smol_case

April 1, 2019

In [1]:
```
import ingestor, modeller, fitter
import numpy as np
import matplotlib.pyplot as plt
```

In [2]:
```
plt.style.use('seaborn-notebook')
plt.rc('text', usetex=True)
plt.rc('font', family='serif')
plt.rcParams['figure.figsize'] = [15, 10]
```

In [3]:
```
from cycler import cycler

new_color = cycler(color=["k"])
plt.rcParams['axes.prop_cycle'] = plt.rcParams['axes.prop_cycle'].concat(new_color)
```

In [4]:
```
from importlib import reload

reload(fitter)
reload(modeller)
reload(ingestor)
```

Out[4]:
```
<module 'ingestor' from '/media/dwu402/Data/wrap-mad/ingestor.py'>
```

In [5]:
```
context = ingestor.Context("runs/minimal5.1.run")
```

In [6]:
```
model = modeller.Model(context)
```

In [7]:
```
solver = fitter.Fitter()
solver.construct_objectives(context, model)
```

In [8]:
```
solver.construct_problems()
```

In [9]:
```
solver.solve(10**-10)
for rhoi in np.logspace(-7, 4.5, num=51):
    solver.solve(rhoi)
    solver.problems[0].initial_guess = solver.solutions[str(rhoi)][-1].x
```

In [10]:
```
solver.solutions
```

```
Out[10]: {'1e-10': [      fun: 0.0035254327739545174
             hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
                  jac: array([ 2.51361881e-16, -1.38692931e-15,  1.47253435e-15, -5.04696300e-15,
                   -4.88465625e-14,  1.84122851e-13,  6.12604795e-14,  6.59657321e-14,
                   -1.57858286e-13,  5.39568002e-15,  1.30661089e-13])
              message: b'CONVERGENCE: NORM_OF_PROJECTED_GRADIENT_<=_PGTOL'
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               status: 0
              success: True
                    x: array([1., 1., 1., 1., 1., 1., 1., 1., 1., 1., 1.])],
            '1e-07': [      fun: 0.003525432773954519
             hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
                  jac: array([ 1.50676637e-14, -1.38720700e-12,  1.44884858e-12, -5.04908029e-12,
                   -4.87201893e-11,  1.84120851e-10,  6.12582260e-11,  6.59678454e-11,
                   -1.57858816e-10,  5.39592931e-12,  1.30587984e-10])
              message: b'CONVERGENCE: NORM_OF_PROJECTED_GRADIENT_<=_PGTOL'
                 nfev: 3
                  nit: 2
               status: 0
              success: True
                    x: array([1.        , 1.        , 1.        , 1.        , 1.        ,
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                   1.00000001])],
            '1.6982436524617461e-07': [      fun: 0.003525432773954519
             hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
                  jac: array([ 1.71306995e-12,  4.41330495e-13,  4.37474061e-12, -8.65681059e-12,
                   -5.23644877e-11,  1.92216419e-10,  6.39672150e-11,  6.64706641e-11,
                   -1.60130229e-10,  1.35650464e-11,  1.36790428e-10])
              message: b'CONVERGENCE: NORM_OF_PROJECTED_GRADIENT_<=_PGTOL'
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               status: 0
              success: True
                    x: array([1.        , 1.        , 1.        , 1.        , 1.        ,
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                   1.00000001])],
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             hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
                  jac: array([ 4.59667433e-12,  3.54664246e-12,  9.34361768e-12, -1.47836136e-11,
                   -5.85533921e-11,  2.05964662e-10,  6.85677433e-11,  6.73245510e-11,
                   -1.63987615e-10,  2.74381942e-11,  1.47323671e-10])
              message: b'CONVERGENCE: NORM_OF_PROJECTED_GRADIENT_<=_PGTOL'
                 nfev: 1
                  nit: 0
               status: 0
              success: True
                    x: array([1.        , 1.        , 1.        , 1.        , 1.        ,
```

