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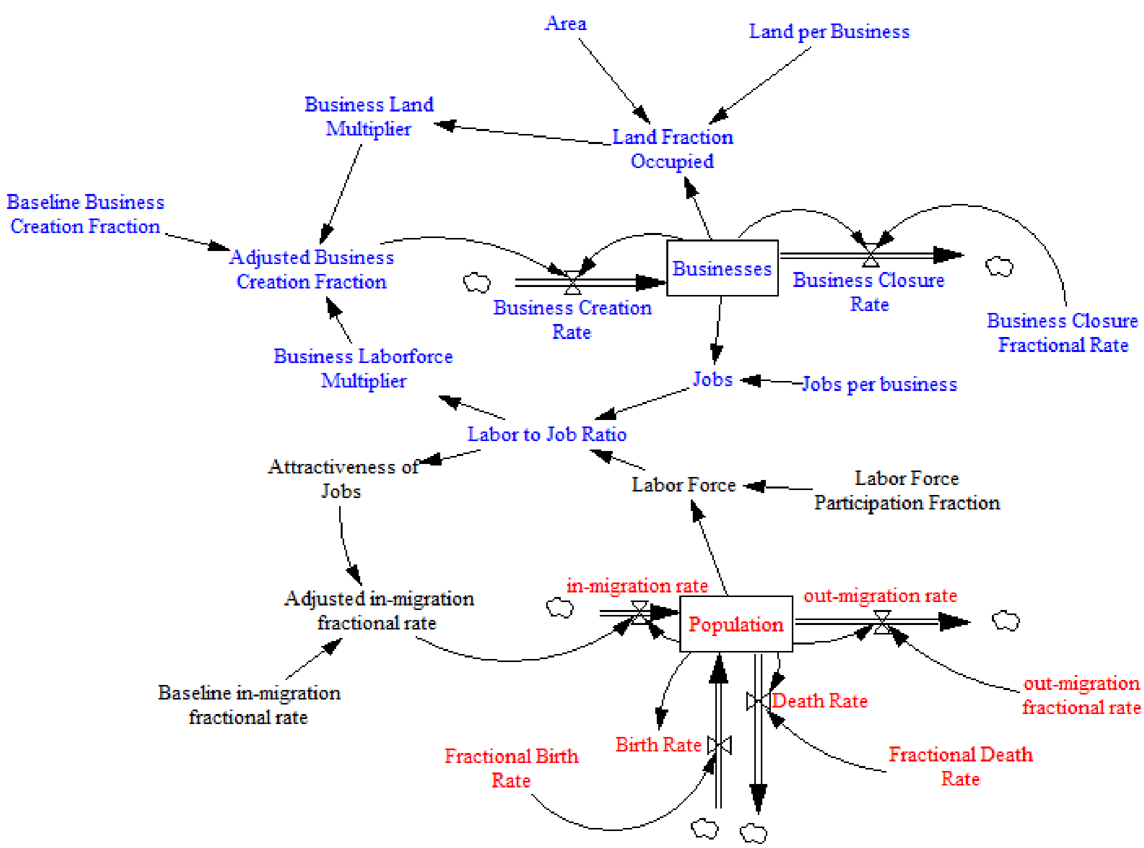
EAS 550/STRATEGY 566: Systems Thinking for Sustainable Development and Enterprise

Lab 8 Modeling Urban Dynamics
Questions are in purple.

The founder of the field of system dynamics, Jay W. Forrester, wrote a book called Urban Dynamics. In it, he controversially concluded that the most commonly accepted plans for improving an urban area (financial aid, job training, low-cost housing, etc.) can actually hurt the long-term health of a city, because these programs can lead to overpopulation and greater tax demands on the unemployed.

We are going to look at a simplified model that only looks at the dynamics of **population** and **business growth** within a city.

1. Modeling non-linear relationships
Create the following urban dynamics model in Vensim. This model is split into 2 parts, a **population** model (in red) and a **business** model (in blue). The two are connected by the variables in black.



