assignment 7 - sensitivity analysis lake model

May 13, 2021

[1]:
```
#%%html
#<link rel="stylesheet" href="style/style.css">
```

1 Lake model continued

In the previous week you used the lake problem as a means of getting aquinted with the workbench. In this assignment we will continue with the lake problem, focussing explicitly on using it for open exploration. You can use the second part of this tutorial for help.

It is paramount that you are using the lake problem with 100 decision variables, rather than the one found on the website with the seperate anthropogenic release decision

1.1 Apply sensitivity analysis

There is substantial support in the ema_workbench for global sensitivity. For this, the workbench relies on SALib and feature scoring which is a machine learning alternative for global sensitivity analysis.

1. Apply Sobol with 3 seperate release policies (0, 0.05, and 0.1) and analyse the results for each release policy seperately focusing on the reliability objective. Do the sensitivities change depending on the release policy? Can you explain why or why not?

hint: you can use sobol sampling for the uncertainties, and set policies to a list with the 3 different release policies. Next, for the analysis using logical indexing on the experiment.policy column you can select the results for each seperate release policy and apply sobol to each of the three seperate release policies. If this sounds too complicated, just do it on each release policy seperately.

Use the Sobol sampling functionality included in the Workbench to perform experiments with a sample size of N=50, then analyze the results with SALib for the same three indicators. This requires specifying the keyword argument 'uncertainty_sampling' of perform_experiments. Note that when using Sobol sampling, the meaning of the keyword argument scenarios changes a bit. In order to properly estimate Sobol scores as well as interaction effects, you require N * (2D+2) scenarios, where D is the number of uncertain parameters, and N is the value for scenarios passed to perform_experiments. Repeat the analysis for larger sample sizes, with N=250 and N=1000. How can we interpret the first-order and total indices? Are these sample sizes sufficient for a stable estimation of the indices? You'll need to use the get_SALib_problem function to convert your Workbench experiments to a problem definition that you can pass to the SALib analysis function.

[2]:

```
import numpy as np
import matplotlib.pyplot as plt
from ema_workbench import (Model, RealParameter, Constant, ScalarOutcome,␣
 ↪perform_experiments, ema_logging, MultiprocessingEvaluator)
from ema_workbench.em_framework.evaluators import LHS, SOBOL
from ema_workbench.analysis import feature_scoring, pairs_plotting
from ema_workbench.analysis.scenario_discovery_util import RuleInductionType
from ema_workbench.em_framework.salib_samplers import get_SALib_problem
from SALib.analyze import sobol
import pandas as pd
import seaborn as sns
```

1.1.1 Sobol sampling for different release policies and number of scenarios

[3]:

```
# Set up model

import lakemodel_function as lake

model = Model('Lakemodel', function=lake.lake_problem)

uncertainties = [RealParameter('mean', 0.01, 0.5),
                 RealParameter('stdev', 0.001, 0.005),
                 RealParameter('b', 0.1, 0.45),
                 RealParameter('q', 2, 4.5),
                 RealParameter('delta', 0.93, 0.99)]

outcomes = [ScalarOutcome('max_P', ScalarOutcome.MINIMIZE),
            ScalarOutcome('utility', ScalarOutcome.MAXIMIZE),
            ScalarOutcome('inertia', ScalarOutcome.INFO),
            ScalarOutcome('reliability', ScalarOutcome.MAXIMIZE)]
# assumption that inertia does not matter and is only there to provide info.

model.uncertainties = uncertainties

# model.levers = [RealParameter("l" + str(number),0,0.1) for number in␣
 ↪range(0,100)]

model.outcomes = outcomes
```