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       1.00000001, 1.        , 1.        , 0.99999999, 1.        ,
       1.00000001])],
'4.897788193684466e-07': [      fun: 0.003525432773954519
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       jac: array([ 9.49368752e-12,  8.82024698e-12,  1.77819802e-11, -2.51884117e-11,
       -6.90636536e-11,  2.29312517e-10,  7.63805754e-11,  6.87745959e-11,
       -1.70538323e-10,  5.09981694e-11,  1.65211625e-10])
   message: b'CONVERGENCE: NORM_OF_PROJECTED_GRADIENT_<=_PGTOL'
      nfev: 1
       nit: 0
    status: 0
   success: True
         x: array([1.        , 1.        , 1.        , 1.        , 1.        ,
       1.00000001, 1.        , 1.        , 0.99999999, 1.        ,
       1.00000001])],
'8.317637711026709e-07': [      fun: 0.003525432773954519
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
       jac: array([ 1.78098659e-11,  1.77761936e-11,  3.21123716e-11, -4.28582764e-11,
       -8.69126208e-11,  2.68962831e-10,  8.96487083e-11,  7.12369434e-11,
       -1.81662807e-10,  9.10087195e-11,  1.95589565e-10])
   message: b'CONVERGENCE: NORM_OF_PROJECTED_GRADIENT_<=_PGTOL'
      nfev: 1
       nit: 0
    status: 0
   success: True
         x: array([1.        , 1.        , 1.        , 1.        , 1.        ,
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       1.00000001])],
'1.4125375446227554e-06': [      fun: 0.003525432773954519
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
       jac: array([ 3.19323502e-11,  3.29858075e-11,  5.64488558e-11, -7.28659609e-11,
       -1.17224465e-10,  3.36298630e-10,  1.12181347e-10,  7.54180848e-11,
       -2.00554275e-10,  1.58956300e-10,  2.47178232e-10])
   message: b'CONVERGENCE: NORM_OF_PROJECTED_GRADIENT_<=_PGTOL'
      nfev: 1
       nit: 0
    status: 0
   success: True
         x: array([1.        , 1.        , 1.        , 1.        , 1.        ,
       1.00000001, 1.        , 1.        , 0.99999999, 1.        ,
       1.00000001])],
'2.3988329190194897e-06': [      fun: 0.003525432773954519
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
       jac: array([ 5.59145785e-11,  5.88161135e-11,  9.77781011e-11, -1.23826174e-10,
       -1.68701214e-10,  4.50650948e-10,  1.50447596e-10,  8.25171685e-11,
       -2.32634809e-10,  2.74347611e-10,  3.34786985e-10])
   message: b'CONVERGENCE: NORM_OF_PROJECTED_GRADIENT_<=_PGTOL'
      nfev: 1
```

