Exploring the Parameter Space

Pt. 1: Sensitivity Analysis

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- 5 Sensitivity Analysis in Python

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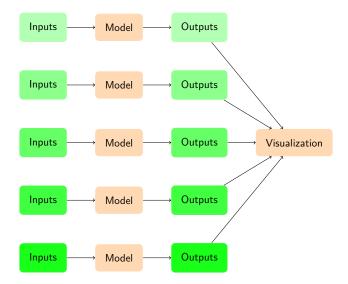
Extra Python Basics

 So far, I have given you some inputs to use and you have been getting one or more outputs from those inputs

 We have not considered how those inputs may change, and how that affects the outputs

 This is where building a model vs. doing a calculation really starts to pay off

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- In this lecture, we will be discussing sensitivity analysis as an approach to exploring the parameter space.
- After we cover probabilistic modeling, we will revisit exploring the parameter space with other methods: scenario analysis and Monte Carlo Simulation.
- In sensitivity analysis, a fixed set of values for the parameters are chosen, while in Monte Carlo Simulation, each parameter is assigned a distribution.
- In scenario analysis, several realistic cases of the inputs are chosen which represent possible real-world situations
- All three methods may be used together to fully understand a model.

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Sensitivity Analysis, Formally

For the model given by:

Explore Parameters

$$y = f(X) \tag{1}$$

$$X = [x_1, x_2, ..., x_n]$$
 (2)

- y : Model output
- X : Model input matrix
- x_i : Value of ith x variable

Follow the following steps:

- Choose a set of values for each x_i
- 2 Take the cartesian product of these values as $[X_1, X_2, ..., X_m]$
- **3** For each X_i calculate $y_i = f(X_i)$
- Store the values of X_i mapped to y_i
- \bullet Visualize y_i versus X_i

Let's take a simple demand model as an example:

$$D = c - EP \tag{3}$$

$$X = [c, E, P] \tag{4}$$

- D : Quantity demanded
- c : Demand constant
- E: Elasticity of demand
- P : Price
- X : Model input matrix

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Sensitivity Analysis Example

$$D = c - EP \tag{5}$$

Follow the following steps:

- ① Choose c = (60000, 100000), E = (200, 500), P = (50, 100)
- 2 Take the cartesian product of these values, yielding $[X_1, X_2, ..., X_m]$:

С	Ε	Ρ		
60000	200	50		
60000	200	100		
60000	500	50		
60000	500	100		
100000	200	50		
100000	200	100		
100000	500	50		
100000	500	100		

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Sensitivity Analysis Example, Pt. 2

$$D = c - EP \tag{6}$$

Continue following the steps:

- § For each X_i calculate $y_i = f(X_i)$
- Store the values of X_i mapped to y_i

			•		
С	Ε	Ρ	D		
60000	200	50	50000		
60000	200	100	40000		
60000	500	50	35000		
60000	500	100	10000		
100000	200	50	90000		
100000	200	100	80000		
100000	500	50	75000		
100000	500	100	50000		

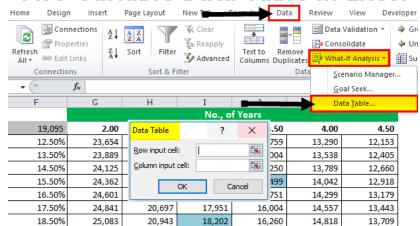
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- 3 Sensitivity Analysis in Excel with Data Tables

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Sensitivity Analysis in Excel

Two-Variable Data Table in Excel



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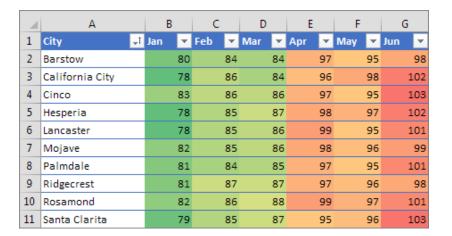
Visualizing Sensitivity Analysis in Excel

• There are two main ways to visualize sensitivity analysis results in Excel: graphing and conditional formatting.