[4]:

```
# Model run
processes = 8
D = len(uncertainties)
i = 0
experiments = {}
outcomes = {}
Si = {}
indexes = []
```

```
for l_value in [0, 0.05, 0.1]:

    model.constants = [Constant('l' + str(i), l_value) for i in range(100)]

    for N in [50, 250, 1000]:

        n_scenarios = N * (2 * D + 2)
        print('N =',str(N))
        print('Release decision:',str(l_value))
        print('Scenarios to perform:',str(n_scenarios))

        # This will be useful later
        indexes.append('l'+str(l_value)+'_N'+str(N))

        # This bit of code is actually preventing a warning from SAlib for some␣
 ↪reason, the one about the 2^n scenarios
        ema_logging.log_to_stderr(ema_logging.INFO)

        with MultiprocessingEvaluator(model, processes) as evaluator:
            # I think no policies because levers is a constant?
            experiments[indexes[-1]], outcomes[indexes[-1]] = evaluator.
 ↪perform_experiments(scenarios = N, uncertainty_sampling=SOBOL)
            # Still have to add more Sobol crap here
            problem = get_SALib_problem(model.uncertainties)
            Si[indexes[-1]] = sobol.analyze(problem,␣
 ↪outcomes[indexes[-1]]['max_P'], calc_second_order=True,␣
 ↪print_to_console=False)
```

```
N = 50
Release decision: 0
Scenarios to perform: 600
```

```
[MainProcess/INFO] pool started
C:\Users\David2\anaconda3\envs\gds\lib\site-
packages\SALib\sample\saltelli.py:52: FutureWarning:
        Convergence properties of the Sobol' sequence is only valid if `N` =
2^n.
        SALib will continue on, but results may have issues.
        In future, this will raise an error.

  warnings.warn(msg, FutureWarning)
[MainProcess/INFO] performing 600 scenarios * 1 policies * 1 model(s) = 600
experiments
[MainProcess/INFO] 60 cases completed
[MainProcess/INFO] 120 cases completed
[MainProcess/INFO] 180 cases completed
[MainProcess/INFO] 240 cases completed
```

```
[MainProcess/INFO] 300 cases completed
[MainProcess/INFO] 360 cases completed
[MainProcess/INFO] 420 cases completed
[MainProcess/INFO] 480 cases completed
[MainProcess/INFO] 540 cases completed
[MainProcess/INFO] 600 cases completed
[MainProcess/INFO] experiments finished
[MainProcess/INFO] terminating pool
```

```
N = 250
Release decision: 0
Scenarios to perform: 3000
```

```
[MainProcess/INFO] pool started
[MainProcess/INFO] performing 3000 scenarios * 1 policies * 1 model(s) = 3000
experiments
[MainProcess/INFO] 300 cases completed
[MainProcess/INFO] 600 cases completed