```
       nit: 0
    status: 0
   success: True
         x: array([1.        , 1.        , 1.        , 1.        , 1.        ,
        1.00000001, 1.        , 1.        , 0.99999999, 1.        ,
        1.00000001])],
'4.073802778041131e-06': [      fun: 0.003525432773954519
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
       jac: array([ 9.66388111e-11,  1.02684216e-10,  1.67965130e-10, -2.10368607e-10,
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        -2.87110239e-10,  4.70309491e-10,  4.83564034e-10])
   message: b'CONVERGENCE: NORM_OF_PROJECTED_GRADIENT_<=_PGTOL'
      nfev: 1
       nit: 0
    status: 0
   success: True
         x: array([1.        , 1.        , 1.        , 1.        , 1.        ,
        1.00000001, 1.        , 1.        , 0.99999999, 1.        ,
        1.00000001])],
'6.9183097091893625e-06': [      fun: 0.0035253762007214275
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
       jac: array([-2.21911925e-10,  2.04178954e-10,  9.58007252e-11, -1.39119730e-10,
        -5.33009323e-11,  2.08974029e-10,  5.95614179e-11, -7.61060784e-10,
         1.25485564e-10,  1.63785975e-10, -1.23752268e-11])
   message: b'CONVERGENCE: NORM_OF_PROJECTED_GRADIENT_<=_PGTOL'
      nfev: 1
       nit: 0
    status: 0
   success: True
         x: array([1.        , 1.        , 1.        , 1.        , 1.        ,
        1.00000001, 1.        , 1.        , 0.99999999, 1.        ,
        1.00000001])],
'1.1748975549395302e-05': [      fun: 0.0035253762007214275
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        -6.01484695e-11,  2.34433745e-10,  6.10958332e-11, -1.33804371e-09,
         3.21062642e-10,  2.82548476e-10, -1.05995971e-10])
   message: b'CONVERGENCE: NORM_OF_PROJECTED_GRADIENT_<=_PGTOL'
      nfev: 1
       nit: 0
    status: 0
   success: True
         x: array([1.        , 1.        , 1.        , 1.        , 1.        ,
        1.00000001, 1.        , 1.        , 0.99999999, 1.        ,
        1.00000001])],
'1.995262314968883e-05': [      fun: 0.0035253762007214275
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       jac: array([-6.35439476e-10,  5.96407192e-10,  2.81460301e-10, -4.01446493e-10,
```

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       -7.17862287e-11,  2.77690461e-10,  6.37208854e-11, -2.31793571e-09,
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  message: b'CONVERGENCE: NORM_OF_PROJECTED_GRADIENT_<=_PGTOL'
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   status: 0
  success: True
        x: array([1.        , 1.        , 1.        , 1.        , 1.        ,
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       1.00000001])],
'3.3884415613920276e-05': [      fun: 0.0035254161573036193
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       -3.49941716e-10,  5.40059519e-10, -6.34131341e-10, -9.47965261e-10,
        5.11082982e-10,  2.23183203e-09,  7.98218597e-10])
  message: b'CONVERGENCE: NORM_OF_PROJECTED_GRADIENT_<=_PGTOL'
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      nit: 0
   status: 0
  success: True
        x: array([1.        , 1.        , 1.        , 1.        , 1.        ,
       1.00000001, 1.        , 1.        , 0.99999999, 1.        ,
       1.00000001])],
'5.7543993733715664e-05': [      fun: 0.0035254190001920704
 hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
      jac: array([-1.81092665e-09,  2.59969214e-09,  4.57969912e-10, -1.26525389e-09,
       -2.96857933e-10,  1.20918088e-09,  4.54698320e-09,  8.98268380e-10,
        3.73688816e-09, -5.97802439e-09, -3.65691158e-09])
  message: b'CONVERGENCE: NORM_OF_PROJECTED_GRADIENT_<=_PGTOL'
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      nit: 0
   status: 0
  success: True
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       1.00000001])],
'9.772372209558111e-05': [      fun: 0.003525397497781974
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      jac: array([ 2.44351756e-09,  7.12320039e-13,  7.58225124e-09, -1.27883878e-08,
       -6.95222771e-09,  1.35197531e-08,  1.28799794e-08, -8.87865372e-09,
       -3.22273330e-10,  4.97062550e-09, -2.56536707e-09])
  message: b'CONVERGENCE: NORM_OF_PROJECTED_GRADIENT_<=_PGTOL'
     nfev: 1
      nit: 0
   status: 0
  success: True
        x: array([1.        , 1.        , 1.        , 1.        , 1.        ,
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```

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       1.00000001])],
'0.00016595869074375615': [      fun: 0.003525461000991956
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
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        -2.22317912e-08,  4.27770822e-08,  5.19067869e-08, -3.99494893e-08,
         1.34054976e-08, -5.17567742e-09, -1.69260746e-08])
   message: b'CONVERGENCE: NORM_OF_PROJECTED_GRADIENT_<=_PGTOL'
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    status: 0
   success: True
         x: array([1.        , 1.        , 1.        , 1.        , 1.        ,
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        1.00000001])],
'0.0002818382931264455': [      fun: 0.0035256672963547755
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
       jac: array([ 6.39089343e-09,  1.06177259e-08,  5.81108811e-08, -1.00641224e-07,
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   message: b'CONVERGENCE: NORM_OF_PROJECTED_GRADIENT_<=_PGTOL'
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       nit: 0
    status: 0
   success: True
         x: array([1.        , 1.        , 1.        , 1.        , 1.        ,
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        1.00000001])],
'0.00047863009232263854': [      fun: 0.0035261323564385115
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
       jac: array([ 7.37790105e-09,  4.96367381e-08,  1.56833541e-07, -2.71712324e-07,
        -1.67188931e-07,  3.13487081e-07,  4.20948130e-07, -2.99247026e-07,
         1.48575386e-07, -6.10497818e-08, -1.13405817e-07])
   message: b'CONVERGENCE: NORM_OF_PROJECTED_GRADIENT_<=_PGTOL'
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       nit: 0
    status: 0
   success: True
         x: array([1.        , 1.        , 1.        , 1.        , 1.        ,
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        1.00000001])],
'0.0008128305161640995': [      fun: 0.0035275284494992783
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       jac: array([ 6.35287588e-08,  1.09825320e-07,  4.77919914e-07, -8.11457186e-07,
        -4.84880594e-07,  9.16556823e-07,  1.17322126e-06, -9.02829561e-07,
         3.59147626e-07, -1.02629197e-07, -3.34182213e-07])
   message: b'CONVERGENCE: NORM_OF_PROJECTED_GRADIENT_<=_PGTOL'
      nfev: 1
       nit: 0
```