Graphing is usually appropriate for one-way data tables

Conditional formatting is usually appropriate for two-way data tables

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Sensitivity Analysis in Excel

Explore Parameters

Adding Sensitivity Analysis to the Dynamic Retirement Excel Model

- I will now go through adding sensitivity analysis to the Dynamic Salary Retirement Model in Excel
- The completed exercise on the course site, "Dynamic Salary Retirement Model Sensitivity.xlsx"

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Adding Sensitivity Analysis to Project 1 - Excel

- Add sensitivity analysis to your Excel model from Project 1
- See how the NPV changes when the number of machines and initial demand change
- Oo a one-way Data Table with a graph for each of the two inputs, then a two-way data table with conditional formatting

Resources: Slide 42

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- Python List Comprehensions, Installing Packages, and More on **Dictionaries**

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We'll cover a couple more Python patterns and a new data type before jumping into sensitivity analysis

Dictionaries

Explore Parameters

- List comprehensions
- Python import system and custom code

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- A dictionary, or dict for short, is another basic Python data type like lists, numbers, and strings.
- Like a list, it is a collection: it holds other objects.

 Unlike a list, a dict is composed of key-value pairs. It holds relationships between objects.



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Basic Dictionary Example

```
>>> coffee_levels_emotions = {
>>>
        'high': 'happy',
>>>
        'pretty high': 'happy',
>>>
       'medium': 'neutral',
       'low': 'sad'.
>>>
>>>
        'empty': 'desparate'
>>> }
>>> coffee_levels_emotions['pretty high']
'happy'
>>> for coffee_level, emotion in coffee_levels_emotions.items():
>>>
       print(f"I'm {emotion} when my coffee is {coffee_level}")
I'm happy when my coffee is high
I'm happy when my coffee is pretty high
I'm neutral when my coffee is medium
I'm sad when my coffee is low
I'm desparate when my coffee is empty
```

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Add and Delete Items from Dictionaries

```
>>> coffee_levels_emotions.update({'overflowing': 'burned'})
>>> coffee_levels_emotions['negative'] = 'confused'
>>> high_value = coffee_levels_emotions.pop('high')
>>> coffee_levels_emotions
{'pretty high': 'happy',
 'medium': 'neutral'.
 'low': 'sad'.
 'empty': 'desparate',
 'overflowing': 'burned',
 'negative': 'confused'}
>>> high_value
'happy'
```

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More About Dictionaries in Python

Using Dictionaries

- I will now start going through the example notebook called "Python Dicts, List comprehensions, and Imports.ipynb"
- I will go through the Dictionaries section for now

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Dictionaries Lab

Explore Parameters

Learning How to Use Dictionaries

- For this Python section, lab exercises are in the Jupyter notebook Dicts and List Comprehensions Lab.ipynb
- Complete the exercises in the dictionaries section for now

Resources: Slide 43

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The Original Way

```
>>> out_values = []
>>> for i in range(5):
>>> out_values.append(i + 10)
>>> out_values
[10, 11, 12, 13, 14]
```

With List Comprehension

```
>>> out_values = [i + 10 for i in range(5)]
>>> out_values
[10, 11, 12, 13, 14]
```

Notice

You **never** need to use list comprehension, it is just for convenience. The original for loop syntax will always work fine.

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Easier Loops in Python

Using List Comprehensions

- I will continue going through the example notebook "Python Dicts, List comprehensions, and Imports.ipynb"
- I will go through the List Comprehensions section for now

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List Comprehensions Lab

Learning How to Use List Comprehensions

- Continue working on the same Jupyter notebook from the previous lab exercise
- Complete the exercises in the List Comprehensions section for now

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Understanding Python imports

- In the past we have used import to load packages such as numpy and pandas
- These packages are just Python files. We can also write our own Python files and import them the same way
- When you import something, Python first searches the current directory for a file something.py and if it doesn't find it, it searches your installed packages
- In fact if you added a numpy.py in the current directory and tried to import numpy it would import the contents of that file rather than the numpy package.

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Importing Custom Code

Explore Parameters

 You can write your own functions and classes, then put them in a Python file and import them into your notebook.

- When you import a file, it executes the contents of that file. So you
 generally want just function and class definitions, and not really
 anything outside of def or class statements.
- Using Python files is a more maintainable structure for building complex models and apps versus Jupyter notebooks only.

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- Sometimes you will need a package which does not already come installed with Anaconda
- The general way to do this is with pip install mypackage replacing mypackage with the package you want to install
- You would run this in Anaconda Prompt, or in Jupyter you can run it but you need to put an exclaimation mark before it to say you want to run it in a terminal. So in Jupyter it would be !pip install mypackage

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How to Install Packages

- I will continue going through the example notebook "Python Dicts, List comprehensions, and Imports.ipynb"
- I will go through the Imports and Installing Packages section for now

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Sensitivity Analysis in Python - Hex-Bin