[MainProcess/INFO] 900 cases completed
[MainProcess/INFO] 1200 cases completed
[MainProcess/INFO] 1500 cases completed
[MainProcess/INFO] 1800 cases completed
[MainProcess/INFO] 2100 cases completed
[MainProcess/INFO] 2400 cases completed
[MainProcess/INFO] 2700 cases completed
[MainProcess/INFO] 3000 cases completed
[MainProcess/INFO] experiments finished
[MainProcess/INFO] terminating pool
```

```
N = 1000
Release decision: 0
Scenarios to perform: 12000
```

```
[MainProcess/INFO] pool started
[MainProcess/INFO] performing 12000 scenarios * 1 policies * 1 model(s) = 12000
experiments
[MainProcess/INFO] 1200 cases completed
[MainProcess/INFO] 2400 cases completed
[MainProcess/INFO] 3600 cases completed
[MainProcess/INFO] 4800 cases completed
[MainProcess/INFO] 6000 cases completed
[MainProcess/INFO] 7200 cases completed
[MainProcess/INFO] 8400 cases completed
[MainProcess/INFO] 9600 cases completed
[MainProcess/INFO] 10800 cases completed
[MainProcess/INFO] 12000 cases completed
[MainProcess/INFO] experiments finished
[MainProcess/INFO] terminating pool
```

```
N = 50
```

```
Release decision: 0.05
Scenarios to perform: 600

[MainProcess/INFO] pool started
[MainProcess/INFO] performing 600 scenarios * 1 policies * 1 model(s) = 600
experiments
[MainProcess/INFO] 60 cases completed
[MainProcess/INFO] 120 cases completed
[MainProcess/INFO] 180 cases completed
[MainProcess/INFO] 240 cases completed
[MainProcess/INFO] 300 cases completed
[MainProcess/INFO] 360 cases completed
[MainProcess/INFO] 420 cases completed
[MainProcess/INFO] 480 cases completed
[MainProcess/INFO] 540 cases completed
[MainProcess/INFO] 600 cases completed
[MainProcess/INFO] experiments finished
[MainProcess/INFO] terminating pool

N = 250
Release decision: 0.05
Scenarios to perform: 3000

[MainProcess/INFO] pool started
[MainProcess/INFO] performing 3000 scenarios * 1 policies * 1 model(s) = 3000
experiments
[MainProcess/INFO] 300 cases completed
[MainProcess/INFO] 600 cases completed
[MainProcess/INFO] 900 cases completed
[MainProcess/INFO] 1200 cases completed
[MainProcess/INFO] 1500 cases completed
[MainProcess/INFO] 1800 cases completed
[MainProcess/INFO] 2100 cases completed
[MainProcess/INFO] 2400 cases completed
[MainProcess/INFO] 2700 cases completed
[MainProcess/INFO] 3000 cases completed
[MainProcess/INFO] experiments finished
[MainProcess/INFO] terminating pool

N = 1000
Release decision: 0.05
Scenarios to perform: 12000

