ban only partially prohibits the use of single-serving plastic water bottles, causing both inconvenience for people and ineffectiveness on the protection of the environment. In another word, though little increase in $\boldsymbol{E}$ occurs, making Concord's environment slightly better, the ban's damages outweigh its benefits.

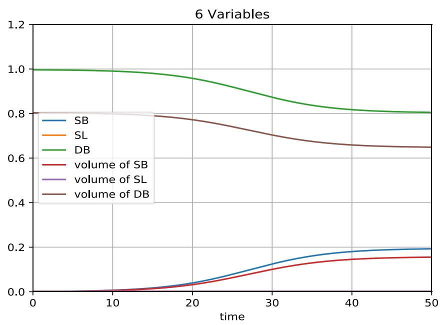
The plot to the right shows the other six measures. The values of $\boldsymbol{P_B}$ and $\boldsymbol{P_W}$ display a similar pattern to that in the General Model: the profits of the companies producing single-serving water and substitutional materials of plastic increase overall compared to their initial state after the ban, so does the employment level. Nearly all variables experience a sharp change at time of about 3. The significant peak of $\boldsymbol{G}$ at that time indicates a fairly pessimistic condition of Concord, but after that the economy gradually proceeds toward prosperity. But increasing $\boldsymbol{G}$ over time means a higher pressure on the government, implying that the enactment of the ban may be detrimental to Concord.





The plot to the left shows the growth of score we define for Concord, which uses the identical equation. Although Concord's people hold a bad opinion toward the ban over the long term, the <u>*score*</u> of the city rises and falls and finally stabilizes at the value close to its initial value. So, overall the welfare of Concord changes little, and enacting the ban does not yield as much benefits as in San Francisco. But after all, Concord was the pioneer of banning single-serving plastic bottles, and experiments to improve the environment and economy should be encouraged.

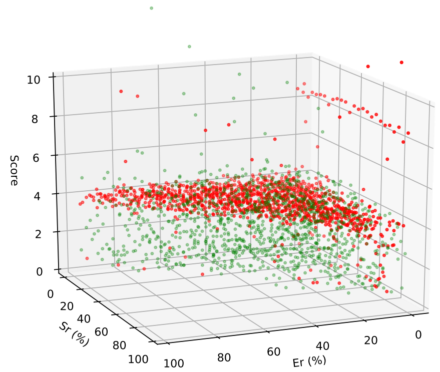
Finally, the graph to the right shows the evolution of $\boldsymbol{S_B}$, $\boldsymbol{S_L}$, and $\boldsymbol{D_B}$, just for a better perception of the drink market.



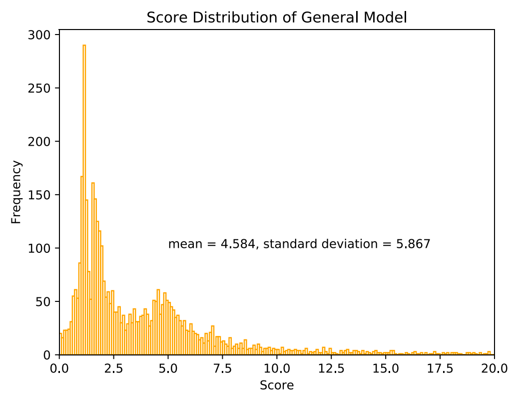
Although the value of S_L remains fairly low, we took it into the model for accuracy. The graph also demonstrates that the total volume of drink supplied rather significantly influences the volume of these three types of drinks.

7.4 *Impact of the Three Parameters* E_r, I_r, *and* S_r

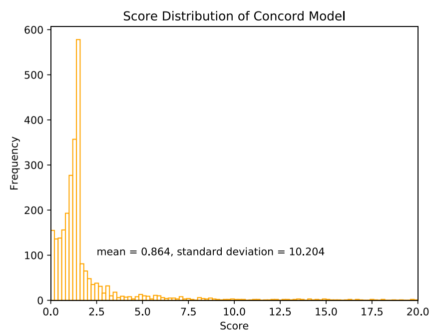
As mentioned before, we would analyze the effect of each of the three variables. We specify all three variables, and left the model run for some time enough for the values to stabilize, and then we plot the stabilized score against these parameters. Since $I_r = 1 - E_r - S_r$, we define $Score(E_r, S_r)$ as the stabilized score of the parameters.