The **population model** is defined as follows:

1. Initial population = 30,000 people
2. Out-migration rate = Population*out-migration fractional rate [people/yr]
    a. Out-migration fractional rate = 0.07 [people/people-yr]

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3. In-migration rate = Population*Adjusted in-migration fractional rate [people/yr]
4. Birth rate = Population*Fractional Birth Rate [people/yr]
    a. Fractional Birth rate = 0.03 [people/people-yr]
5. Death rate = Population*Fractional Death Rate [people/yr]
6. Fractional Death Rate = 0.015 [people/people-yr]

The **business model** is defined as follows:

a. Assume the decision to create new businesses is based on two factors: **land availability** and **labor availability**
b. Initial stock of businesses = 1,000 businesses
    a. Each business creates 18 jobs
c. Business closure rate = Businesses*Business Closure Fractional Rate [businesses/yr]
    a. Business Closure Fractional Rate = 0.15 [businesses/business-yr]
d. Business Creation Rate = Businesses*Adjusted Business Creation Fraction
    a. Baseline business creation fraction = 0.2 businesses/business-yr
    b. Adjusted Business Creation Fraction = Baseline Business Creation Fraction* Business Laborforce Multiplier*Business Land Multiplier
e. Total Area = 1,000 acres
    a. Land per Business = 0.4 acres/business

Question: Determine what you think should be the equation for Land Fraction Occupied, report it below:

$$\boldsymbol{Land\ Fraction\ Occupied = \frac{Business * Land\ per\ business}{Area}}\ \textbf{(unit: 1)}$$

Business Land Multiplier relates land availability. We do not have good available data for this variable, so we need to follow the guidelines for formulating graphical functions when observations are not available.

1. Normalize to dimensionless ratios:
    a. Normalize this function on a scale of 0 to 1. This allows us to consider the extreme conditions when there are extreme land constraints (multiplier = 0) and when there are no land constraints at all (multiplier = 1).
2. Identify reference points:
    a. We know 3 things. When land is freely available (land fraction occupied = 0), there are no land constraints. When land is fully utilized, there is no new land for business creation. When land usage first increases from zero, there is a less than proportional decrease in the business creation (i.e.: land costs don't increase greatly until little land is left).
3. Identify plausible shapes for the function:
    a. **Question:** What will this graphical function look like? Use the information above to draw the curve for Business Land Multiplier as a function of Land Fraction Occupied. Paste a screenshot of that curve below:

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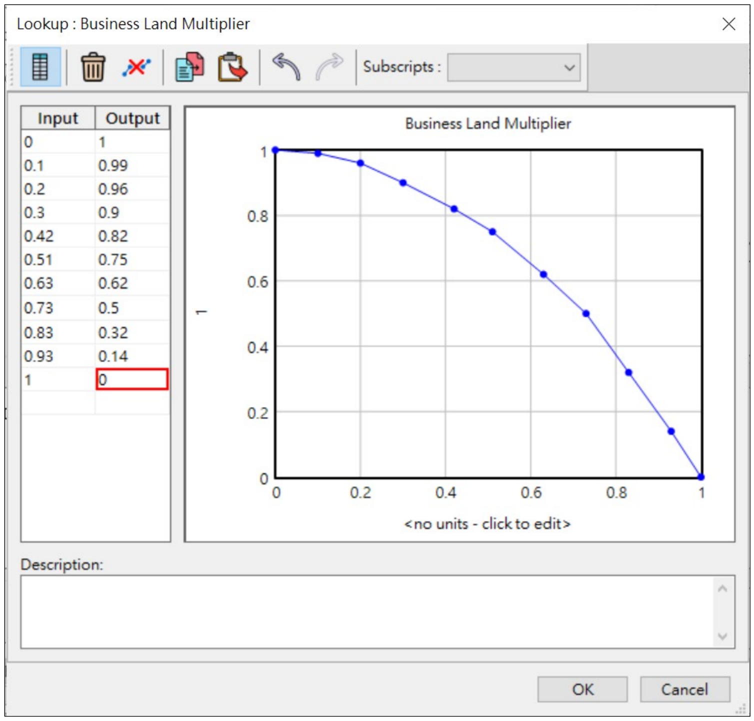

Question: Determine what you think should be the equation for Labor to Job Ratio, report it below.

$$\boldsymbol{Labor\ to\ Job\ Ratio} = \frac{\boldsymbol{Labor\ Force}}{\boldsymbol{Jobs}}\ \textbf{(unit: people/jobs)}$$

Question: Determine what you think should be the equation for Jobs, report it below.

$$\boldsymbol{Jobs} = \boldsymbol{Business} * \boldsymbol{Jobs\ per\ business}\ \textbf{(unit: jobs)}$$

Business Laborforce Multiplier relates labor availability. We do not have good available data for this variable, so we need to follow the guidelines for formulating graphical functions when observations are not available.