[MainProcess/INFO] pool started
[MainProcess/INFO] performing 12000 scenarios * 1 policies * 1 model(s) = 12000
experiments
[MainProcess/INFO] 1200 cases completed
[MainProcess/INFO] 2400 cases completed
[MainProcess/INFO] 3600 cases completed
[MainProcess/INFO] 4800 cases completed
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[MainProcess/INFO] 6000 cases completed
[MainProcess/INFO] 7200 cases completed
[MainProcess/INFO] 8400 cases completed
[MainProcess/INFO] 9600 cases completed
[MainProcess/INFO] 10800 cases completed
[MainProcess/INFO] 12000 cases completed
[MainProcess/INFO] experiments finished
[MainProcess/INFO] terminating pool
```

```
N = 50
Release decision: 0.1
Scenarios to perform: 600
```

```
[MainProcess/INFO] pool started
[MainProcess/INFO] performing 600 scenarios * 1 policies * 1 model(s) = 600
experiments
[MainProcess/INFO] 60 cases completed
[MainProcess/INFO] 120 cases completed
[MainProcess/INFO] 180 cases completed
[MainProcess/INFO] 240 cases completed
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[MainProcess/INFO] 360 cases completed
[MainProcess/INFO] 420 cases completed
[MainProcess/INFO] 480 cases completed
[MainProcess/INFO] 540 cases completed
[MainProcess/INFO] 600 cases completed
[MainProcess/INFO] experiments finished
[MainProcess/INFO] terminating pool
```

```
N = 250
Release decision: 0.1
Scenarios to perform: 3000
```

```
[MainProcess/INFO] pool started
[MainProcess/INFO] performing 3000 scenarios * 1 policies * 1 model(s) = 3000
experiments
[MainProcess/INFO] 300 cases completed
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[MainProcess/INFO] 1500 cases completed
[MainProcess/INFO] 1800 cases completed
[MainProcess/INFO] 2100 cases completed
[MainProcess/INFO] 2400 cases completed
[MainProcess/INFO] 2700 cases completed
[MainProcess/INFO] 3000 cases completed
[MainProcess/INFO] experiments finished
[MainProcess/INFO] terminating pool
```

```
N = 1000
```

```
Release decision: 0.1
Scenarios to perform: 12000
```

```
[MainProcess/INFO] pool started
[MainProcess/INFO] performing 12000 scenarios * 1 policies * 1 model(s) = 12000
experiments
[MainProcess/INFO] 1200 cases completed
[MainProcess/INFO] 2400 cases completed
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[MainProcess/INFO] 10800 cases completed
[MainProcess/INFO] 12000 cases completed
[MainProcess/INFO] experiments finished
[MainProcess/INFO] terminating pool
```
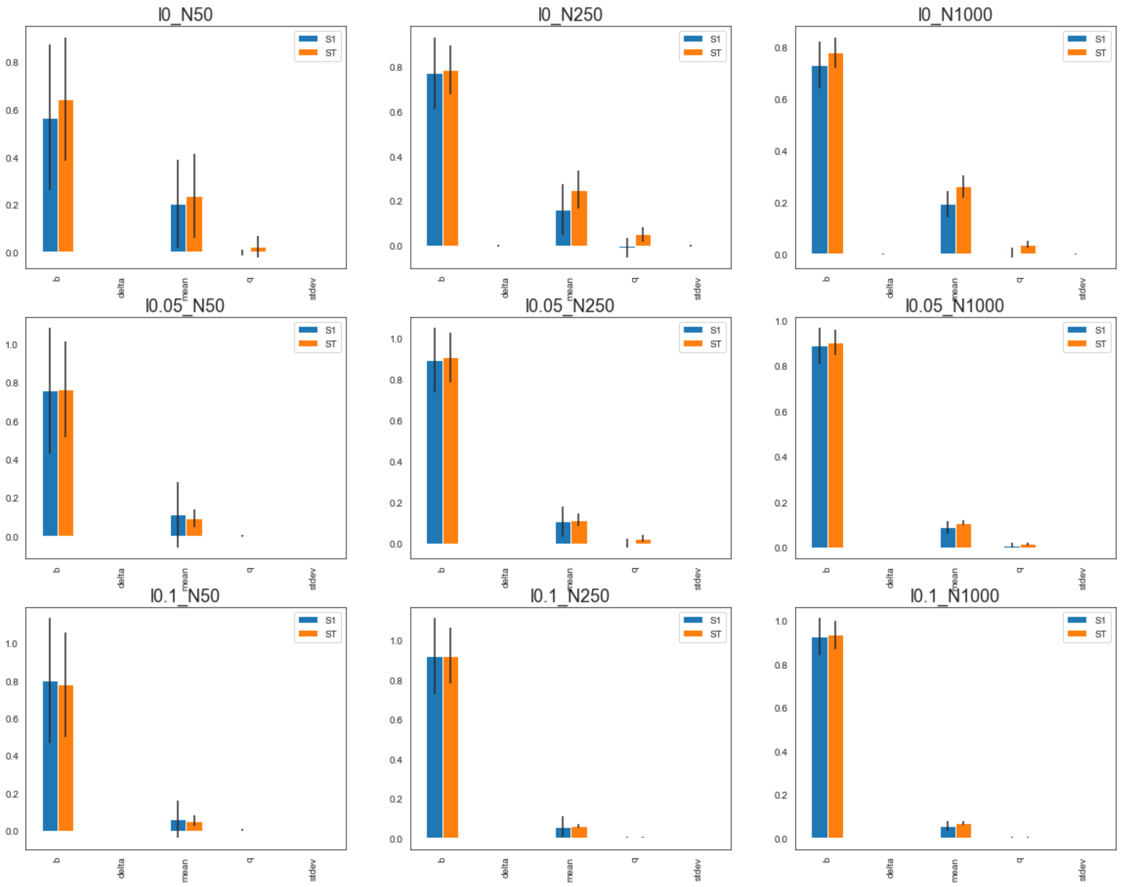