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SA Python

Sensitivity Analysis in Python - Styled DataFrame

Result - value1 vs. value2

10 11 12 13 14 15 16 17 18 19

value1

valuei										
0	15	16	17	18	19	20	21	22	23	24
1	16	17	18	19	20	21	22	23	24	25
2	17	18	19	20	21	22	23	24	25	26
3	18	19	20	21	22	23	24	25	26	27
4	19	20	21	22	23	24	25	26	27	28
5	20	21	22	23	24	25	26	27	28	29
6	21	22	23	24	25	26	27	28	29	30
7	22	23	24	25	26	27	28	29	30	31
8	23	24	25	26	27	28	29	30	31	32
9	24	25	26	27	28	29	30	31	32	33

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How to Do Sensitivity Analysis in Python (The Hard Way)

Extra Python Basics

- Generally, to do sensitivity analysis in Python without any special tools, you would just create one nested for loop for each input, and finally within all the loops, run your model with the inputs from the loops
- This will work fine, but you will have many nested loops which can become hard to read. Also it is a fair bit of setup involved.
- You can avoid the nested loops with itertools.product but then this becomes more difficult to use and read

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Sensitivity Analysis Example (Hard Way)

 Say you have a function which runs your model, called model, which takes inputs of inp1 and inp2

Sensitivity Analysis in Python with No Libraries

```
inp1_values = [1, 2]
inp2\_values = [4, 5]
results = []
for inp1 in inp1_values:
    for inp2 in inp2_values:
        result = model(inp1, inp2,)
        results.append(
            (inp1, inp2, result)
        )
pd.DataFrame(results, columns=['inp1', 'inp2', 'Result'])
   inp1
       inp2 Result
         5
```

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Explore Parameters

SA Python

How to Do Sensitivity Analysis in Python (The Easy Way)

 When I first created this course, I thought there should be a good sensitivity analysis tool in Python and I couldn't find it

- The beauty of Python is if you want a tool that doesn't exist, you can create it, and share it with others so that nobody else has to deal with the problem.
- So I created sensitivity a package for sensitivity analysis in Python, which makes it very easy

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Sensitivity Analysis Example (Easy Way)

 Say you have a function which runs your model, called model, which takes inputs of inp1 and inp2

Sensitivity Analysis in Python with sensitivity

```
from sensitivity import SensitivityAnalyzer
sensitivity values = {
    'inp1': [1, 2],
    'inp2': [4, 5],
}
     SensitivityAnalyzer(sensitivity_values, model)
sa.df
   inp1
       inp2 Result
               6
```

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6

7

4

5

Intro to Sensitivity Analysis in Python

An Overview of the Manual and Automated Approaches

- I will now go through Sensitivity Analysis example Jupyter notebook
- This notebook shows both the standard approach and using the sensitivity package

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Applying Sensitivity Analysis in Python

Adding Sensitivity Analysis to the Dynamic Retirement Python Model

- I will now go through adding sensitivity analysis to the Dynamic Salary Retirement Model in Python
- The completed exercise available on the course site is called "Dynamic Salary Retirement Model Sensitivity.ipynb"

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Sensitivity Analysis in Python Lab

Adding Sensitivity Analysis to Project 1 - Python

- Add sensitivity analysis to your Python model from Project 1
- See how the NPV changes when the number of machines and initial demand change
- Output both a hex-bin plot and a styled DataFrame

Resources: Slide 45

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Lecture Resources

Lecture Resources

- Slides Exploring the Parameter Space
- Lecture Notes Exploring the Parameter Space
- Oynamic Salary Retirement Model Excel
- Python Dicts, List Comprehensions, and Imports
- Oictionaries, List Comprehensions, and Imports Labs
- Guide to Python Imports
- Sensitivity Analysis
- Oynamic Salary Retirement Model Python

Sensitivity Analysis in Excel Lab Resources

Adding Sensitivity Analysis to Project 1 - Excel Resources

Slides - Exploring the Parameter Space

Exercise: Slide 16

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Dictionaries Lab Resources

Learning How to Use Dictionaries Resources

- Slides Exploring the Parameter Space
- Python Dicts, List Comprehensions, and Imports
- Oictionaries, List Comprehensions, and Imports Labs

Exercise: Slide 23

List Comprehensions Lab Resources

Learning How to Use List Comprehensions Resources

- Slides Exploring the Parameter Space
- Python Dicts, List Comprehensions, and Imports
- Oictionaries, List Comprehensions, and Imports Labs

Exercise: Slide 26

Sensitivity Analysis in Python Lab Resources

Adding Sensitivity Analysis to Project 1 - Python Resources

Slides - Exploring the Parameter Space

Exercise: Slide 40

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