1. Normalize to dimensionless ratios.
   a. The range for the Business Laborforce Multiplier should be from 0 to 2.
   b. Normalize this variable such that when the labor force equals the number of jobs available, the business labor force multiplier = 1.
2. Identify Reference Points.
   a. When the number of available jobs exceeds the labor force by 25% (labor to job ratio = 0.8), new business creation grinds to a halt. There simply aren't enough workers to support new development.
   b. When the size of the labor force exceeds the number of jobs, the creation of new businesses is increasingly attractive. This increasing response holds until the labor force is roughly **twice** as large as the number of jobs, at which point the response holds flat.
3. Identify plausible shapes for the function.

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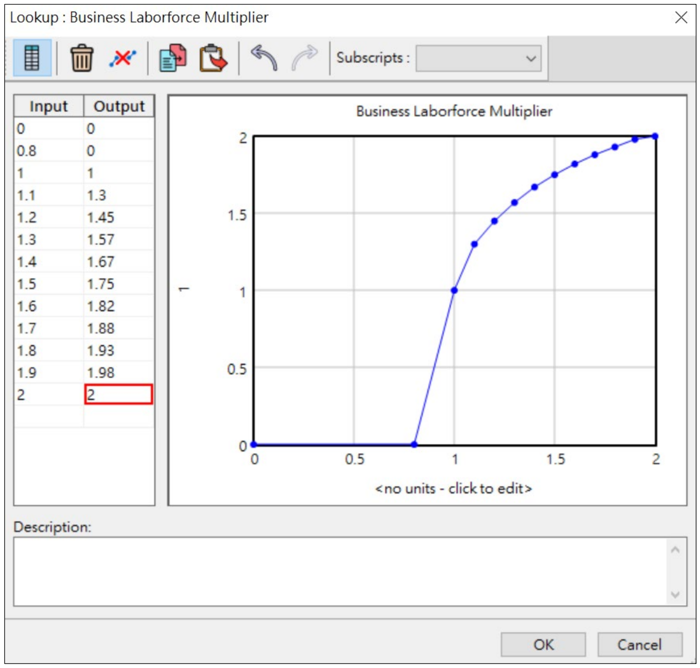
a. **Question:** What will this graphical function look like? Use the information above to draw the curve for Business Laborforce Multiplier as a function of Labor to Job Ratio. Paste a screenshot of that curve below**:**



The **connecting variables** are defined as follows:

a. Assume 35% of the population is willing and able to work, thus constituting the workforce.
b. Laborforce = Population*Labor Force Participation Fraction
c. Baseline in-migration fractional rate = 0.1 [people/people-yr]
d. Adjusted in-migration fractional rate = Attractiveness of Jobs*Baseline in-migration fractional rate
e. Attractiveness of Jobs is a graphical function normalized to 1 when the labor force equals the total number of jobs. The variable assumes that when labor is very scarce relative to jobs, the attractiveness of the job market is twice as high as normal. Additionally, when there is too much labor (2 people for every job), the attractiveness of the job market falls by 90% (attractiveness of jobs = 0.2)