[5]:

```python
Si_df = {}
indices = {}
err = {}

# Get data for visual stuff
for i in indexes:

    scores_filtered = {k:Si[i][k] for k in ['ST','ST_conf','S1','S1_conf']}
    Si_df[i] = pd.DataFrame(scores_filtered, index=problem['names'])
    indices[i] = Si_df[i][['S1','ST']]
    err[i] = Si_df[i][['S1_conf','ST_conf']]

# Set up figure

sns.set_style('white')
fig, ax = plt.subplots(3,3)
fig.set_size_inches(20,15)
fig.subplots_adjust(bottom=0.1)

# Set up sub figures

for i in range(9):

    indices[indexes[i]].plot.bar(yerr=err[indexes[i]].values.T,ax=ax.
 ↪flatten()[i])
    ax.flatten()[i].set_title(indexes[i], fontsize=18)

plt.show()
```



1.1.2 Analysis

In this model the contribution (or sensitivity) of the uncertain inputs when analyzed without contribution from other inputs (S1) and the contribution with interaction from other inputs (ST) we see that it is not too different for both cases, suggesting that the sensitive variables are mostly independent of each other, even though in some cases we can see that ST is slightly more sensitive than S1. However, the margin of error is big enough in these cases that we can disregard this small difference.

More importantly, however, is the fact that we can see that delta, q, and stdev contribute very little to changes in the model, which means the model is not sensitive to these uncertain variables.

2. Repeat the above analysis for the 3 release policies but now with extra trees feature scoring and for all outcomes of interest. As a bonus, use the sobol experiment results as input for extra trees, and compare the results with those resulting from latin hypercube sampling.

hint: you can use seaborn heatmaps for a nice figure of the results

1.1.3 Compare Sobol and LHS

Sobol

[6]:

```python
# Feature scoring

fs = {}

for i in indexes:
    x = experiments[i]
    y = outcomes[i]
    fs[i] = feature_scoring.get_feature_scores_all(x, y, alg='extra trees')

# Set up figure
sns.set_style('white')
fig, ax = plt.subplots(3,3)
fig.set_size_inches(20,15)

# Individual figures

for i in range(9):

    sns.heatmap(fs[indexes[i]], cmap='viridis', annot=True, ax=ax.flatten()[i])
    ax.flatten()[i].set_title(indexes[i], fontsize=18)

plt.show()
```

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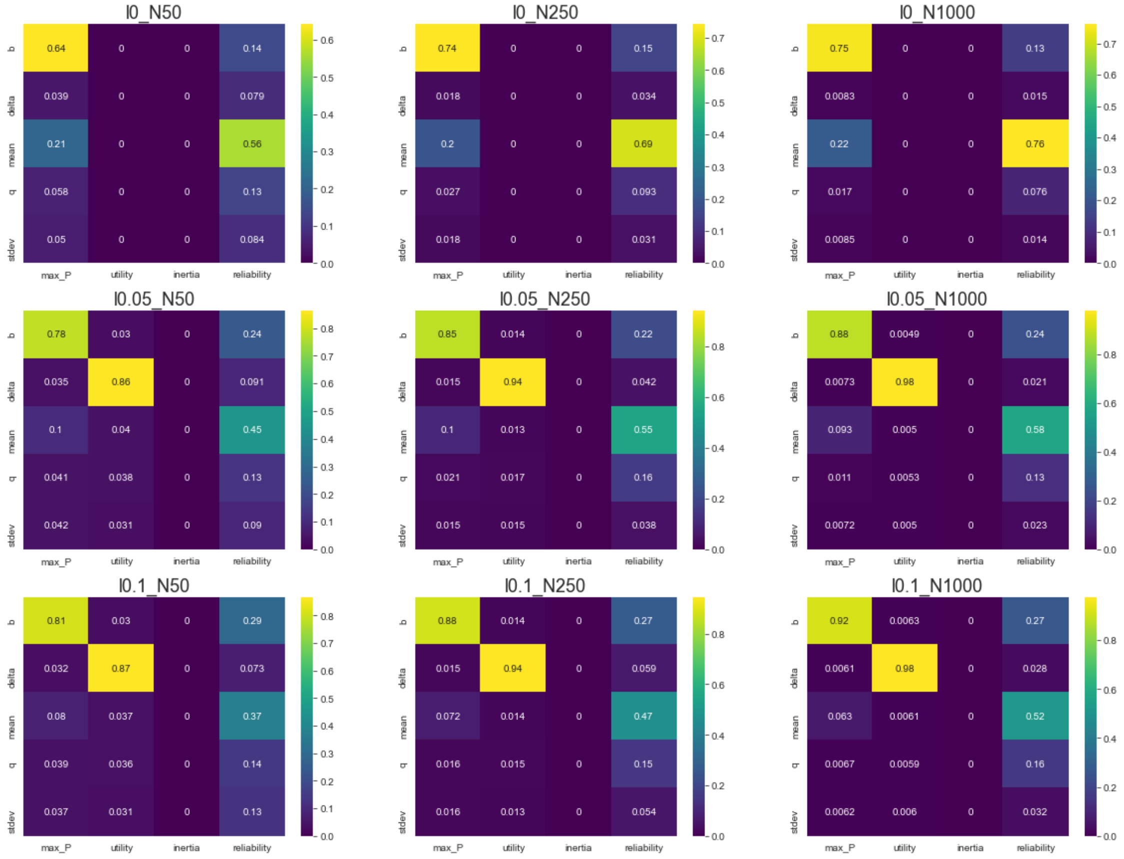
[MainProcess/INFO] model dropped from analysis because only a single category
```



LHS