We set E_r and S_r each to a multiple of 1%, and for each set of E_r and S_r such that $E_r - S_r \leq 99\%$ for I_r to be positive, we run the model to obtain $Score(E_r, S_r)$. We first plotted the score values in the 3D space shown left. It displays a chaotic situation – meaning that small changes to the parameters causes huge discrepancies in the final result, but one pattern is clear: the scores of the Concord Model are dominantly below those of the General Model, supporting the earlier finding that the ban in Concord is much less successfully than that in San Francisco.



Since it is too difficult to analyze the relationship between the parameters and the score, we made histograms for both models to look for other patterns. The histogram above shows that scores of the General Model have a mean of 4.584, significantly higher than the score's initial value of 1.6, but a standard deviation of 5.867 means that the government's plan to distribution its spending very powerfully affect the welfare of the city.



The histogram for the Concord Model shown to the above left surprises us: most of the scores are below 2, while the mean of scores is as low as 0.864, rough half of its initial score value. Whereas the previous histogram looks like several normal distribution curves adding together, this histogram does not look normal at all, that is, many scores lie at almost 0, and there are fewer large scores (above 10) than the General Model. Moreover, this distribution has a standard deviation of 10.204, much greater than that of the General Model, which hints at greater social instability and a greater difficulty for the Concord government to plan its spending. To improve Concord's conditions, propose the recommendations in section 7.6 below.

7.5 *Discussion of Generalization*

We believe that the results conclusions yielded above can be generalized to most other communities as long as targets of the ban are identical. This is because our models only consider local drink and material producers and sellers, and most communities have industries related to this, like grocery stores.

Besides, as we have seen, though the General Model only slightly differs from the Concord Model, as we included $\boldsymbol{S_L}$ and cancelled $\boldsymbol{D}$, the outcome of the Concord Model sharply differs from that of the General Model. The consideration of just one additional variable may lead to huge changes, so the prerequisite for the Concord model to be applied to larger communities is that they should have the same targets of ban. Nonetheless, if the target of ban is consistent, we deduce that our model applied on the new community will have the same outcomes; we believe that a change in city size would change certain variables proportionately and be balanced out.

7.6 *Recommendations and Community Measures*

1. Concord should utilize better filtering technique in their water fountains to ensure the health of the local residents so drinking fountains will be more acceptable and diminish the negative impact of the ban of bottled water
2. Concord should set up more welfares including public sanitations, health check and gym in response to the heath problem brought by increase demand of beverages.
3. Concord should set up more water fountains to make clean water accessible to most of the citizens in order to diminish the inconvenience brought by the ban of plastic bottle and counter the increase in demand of beverages
4. Concord should permit community centers, not individuals, to hold and store single-serving water bottles for allocation purpose in case of emergencies and natural disaster.
5. Concord should subsidize the industries that produce alternatives to the plastic bottle so that the substitutes can be released into the market in good quality, large quantity and acceptable price in order to diminish the inconvenience of the banning policy

8 *Discussion of Strengths and Weaknesses of the Models*

8.1 ***Strengths:*** To ensure objectiveness, our models do not include any weight arbitrarily set, and we base all calculations on proportion changed instead of actual values. Our dimensionless simulation strictly assigns each variable a range and adjusts one variable appropriately when calculating its weight. Therefore. we get the right trend.

8.2 ***Weaknesses:*** However, our model cannot predict how long it means by "short-term" and "long-term." Also, the variables used only describe levels **within** the city. Our models start immediately after the ban is issued, when we assume the supply of all illegal bottles is zero. We compare the variables' future values to this point, but not to the values **before** the ban. Hence, if one variable's value is higher after stabilization than the beginning, it does not necessary exceed the value right before the ban. Our models also do not consider the population and area of the city or town, because we reason that a larger city would have the variables changed in such a way that the changes are balanced out. But still, without ample big data, we try our best to make our model as comprehensive and realistic as possible; and the trends are our very focus.