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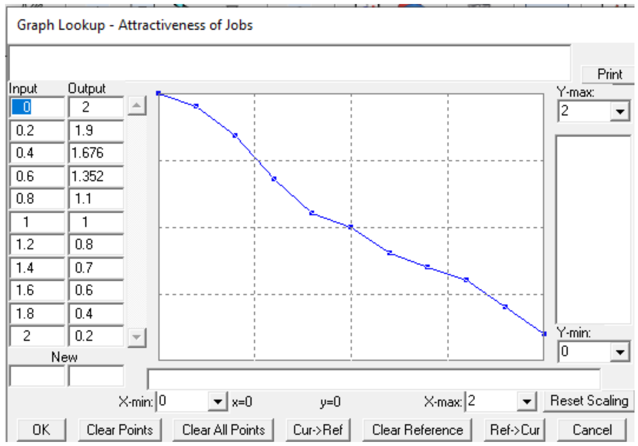
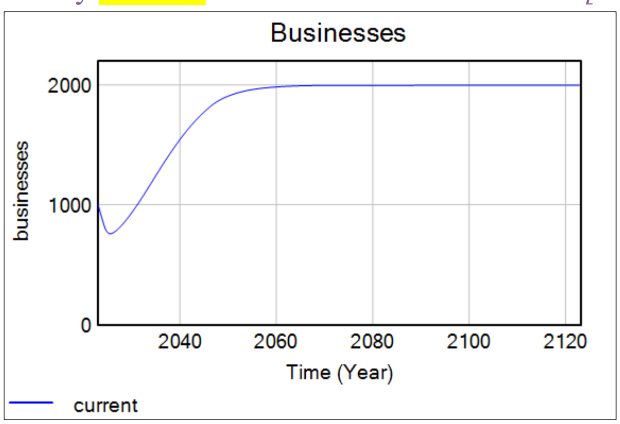
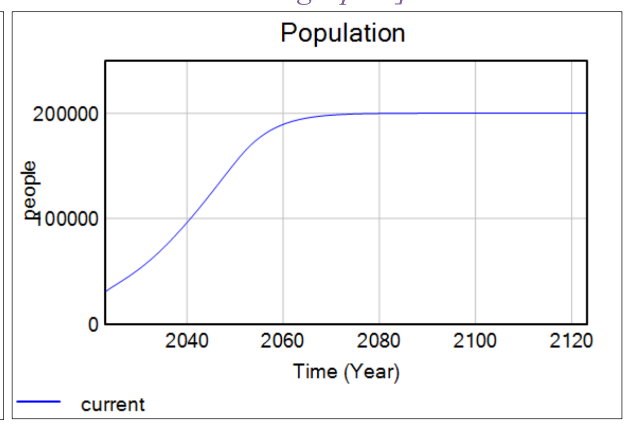
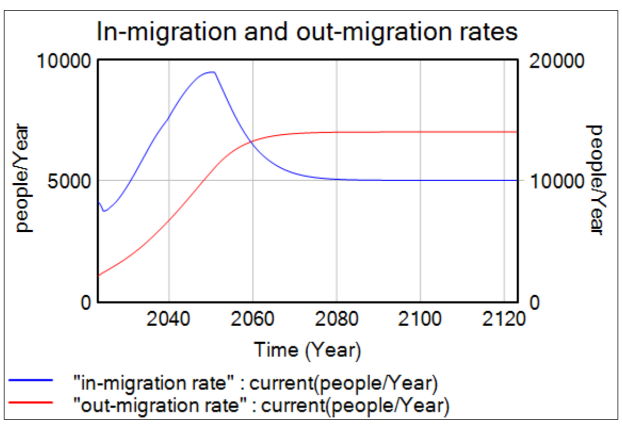
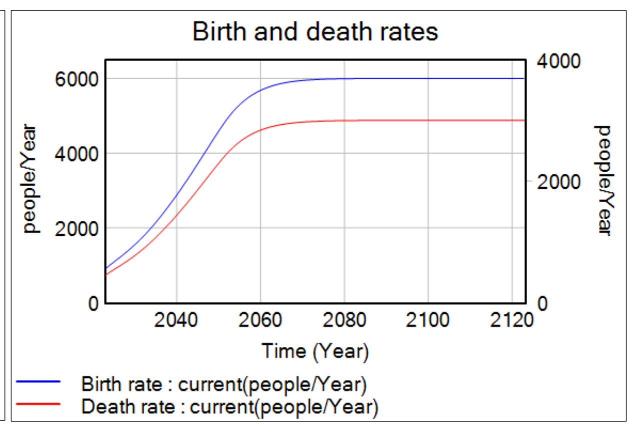


Question: Simulate the model over 100 years (time step = 0.125) and paste graphs of (1) businesses, (2) population, (3) in-migration and out-migration rate, (4) birth and death rate. Briefly describe the trends in these variables. *[You should have FOUR graphs!]*









1) **Business: The number of businesses has a small decrease in the first three years, and then increases quickly until the middle of year 2071, when it starts to reach its equilibrium at about 1995 businesses.**
2) **Population: Population size keeps growing constantly and greatly until the third season in year 2070. It reaches its equilibrium at approximately 200160 in the year of 2098, and the growth rate is mitigated.**