```
[7]: # LHS sampling to compare

     experiments = {}
     outcomes = {}
     indexes = []

     for l_value in [0, 0.05, 0.1]:

         model.constants = [Constant('l' + str(i), l_value) for i in range(100)]

         for N in [50, 250, 1000]:

             indexes.append('l'+str(l_value)+'_N'+str(N))

             print('N =',str(N))
             print('Release decision:',str(l_value))

             ema_logging.log_to_stderr(ema_logging.INFO)
```

```
        with MultiprocessingEvaluator(model, processes) as evaluator:
            # I think no policies because levers is a constant?
            experiments[indexes[-1]], outcomes[indexes[-1]] = evaluator.
↪perform_experiments(scenarios = N, uncertainty_sampling=LHS)
```

```
N = 50
Release decision: 0
```

```
[MainProcess/INFO] pool started
[MainProcess/INFO] performing 50 scenarios * 1 policies * 1 model(s) = 50
experiments
[MainProcess/INFO] 5 cases completed
[MainProcess/INFO] 10 cases completed
[MainProcess/INFO] 15 cases completed
[MainProcess/INFO] 20 cases completed
[MainProcess/INFO] 25 cases completed
[MainProcess/INFO] 30 cases completed
[MainProcess/INFO] 35 cases completed
[MainProcess/INFO] 40 cases completed
[MainProcess/INFO] 45 cases completed
[MainProcess/INFO] 50 cases completed
[MainProcess/INFO] experiments finished
[MainProcess/INFO] terminating pool
```

```
N = 250
Release decision: 0
```

```
[MainProcess/INFO] pool started
[MainProcess/INFO] performing 250 scenarios * 1 policies * 1 model(s) = 250
experiments
[MainProcess/INFO] 25 cases completed
[MainProcess/INFO] 50 cases completed
[MainProcess/INFO] 75 cases completed
[MainProcess/INFO] 100 cases completed
[MainProcess/INFO] 125 cases completed
[MainProcess/INFO] 150 cases completed
[MainProcess/INFO] 175 cases completed
[MainProcess/INFO] 200 cases completed
[MainProcess/INFO] 225 cases completed
[MainProcess/INFO] 250 cases completed
[MainProcess/INFO] experiments finished
[MainProcess/INFO] terminating pool
```

```
N = 1000
Release decision: 0
```

```
[MainProcess/INFO] pool started
[MainProcess/INFO] performing 1000 scenarios * 1 policies * 1 model(s) = 1000
experiments
[MainProcess/INFO] 100 cases completed
```

```
[MainProcess/INFO] 200 cases completed
[MainProcess/INFO] 300 cases completed
[MainProcess/INFO] 400 cases completed
[MainProcess/INFO] 500 cases completed
[MainProcess/INFO] 600 cases completed
[MainProcess/INFO] 700 cases completed
[MainProcess/INFO] 800 cases completed
[MainProcess/INFO] 900 cases completed
[MainProcess/INFO] 1000 cases completed
[MainProcess/INFO] experiments finished
[MainProcess/INFO] terminating pool
```

```
N = 50
Release decision: 0.05
```

```
[MainProcess/INFO] pool started
[MainProcess/INFO] performing 50 scenarios * 1 policies * 1 model(s) = 50
experiments
[MainProcess/INFO] 5 cases completed
[MainProcess/INFO] 10 cases completed
[MainProcess/INFO] 15 cases completed
[MainProcess/INFO] 20 cases completed
[MainProcess/INFO] 25 cases completed
[MainProcess/INFO] 30 cases completed
[MainProcess/INFO] 35 cases completed
[MainProcess/INFO] 40 cases completed
[MainProcess/INFO] 45 cases completed
[MainProcess/INFO] 50 cases completed
[MainProcess/INFO] experiments finished
[MainProcess/INFO] terminating pool
```