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    status: 0
   success: True
         x: array([1.        , 1.        , 1.        , 1.        , 1.        ,
        1.00000001, 1.        , 1.        , 0.99999999, 1.        ,
        1.00000001])],
'0.0013803842646028866': [      fun: 0.0035316511022465682
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       jac: array([ 1.52728595e-07,  3.78857367e-07,  1.40842818e-06, -2.38385833e-06,
        -1.30314514e-06,  2.43843781e-06,  3.27240023e-06, -2.58895064e-06,
         1.20749665e-06, -3.63913085e-07, -9.83662097e-07])
   message: b'CONVERGENCE: NORM_OF_PROJECTED_GRADIENT_<=_PGTOL'
      nfev: 1
       nit: 0
    status: 0
   success: True
         x: array([1.        , 1.        , 1.        , 1.        , 1.        ,
        1.00000001, 1.        , 1.        , 0.99999999, 1.        ,
        1.00000001])],
'0.0023442288153199225': [      fun: 0.003542577877894079
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
       jac: array([ 3.85291502e-07,  1.08720758e-06,  3.92114719e-06, -6.65817955e-06,
        -3.64855866e-06,  6.85743022e-06,  9.20013048e-06, -7.00644739e-06,
         3.34858461e-06, -1.04874585e-06, -2.71183326e-06])
   message: b'CONVERGENCE: NORM_OF_PROJECTED_GRADIENT_<=_PGTOL'
      nfev: 1
       nit: 0
    status: 0
   success: True
         x: array([1.        , 1.        , 1.        , 1.        , 1.        ,
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        1.00000001])],
'0.003981071705534978': [      fun: 0.0035720476237871964
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
       jac: array([ 9.30652496e-07,  3.10060305e-06,  1.07688386e-05, -1.83074332e-05,
        -1.00911660e-05,  1.91444838e-05,  2.55833533e-05, -1.86404088e-05,
         9.09363521e-06, -2.89970680e-06, -7.54610288e-06])
   message: b'CONVERGENCE: REL_REDUCTION_OF_F_<=_FACTR*EPSMCH'
      nfev: 19
       nit: 1
    status: 0
   success: True
         x: array([1.        , 1.        , 1.        , 1.        , 1.        ,
        1.00000001, 1.        , 1.        , 0.99999999, 1.        ,
        1.00000001])],
'0.006760829753919818': [      fun: 0.003649342184785873
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
       jac: array([ 2.32807346e-06,  8.49189738e-06,  2.93687813e-05, -4.99915230e-05,
        -2.74938704e-05,  5.30732169e-05,  7.02771456e-05, -4.80149591e-05,
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        2.33829011e-05, -7.37397840e-06, -2.06666412e-05])
  message: b'CONVERGENCE: REL_REDUCTION_OF_F_<=_FACTR*EPSMCH'
     nfev: 21
      nit: 1
   status: 0
  success: True
        x: array([1.        , 1.        , 1.        , 1.        , 1.        ,
       1.00000001, 1.        , 1.        , 0.99999999, 1.        ,
       1.00000001])],
'0.01148153621496884': [      fun: 0.00383810156107003
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      jac: array([-1.21334872e-06,  2.51542739e-06,  3.10471509e-06, -5.16174552e-06,
       -1.90643826e-06,  3.37559042e-06,  4.82450052e-06, -3.26856314e-06,
        3.42746411e-06,  1.69197320e-07, -1.59232347e-06])
  message: b'CONVERGENCE: NORM_OF_PROJECTED_GRADIENT_<=_PGTOL'
     nfev: 3
      nit: 2
   status: 0
  success: True
        x: array([0.99965575, 0.9990247 , 0.9964812 , 1.0059049 , 1.00339142,
       0.99321737, 0.99132073, 1.00536719, 0.99758333, 1.00091387,
       1.00246129])],
'0.019498445997580455': [      fun: 0.004263261181006385
 hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
      jac: array([-1.81235834e-06,  2.41565094e-06,  1.15750077e-06, -2.17422702e-06,
       -1.85727044e-06,  4.37618437e-06,  3.94443843e-06, -4.58811641e-06,
        3.59160392e-06,  2.97605692e-06,  1.38099675e-06])
  message: b'CONVERGENCE: NORM_OF_PROJECTED_GRADIENT_<=_PGTOL'
     nfev: 3
      nit: 2
   status: 0
  success: True
        x: array([0.99935989, 0.99731756, 0.99141384, 1.01407099, 1.00828304,
       0.98287394, 0.97882955, 1.01125458, 0.9950828 , 1.00221936,
       1.00590843])],
'0.03311311214825914': [      fun: 0.005122312688718591
 hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
      jac: array([-2.96789121e-06,  2.60812584e-06, -2.21317979e-06,  3.30159000e-06,
       -2.60601910e-06,  4.89245869e-06, -3.58326330e-06,  2.98083569e-06,
        1.64463728e-06, -3.42212316e-06,  5.48117179e-06])
  message: b'CONVERGENCE: NORM_OF_PROJECTED_GRADIENT_<=_PGTOL'
     nfev: 3
      nit: 2
   status: 0
  success: True
        x: array([0.99900449, 0.99341679, 0.98195127, 1.02816784, 1.0181926 ,
       0.96034606, 0.95401756, 1.02045437, 0.99265795, 1.00415273,
       1.01234522])],
```