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3) **In-migration and out-migration rates: The in-migration rate decreases a little bit in the first two years, and then greatly increases and reaches its peak in year 2050.88 at 9475.69 people/year. After the peak, the rate does not stop decreasing until half-way through year 2075, when it starts reaching its equilibrium at 5100 people/year. On the contrary, the out-migration rate shows a constant increase throughout the 100 years of simulation and reaches its equilibrium at approximately 14000 people/year in the beginning of year 2083.**
4) **Birth and death rates: The birth rate and the death rate show similar trends of increases throughout the 100 years of simulation. Slopes of growths become smaller for both rates starting from year 2060, and the equilibriums are about 6000 for the birth rate and about 3000 for the death rate.**

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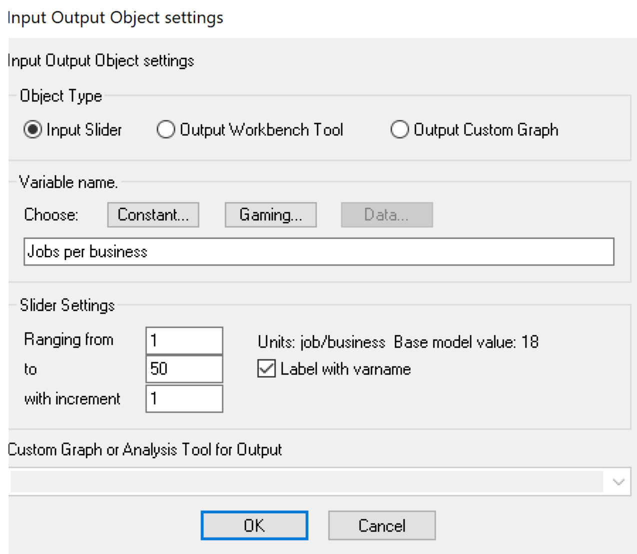
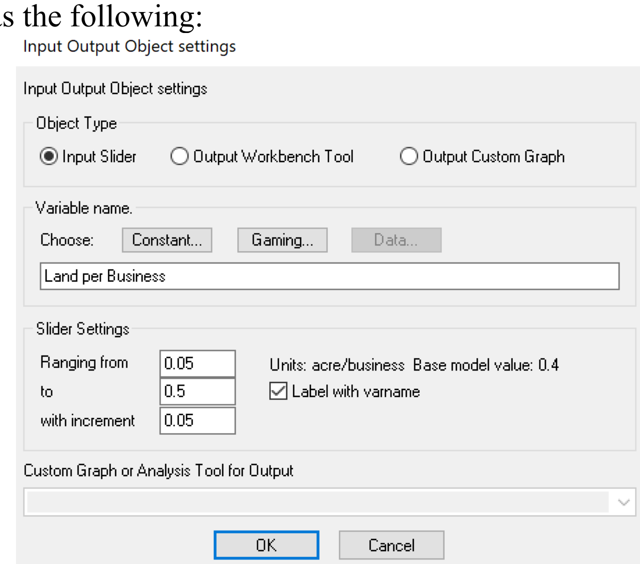
2. Sensitivity

Create a new copy of your model for part 2. The city is considering increasing development density to try and influence urban dynamics. They want to test the sensitivity of this issue. Start by creating two slider bars using the "IO Object" menu.

- The first input slider should be for the "Jobs per business" constant, and you should set the slider settings as the following:



- The second input slider should be for the "Land per Business" constant, and you should set the slider settings as the following:



Next, create Custom Graph Output of "Businesses" and "Population", again using IO Object. Remember that you will need to first create the graph in the Control Panel.

Question: Run a simulation with the "Land per Business" as 0.2 and the "Jobs per business" as 25. Insert your new Businesses & Population graph below and briefly discuss how the dynamics changed compared to part one.