9 Newspaper Article:

"Modeling: True Power of Plastic Bottles"

Environmental sustainability is gaining support from not only private organizations, but also governments that integrate it into municipal and national policies. Six years back, Concord, a small town in MA, enacted a single-serving bottled water ban policy, and a year later San Francisco also issued a ban, prohibiting the sale of single-serving bottled water to preserve the environment.

While the single-serving bottled water ban policy is primarily in support of environmentalism, it inevitably results in several social and economic impacts which in turn trigger a cascade of reactions in the society. In order to take into account the various multitude of impacts caused both directly and indirectly by the policy on an interconnected society, our team designed a model that evaluates the change in 12 major interdependent variables affected by the ban, including those on public attitude and convenience, environmental conservation and appearance, employment, and changes in related markets and industries, thus providing a comprehensive and significant overview of the ban's effect despite minor errors resulting from overlooking a few inessential and unrepresentative factors and relationships.Our general model aims to provide the government with essential information to accurately predict and adjust the economic, environmental, and social changes resulting from the ban. The government's main tools in stabilizing social welfare after the ban will be changing government spending in three main ares: subsidies for producers of single-serving bottled water substitutes, preservation of the environment, and construction of infrastructure in facilitating the accessibility of drinkable water. For example, regarding impacts on domestic economy, the government can use the model to anticipate the loss and profit of relative industries, thus allowing it to provide timely subsidies to stabilize the markets and employment level.

Our model is also beneficial to various other groups, such as investors, who can gain insight from the modeling of changes in the market and invest smartly in respective industries. Local industries can use our model to determine the prospect of their companies and allocate their resources accordingly. Furthermore, our model enables the environmentalists to check the progress of environmental conservation and provides the average citizens with a detailed and easily comprehensive view of the new policy.

In differing situations and regions, we found that after slight modifications according to the ban's varying magnitude of impact on certain variables under particular circumstances, the general model's structure can be applied. Thus, as the weight of impact on variables change, governments may refer to our model and utilize a different combination of fiscal acts to maximize total welfare in all social, economic and environmental aspects.

10 References

[1] https://www.cbsnews.com/video/san-francisco-airport-rolls-out-ban-on-plastic-water-bottles/
[2] https://www.parkstreet.com/alcoholic-beverage-market-overview/
[3] https://en.wikipedia.org/wiki/Canned_water

11 Glossary

Term	Definition
General Model	*The model for a city that bans all single-serving plastic bottled water, such as San Francisco*
substitutional bottled water	*The water not sold in single-serving plastic bottles*
starting variable	*The variable that is determined only by time in the models*
S_B	*The proportion of the volume of substitutional bottled water*
V	*The percentage of current total volume to final total volume supplied in the entire drink market*
D_B	*The proportion of volume of beverages demanded*
P_B	*The profit of companies who initially benefit from the ban*
P_W	*The profit of companies who are initially hurt by the ban*
H	*The overall healthiness level of all citizens*
E	*The condition of the environment*
e	*Overall employment level*
A	*The public's overall acceptance of the law, or their opinion on it*
D	*The ability to deal with disasters and water inaccessibility*
G	*The government spending*
S	*The subsidy given by government to the companies with great losses*
I	*Amount of public infrastructure build that provide free drinking water*
dt	*Time duration of each iteration of the models*
X'	*The new value of the variable* X
X_{adj}	*The adjusted value of variable* X *used to calculate the weight of this variable*
X_i	*The value of variable* X *right after the ban, when the model is initiated*
X_f	*The value of variable* X *a long time after the ban, when every variable has stabilized,*
Concord Model	*The model that for a city that bans all single-serving plastic bottled water of volume over 1 liter, such as Concord*
Score	*The level of welfare of the city*
S_L	*The proportion of the volume of single-serving plastic bottled water over 1 liter*