```
'0.05623413251903491': [      fun: 0.0067321151447636025
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
       jac: array([-4.86745041e-05,  1.95718561e-04,  4.10291805e-04, -6.17273849e-04,
        -4.43832612e-04,  1.02577942e-03,  1.15768151e-03, -3.23394002e-04,
         1.55460352e-04, -8.56121701e-05, -2.90828746e-04])
   message: b'CONVERGENCE: REL_REDUCTION_OF_F_<=_FACTR*EPSMCH'
      nfev: 82
       nit: 1
    status: 0
   success: True
         x: array([0.99900449, 0.99341679, 0.98195127, 1.02816784, 1.0181926 ,
        0.96034606, 0.95401756, 1.02045437, 0.99265795, 1.00415273,
        1.01234522])],
'0.09549925860214369': [      fun: 0.009187228709935668
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
       jac: array([-6.64831935e-06,  5.59525429e-06,  1.09922852e-07, -1.06677105e-06,
        -5.27772528e-06,  1.80347626e-05,  1.00292655e-05, -4.11125861e-06,
        -7.36622529e-06, -3.32796242e-06,  4.49843263e-06])
   message: b'CONVERGENCE: REL_REDUCTION_OF_F_<=_FACTR*EPSMCH'
      nfev: 65
       nit: 6
    status: 0
   success: True
         x: array([1.00121428, 0.97011894, 0.95308315, 1.05287901, 1.06193138,
        0.84704279, 0.86896688, 1.03121278, 1.01097011, 1.01755862,
        1.03595017])],
'0.16218100973589297': [      fun: 0.01292113502825995
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
       jac: array([ 1.98445816e-05,  5.33080351e-05,  4.93450072e-05,  1.30034858e-04,
         2.37603468e-05,  3.02131684e-05, -1.08342361e-04,  1.13712368e-05,
        -1.01899079e-04, -5.52138255e-05, -6.68965722e-05])
   message: b'CONVERGENCE: REL_REDUCTION_OF_F_<=_FACTR*EPSMCH'
      nfev: 25
       nit: 6
    status: 0
   success: True
         x: array([1.00711688, 0.95128072, 0.93359171, 1.0519999 , 1.08117728,
        0.78528667, 0.82999904, 1.0297978 , 1.03144742, 1.03266366,
        1.05577459])],
'0.2754228703338169': [      fun: 0.018230062051871374
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
       jac: array([ 9.56662301e-05, -1.25206835e-04, -2.77576055e-05, -3.20437533e-05,
        -4.86002583e-05,  7.67929888e-05,  3.12884646e-05,  1.16637028e-04,
        -7.48760791e-05,  3.98098331e-05,  4.37191754e-05])
   message: b'CONVERGENCE: REL_REDUCTION_OF_F_<=_FACTR*EPSMCH'
      nfev: 65
       nit: 6
    status: 0
```

```
   success: True
         x: array([1.02169407, 0.93070979, 0.87209252, 1.05878561, 1.07694065,
        0.75981533, 0.81611017, 1.01241384, 1.064706  , 1.07838925,
        1.09860921])],
'0.4677351412871981': [      fun: 0.02511545076117692
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
       jac: array([ 5.72614707e-05, -6.31561984e-05,  3.53381962e-05, -2.79095202e-05,
         3.55029476e-06,  2.91177109e-06, -9.83575672e-06,  8.15307649e-05,
        -1.03739954e-04,  2.94786563e-05,  8.45789430e-05])
   message: b'CONVERGENCE: REL_REDUCTION_OF_F_<=_FACTR*EPSMCH'
      nfev: 102
       nit: 11
    status: 0
   success: True
         x: array([1.09058786, 0.92774161, 0.81369131, 1.12522583, 1.03812483,
        0.70187954, 0.87251765, 0.89337851, 1.11219927, 1.16317349,
        1.162279  ])],
'0.7943282347242822': [      fun: 0.03116818882919213
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
       jac: array([-9.17027448e-05,  8.01528327e-05, -6.33167976e-05,  8.36903694e-05,
        -2.09274946e-04,  5.24965008e-05,  2.83628168e-04, -3.13195075e-04,
         2.97810908e-04, -2.02458628e-05, -2.69755908e-05])
   message: b'CONVERGENCE: REL_REDUCTION_OF_F_<=_FACTR*EPSMCH'
      nfev: 54
       nit: 19
    status: 0
   success: True
         x: array([1.23672254, 0.89939514, 0.95486434, 1.08739759, 1.09113229,
        0.48713813, 1.02597164, 0.65536771, 1.16730967, 1.26384601,
        1.19314169])],
'1.3489628825916533': [      fun: 0.03740561574042764
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
       jac: array([ 1.21050513e-04,  3.87742976e-06,  3.64609960e-05, -4.23579186e-05,
        -1.40835363e-05, -1.32005604e-04,  7.15241882e-06,  7.57761171e-05,
        -2.56544921e-05, -1.68705339e-05, -3.10650923e-05])
   message: b'CONVERGENCE: REL_REDUCTION_OF_F_<=_FACTR*EPSMCH'
      nfev: 89
       nit: 15
    status: 0
   success: True
         x: array([1.36606754, 0.97783575, 1.05268244, 1.06385724, 1.10771057,
        0.50124578, 0.99345707, 0.54528227, 1.14487063, 1.38914301,
        1.27881929])],
'2.290867652767775': [      fun: 0.04244402910267571
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
       jac: array([-3.13829184e-05,  1.42315550e-06, -1.63899122e-05,  2.44899369e-05,
        -7.14496928e-06,  6.87693100e-06, -1.74602609e-05, -2.77044803e-05,
         1.93245415e-05,  5.78974584e-05, -5.02462929e-05])
```