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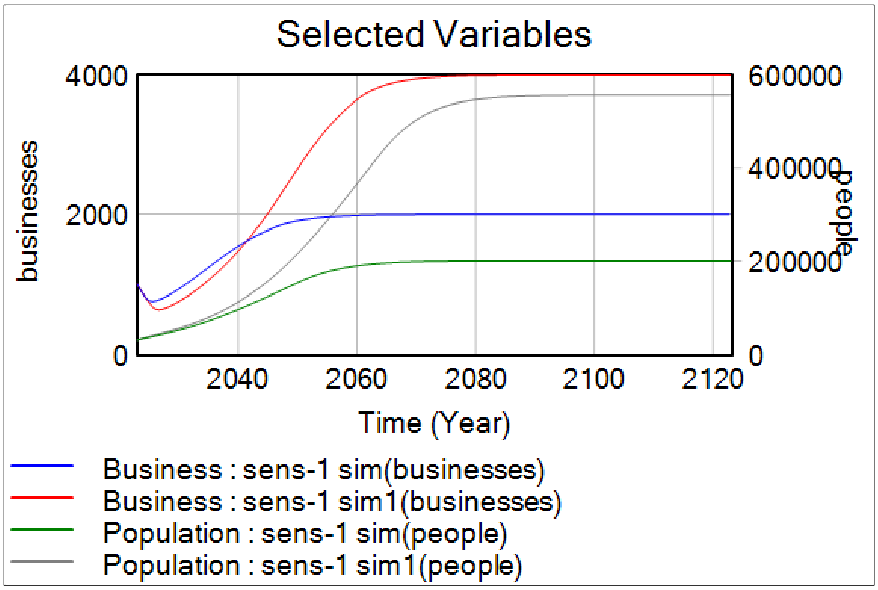
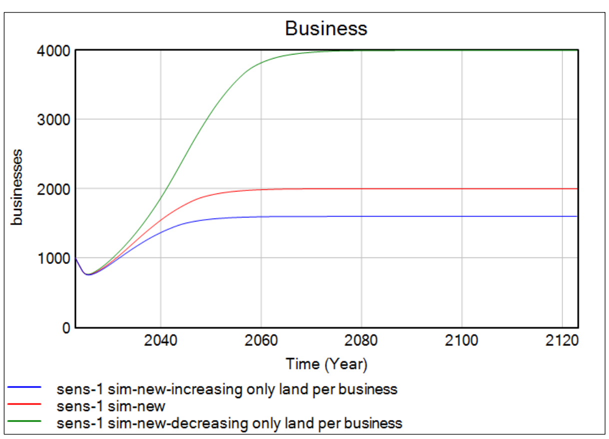
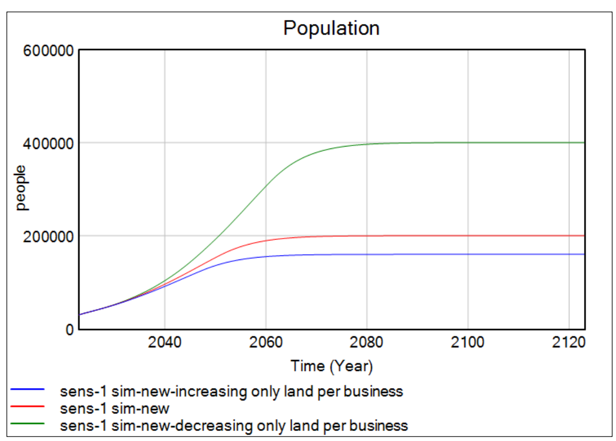


1) **"sens-1 sim" is the copy of my model from part 1.**
2) **Business: With the values of "Land per Business" at 0.2 and "Jobs per business" at 25, the number of businesses has a longer decrease comparing to the original values of "Land per Business" at 0.4 and "Jobs per business" at 18, but the increase exceeds the original simulation in part 1. The equilibrium number of businesses is approximately twice as large as the model in part 1.**
3) **Population: There is no cross in the trends of population from the two simulations. However, the difference is shown starting from year 2035. The size of the population increases greater in the second simulation, in which the equilibrium is almost three times as large as in the original simulation.**

Question: Click "Sim Setup" and then "SyntheSim" to be able to manipulate different variables using the sliders and see the graph change instantly. Play with the two different sliders and describe (2-4 sentences each) how "Land per Business" and "Jobs per Business" affect population and number of businesses.

Land per business: 0.2 (decreasing), 0.4, 0.5 (increasing):





"sens-1 sim-new" is the copy of my model from part 1.