```
N = 250
Release decision: 0.05
```

```
[MainProcess/INFO] pool started
[MainProcess/INFO] performing 250 scenarios * 1 policies * 1 model(s) = 250
experiments
[MainProcess/INFO] 25 cases completed
[MainProcess/INFO] 50 cases completed
[MainProcess/INFO] 75 cases completed
[MainProcess/INFO] 100 cases completed
[MainProcess/INFO] 125 cases completed
[MainProcess/INFO] 150 cases completed
[MainProcess/INFO] 175 cases completed
[MainProcess/INFO] 200 cases completed
[MainProcess/INFO] 225 cases completed
[MainProcess/INFO] 250 cases completed
[MainProcess/INFO] experiments finished
[MainProcess/INFO] terminating pool
```

```
N = 1000
Release decision: 0.05

[MainProcess/INFO] pool started
[MainProcess/INFO] performing 1000 scenarios * 1 policies * 1 model(s) = 1000
experiments
[MainProcess/INFO] 100 cases completed
[MainProcess/INFO] 200 cases completed
[MainProcess/INFO] 300 cases completed
[MainProcess/INFO] 400 cases completed
[MainProcess/INFO] 500 cases completed
[MainProcess/INFO] 600 cases completed
[MainProcess/INFO] 700 cases completed
[MainProcess/INFO] 800 cases completed
[MainProcess/INFO] 900 cases completed
[MainProcess/INFO] 1000 cases completed
[MainProcess/INFO] experiments finished
[MainProcess/INFO] terminating pool

N = 50
Release decision: 0.1

[MainProcess/INFO] pool started
[MainProcess/INFO] performing 50 scenarios * 1 policies * 1 model(s) = 50
experiments
[MainProcess/INFO] 5 cases completed
[MainProcess/INFO] 10 cases completed
[MainProcess/INFO] 15 cases completed
[MainProcess/INFO] 20 cases completed
[MainProcess/INFO] 25 cases completed
[MainProcess/INFO] 30 cases completed
[MainProcess/INFO] 35 cases completed
[MainProcess/INFO] 40 cases completed
[MainProcess/INFO] 45 cases completed
[MainProcess/INFO] 50 cases completed
[MainProcess/INFO] experiments finished
[MainProcess/INFO] terminating pool

N = 250
Release decision: 0.1

[MainProcess/INFO] pool started
[MainProcess/INFO] performing 250 scenarios * 1 policies * 1 model(s) = 250
experiments
[MainProcess/INFO] 25 cases completed
[MainProcess/INFO] 50 cases completed
[MainProcess/INFO] 75 cases completed
[MainProcess/INFO] 100 cases completed
[MainProcess/INFO] 125 cases completed
[MainProcess/INFO] 150 cases completed
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[MainProcess/INFO] 175 cases completed
[MainProcess/INFO] 200 cases completed
[MainProcess/INFO] 225 cases completed
[MainProcess/INFO] 250 cases completed
[MainProcess/INFO] experiments finished
[MainProcess/INFO] terminating pool
```

```
N = 1000
Release decision: 0.1
```

```
[MainProcess/INFO] pool started
[MainProcess/INFO] performing 1000 scenarios * 1 policies * 1 model(s) = 1000
experiments
[MainProcess/INFO] 100 cases completed
[MainProcess/INFO] 200 cases completed
[MainProcess/INFO] 300 cases completed
[MainProcess/INFO] 400 cases completed
[MainProcess/INFO] 500 cases completed
[MainProcess/INFO] 600 cases completed
[MainProcess/INFO] 700 cases completed
[MainProcess/INFO] 800 cases completed
[MainProcess/INFO] 900 cases completed
[MainProcess/INFO] 1000 cases completed
[MainProcess/INFO] experiments finished
[MainProcess/INFO] terminating pool
```

[8]:

```
# Figures to compare with sobol

fs = {}

for i in indexes:
    x = experiments[i]
    y = outcomes[i]
    fs[i] = feature_scoring.get_feature_scores_all(x, y, alg='extra trees')


sns.set_style('white')
fig, ax = plt.subplots(3,3)
fig.set_size_inches(20,15)


for i in range(9):

    sns.heatmap(fs[indexes[i]], cmap='viridis', annot=True, ax=ax.flatten()[i])
    ax.flatten()[i].set_title(indexes[i], fontsize=18)

plt.show()
```

```
[MainProcess/INFO] policy dropped from analysis because only a single category
```

```
[MainProcess/INFO] model dropped from analysis because only a single category
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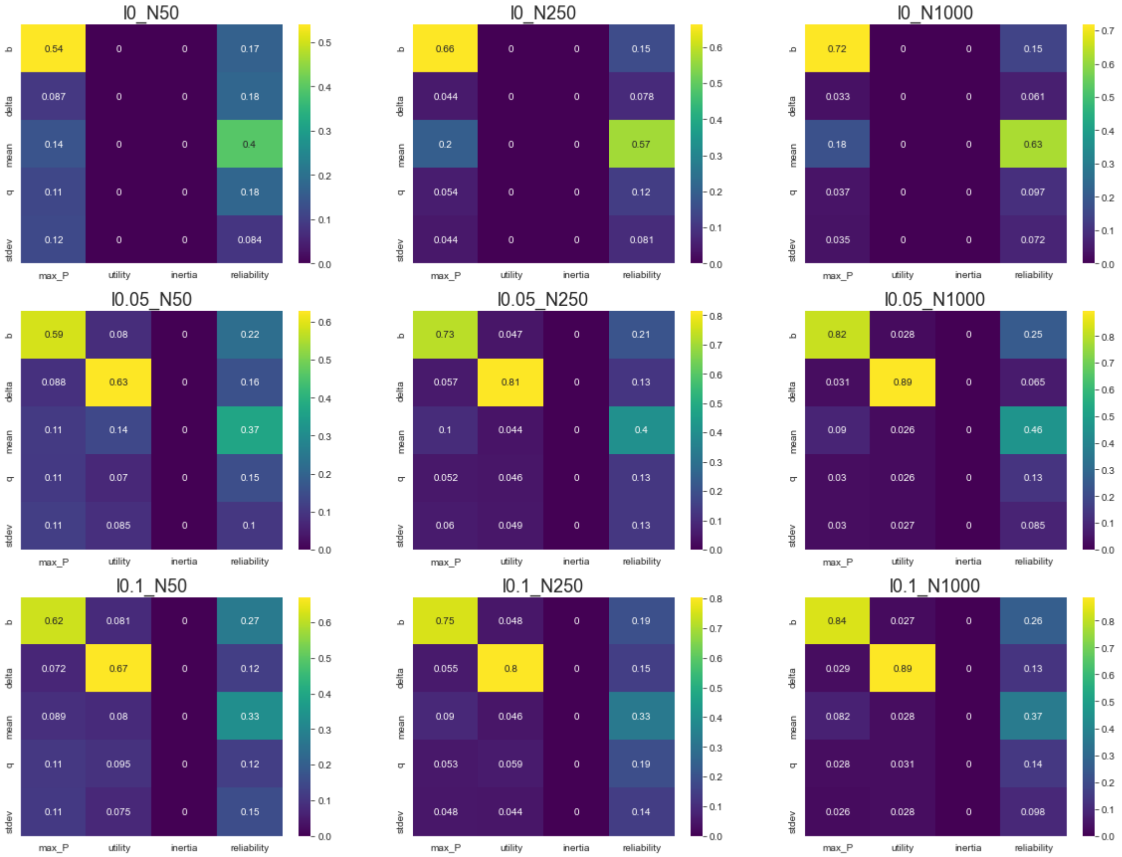

1.1.4 Analysis

With LHS sampling, the feature scoring is fuzzier and it is slightly more difficult to see what uncertainties drive the outcomes of interest, in some runs more than others (especially regarding max_P). In comparison, SOBOL sampling produces more consistent results and it is clearer that max_P is driven mostly by b.

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