```
   message: b'CONVERGENCE: REL_REDUCTION_OF_F_<=_FACTR*EPSMCH'
      nfev: 93
       nit: 25
    status: 0
   success: True
         x: array([1.50693986, 1.07131232, 1.23290985, 0.91770331, 1.15920225,
        0.60676011, 0.94858508, 0.34535973, 1.02501794, 1.61552798,
        1.37951663])],
'3.890451449942813': [      fun: 0.04651025480096768
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
       jac: array([ 2.77884135e-05,  6.57677372e-05, -5.43070576e-05,  9.92455865e-05,
         1.01968663e-05, -7.13447208e-05,  6.08301897e-05, -2.05370953e-04,
         1.75156094e-04, -9.46792173e-05, -1.88132343e-05])
   message: b'CONVERGENCE: REL_REDUCTION_OF_F_<=_FACTR*EPSMCH'
      nfev: 95
       nit: 15
    status: 0
   success: True
         x: array([1.58821067, 1.14081607, 1.30154809, 0.90336633, 1.18702752,
        0.64476895, 0.93517092, 0.30735778, 1.01452196, 1.70991056,
        1.40230507])],
'6.606934480075965': [      fun: 0.05041785232852593
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
       jac: array([ 6.60560572e-05, -2.44693836e-05,  1.02549079e-04, -1.02643910e-04,
         2.03286638e-04, -4.08738682e-04, -2.81277845e-04, -1.56167835e-05,
         4.61264502e-05, -5.88515617e-05,  9.22999936e-05])
   message: b'CONVERGENCE: REL_REDUCTION_OF_F_<=_FACTR*EPSMCH'
      nfev: 58
       nit: 12
    status: 0
   success: True
         x: array([1.63228682, 1.20251148, 1.33987797, 0.91099098, 1.20793354,
        0.69156537, 0.92525951, 0.3014799 , 1.02886137, 1.79649474,
        1.41863075])],
'11.220184543019652': [      fun: 0.054202789780851725
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
       jac: array([-5.92696133e-05, -2.59266789e-05, -7.23710635e-07,  9.81835046e-05,
         9.21583628e-05,  1.94238675e-04, -5.91788199e-05,  2.80065802e-04,
        -4.90904582e-05,  2.25828496e-05,  1.06213601e-04])
   message: b'CONVERGENCE: REL_REDUCTION_OF_F_<=_FACTR*EPSMCH'
      nfev: 72
       nit: 17
    status: 0
   success: True
         x: array([1.63971651, 1.26784814, 1.36478305, 0.93327151, 1.23910418,
        0.73585584, 0.93194777, 0.31059116, 1.04521355, 1.90385951,
        1.42041319])],
'19.054607179632523': [      fun: 0.057638189845416375
```

```
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
       jac: array([ 5.95492653e-04, -9.21247848e-04, -6.45282672e-05,  2.69627562e-04,
         2.75185385e-04, -3.85493656e-04, -3.49114522e-04,  1.56605086e-03,
        -7.88581014e-04,  1.12226109e-04,  4.76656438e-04])
   message: b'CONVERGENCE: REL_REDUCTION_OF_F_<=_FACTR*EPSMCH'
      nfev: 42
       nit: 13
    status: 0
   success: True
         x: array([1.63073191, 1.32245308, 1.38754187, 0.96313864, 1.2724044 ,
        0.76484937, 0.94710304, 0.32374835, 1.06178971, 2.00624799,
        1.41940272])],
'32.35936569296281': [      fun: 0.06045188981838615
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
       jac: array([-2.44100179e-04,  3.53220384e-04,  7.16491034e-05, -1.41693768e-04,
        -7.95694720e-05,  1.99871697e-06,  2.04076500e-04, -7.21685108e-04,
         4.72519361e-04, -1.10480753e-04, -1.72004586e-04])
   message: b'CONVERGENCE: REL_REDUCTION_OF_F_<=_FACTR*EPSMCH'
      nfev: 75
       nit: 26
    status: 0
   success: True
         x: array([1.61169937, 1.391738  , 1.40179319, 1.00166207, 1.30740314,
        0.77999815, 0.97218811, 0.32935554, 1.04384572, 2.11027657,
        1.38412505])],
'54.954087385762485': [      fun: 0.0625945100879643
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
       jac: array([ 0.00044653, -0.00048694, -0.00057566,  0.00072492, -0.00029784,
         0.00035091,  0.00055388, -0.0011424 ,  0.00095989,  0.00010416,
         0.00017581])
   message: b'CONVERGENCE: REL_REDUCTION_OF_F_<=_FACTR*EPSMCH'
      nfev: 94
       nit: 16
    status: 0
   success: True
         x: array([1.5905771 , 1.43289354, 1.42168463, 1.04364469, 1.33882392,
        0.7839856 , 0.99080595, 0.33818083, 1.04687796, 2.17997191,
        1.3853983 ])],
'93.32543007969925': [      fun: 0.06426940287207074
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
       jac: array([ 0.00046928, -0.00336475, -0.00226001,  0.00064958, -0.00091966,
         0.00386498,  0.00436409,  0.00394194, -0.00349651, -0.00067439,
         0.00074641])
   message: b'CONVERGENCE: REL_REDUCTION_OF_F_<=_FACTR*EPSMCH'
      nfev: 22
       nit: 10
    status: 0
   success: True
```