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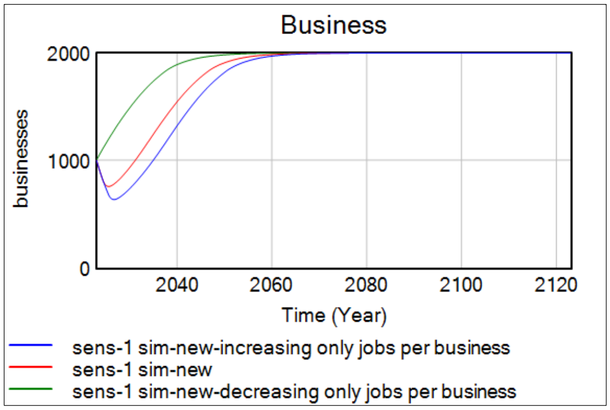
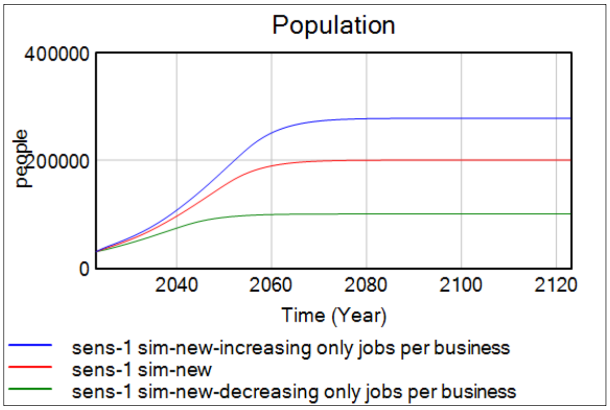
Different values of "land per business" do not lengthen the duration of the decrease in numbers of businesses. They do not change the trends of changes in numbers of businesses and population size, either. However, higher space per business leads to fewer businesses and smaller population size at the end of the 100-year simulation. The gaps between the equilibriums are exponential, which can be proved by that both the gaps in the number of businesses and population size between values of "land per business" set at 0.2 and at 0.4 is greater than two times as the gap between 0.4 and 0.5.

Jobs per business: 9 (decreasing), 18, 25 (increasing):





Different values of "jobs per business" result in different changing trends in numbers of businesses at the beginning of the simulations. There is no decrease in the number of businesses with "jobs per business" set at 9 throughout the simulation period. Nonetheless, the decrease of the same variable takes place longer when "jobs per business" is 25 over 18. Higher values of "jobs per business" also cause less numbers of businesses in the first stage of our simulation. Interestingly, the equilibrium values of number of businesses are very similar no matter which value of "jobs per business" is applied to the simulation. Different values of "jobs per business" do not change the trends of changes in population sizes—they are all increasing and reaching an equilibrium. More jobs per business leads to greater size of population at the end of the 100-year simulation. The relationship between the gaps of the equilibriums and the gaps of the input values of "jobs per business" are close to linear, where the differences in equilibriums look similar to the differences among the values of jobs per business.

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3. Stochastic Modeling

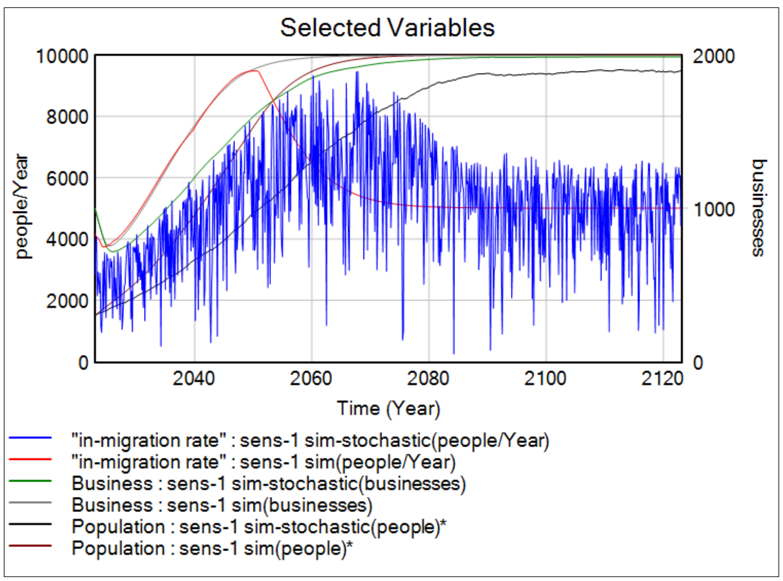
Create a new copy of the model from part 1. Assume the in-migration rate changes from Population*Adjusted in-migration fractional rate to instead follow a random normal distribution. Create a noise seed equal to 0 so that we can set stream ID = 0. Set the maximum return value to "Adjusted in-migration fractional rate*Population", and the minimum return value to 0. Set the mean to 8500 and the standard deviation to 3000.