```
        x: array([1.56699576, 1.4540872 , 1.42766417, 1.07226737, 1.35245872,
       0.79361168, 0.99170435, 0.34236754, 1.04212202, 2.19501619,
       1.38906843])],
'158.48931924611173': [      fun: 0.06621100094235857
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
       jac: array([ 4.36082848e-03, -1.38868302e-02,  5.17561721e-03, -2.12884458e-02,
         5.00224437e-05, -2.25439567e-02,  1.21269441e-02,  1.26031553e-02,
        -7.61716190e-03, -2.96410350e-03,  1.81138349e-04])
   message: b'CONVERGENCE: REL_REDUCTION_OF_F_<=_FACTR*EPSMCH'
      nfev: 38
       nit: 5
    status: 0
   success: True
        x: array([1.56300201, 1.45750967, 1.42956841, 1.07079213, 1.35524775,
       0.79397894, 0.98537782, 0.3448342 , 1.04033349, 2.19571543,
       1.39001934])],
'269.1534803926914': [      fun: 0.06781775811780852
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
       jac: array([ 0.02331155, -0.01595703, -0.01281403,  0.0159797 , -0.02744481,
         0.02649049,  0.06224614, -0.02559429,  0.01922459, -0.00050388,
        -0.00654665])
   message: b'CONVERGENCE: REL_REDUCTION_OF_F_<=_FACTR*EPSMCH'
      nfev: 61
       nit: 12
    status: 0
   success: True
        x: array([1.49682062, 1.4348174 , 1.40652665, 1.06662713, 1.31942433,
       0.83195103, 0.96703312, 0.35645865, 1.04016414, 2.18979679,
       1.38784787])],
'457.0881896148752': [      fun: 0.17386839274996427
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
       jac: array([ 0.32726818,  0.14841316,  0.23445891, -0.22894504,  0.21047047,
        -0.65271605, -0.09260415, -0.45690109,  0.26287933,  0.00314721,
        -0.07434178])
   message: b'CONVERGENCE: REL_REDUCTION_OF_F_<=_FACTR*EPSMCH'
      nfev: 81
       nit: 1
    status: 0
   success: True
        x: array([1.49682062, 1.4348174 , 1.40652665, 1.06662713, 1.31942433,
       0.83195103, 0.96703312, 0.35645865, 1.04016414, 2.18979679,
       1.38784787])],
'776.2471166286928': [      fun: 0.1980356855675153
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
       jac: array([-4.34054001e-03, -3.12382060e-04, -4.60609091e-03,  5.16141556e-02,
        -2.49046333e-06,  4.85803369e-04, -2.61046732e-02,  1.13478566e-02,
        -1.88332057e-02,  2.62966713e-03,  2.44133861e-03])
   message: b'CONVERGENCE: REL_REDUCTION_OF_F_<=_FACTR*EPSMCH'
```