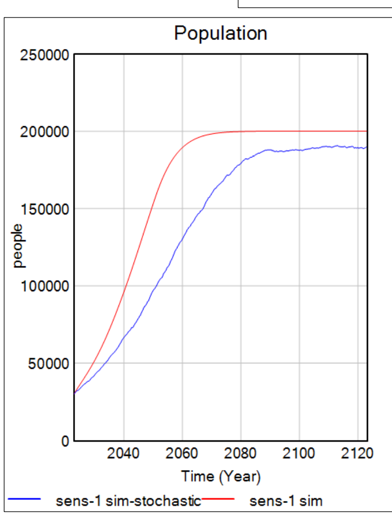
Paste the equation you gave to in-migration rate below**:**

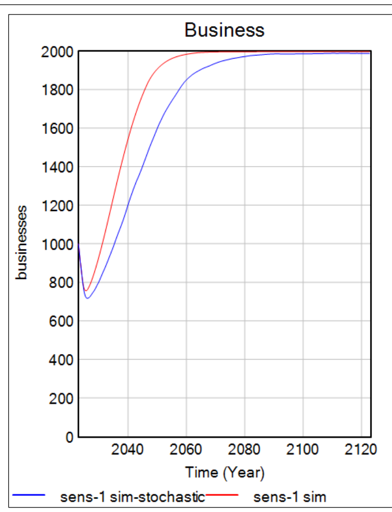
$$\boldsymbol{In - migration\ rate} \\ = \boldsymbol{RANDOM\ NORMAL(0, "Adjusted\ in - migration\ fractional\ rate"} \\ \boldsymbol{* Population, 8500, 3000, 0)}$$

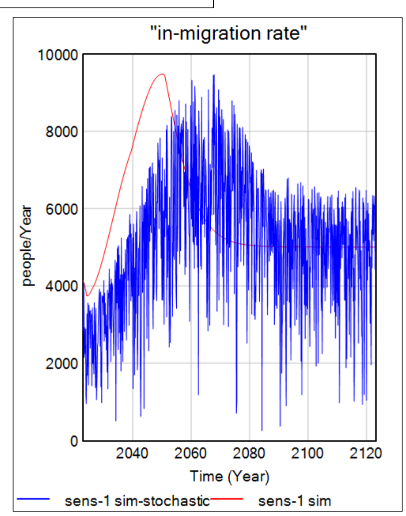
(unit: people/Year)

Question: Run the simulation again and paste a new graph the compares the in-migration rate, businesses, and population over time for part 1 and part 3. Comment on how the system behavior changed.









"sens-1 sim" is the copy of my model from part 1.

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1) **In-migration rate: Assigning noise to in-migration rate generates great changes in its output throughout the 100 years of simulation. Prior to the noise was introduced, the rate first decreased for a short term, and then increased sharply to its peak, and decreased and reached its equilibrium later on. After the noise is introduced, the rate changes its direction of growth each time step. And a chaotic outcome is seen. Interestingly, the large-scale trend looks kind of similar to the trend before the noise is introduced.**
2) **Population: Adding noise to in-migration rate also results in the changes of the size of population to have more micro-vibrant. Before the noise, the population increased annually without any small decreases, and it reached its equilibrium in year 2070 or so. With the noise, the population size keeps going up and down, while the large-scale trend remains to be an increase. It reaches its equilibrium later and with a smaller quantity than without the noise.**
3) **Business: The noise lengthens the period of the decrease seen in the number of businesses, and pulls it down more to a smaller number of businesses. Small-scale vibrant driving the periodic ups and downs is also seen in the trend of the number of businesses with noise. The noise also postpones the time the number of businesses reaches its equilibrium. However, the equilibrium values are close with and without the noise. Except for all these differences, the trend of decreasing in the beginning of the simulation followed by a positive growth are presented in both lines.**

Question: How is the Urban Dynamics model too simple? (i.e.: what is one other sub-model you would include? Think about other ways land is used in a city besides being space for businesses)

Spaces in urban cities can also be used for a better public transportation system or building more agencies for convenient public services (such as USPS and government departments). I would like to include a sub-model of an advanced public transportation system since people being brought in and out of this urban area through convenience public transportations can be huge and dynamic. In addition, public transportations have flexibility of being right on, above, or under the ground. These two elements can create great complexity to this Urban Dynamics model and make it challenging in building, inserting values and equations, and even interpreting the changes over time.