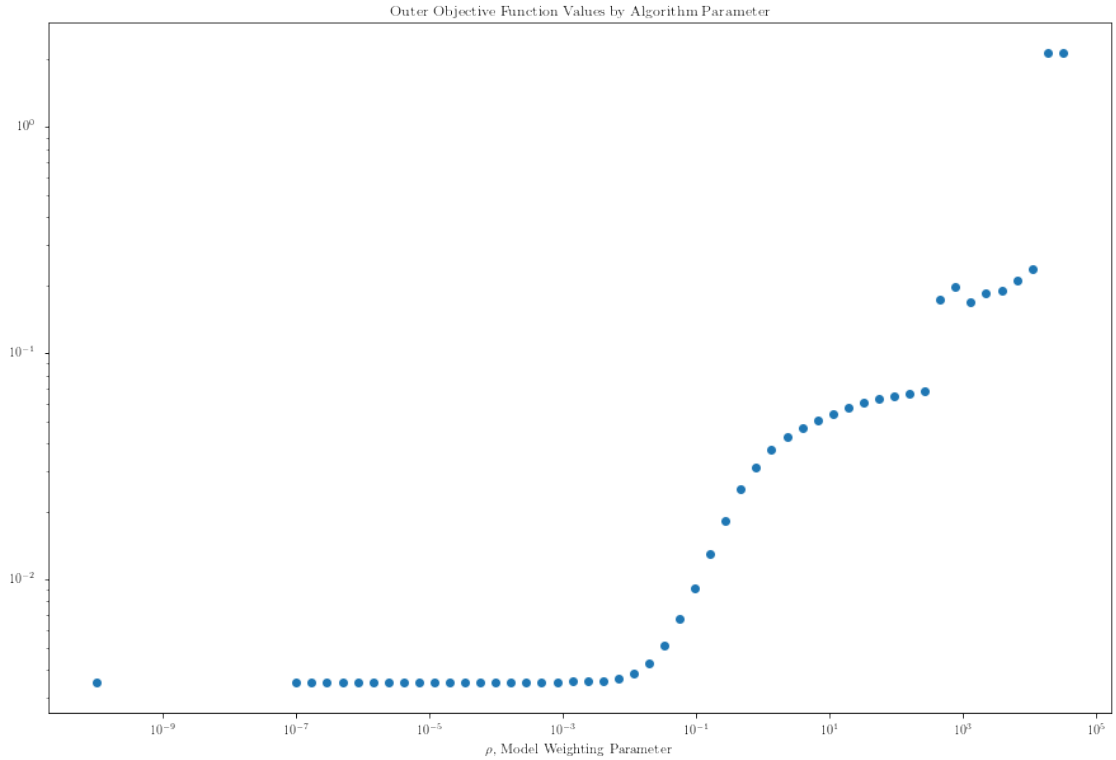
```
      nfev: 17
       nit: 5
    status: 0
   success: True
         x: array([0.54659582, 0.99439962, 1.2089932 , 0.3261994 , 0.99708895,
        1.03289364, 0.0226836 , 1.75370562, 0.        , 1.12673063,
        1.28709621])],
'1318.25673855641': [      fun: 0.1690888281661306
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
       jac: array([-6.25333381e-04,  1.45566147e-02, -5.26492458e-04,  3.85301834e-02,
        -6.51747573e-03,  5.92116939e-03,  1.69493067e-02, -6.22314662e-03,
         2.31149120e-02,  1.18259016e-02,  5.78363063e-05])
   message: b'CONVERGENCE: REL_REDUCTION_OF_F_<=_FACTR*EPSMCH'
      nfev: 137
       nit: 17
    status: 0
   success: True
         x: array([0.79850867, 0.96269428, 1.38176182, 0.40842054, 0.74009477,
        1.12997846, 1.17322575, 1.58879708, 0.82790798, 1.52718764,
        0.43014259])],
'2238.7211385683377': [      fun: 0.18558195548549658
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
       jac: array([-2.24852790e-02,  7.10722906e-03,  1.62261088e-02, -1.14216659e-01,
         4.85030249e-05, -7.06082958e-03, -9.64169887e-03,  2.68956283e-02,
        -5.23601037e-02,  7.10304297e-03, -5.64441071e-02])
   message: b'CONVERGENCE: REL_REDUCTION_OF_F_<=_FACTR*EPSMCH'
      nfev: 15
       nit: 5
    status: 0
   success: True
         x: array([0.76745125, 0.8645582 , 1.34881479, 0.23926704, 0.76263899,
        1.16614146, 1.17719248, 1.57283138, 0.90204183, 1.45074536,
        0.66942692])],
'3801.8939632056126': [      fun: 0.1894611602383769
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
       jac: array([-7.41319600e-03,  7.08203121e-03,  2.44999537e-03, -1.68040829e-02,
         2.98842738e-04, -2.17259808e-03, -1.94685909e-02, -1.37420678e-02,
        -8.85487257e-03,  7.34002120e-05,  3.40122284e-03])
   message: b'CONVERGENCE: REL_REDUCTION_OF_F_<=_FACTR*EPSMCH'
      nfev: 100
       nit: 18
    status: 0
   success: True
         x: array([0.91811324, 1.12924246, 1.11706029, 0.24431411, 0.87722571,
        1.390221  , 0.68270749, 1.10261101, 0.47628008, 1.03318563,
        0.13406717])],
'6456.542290346562': [      fun: 0.20993609661863283
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
```

```
        jac: array([-0.00481024,  0.01240636, -0.00157912,  0.02294617, -0.00231538,
          0.00821097, -0.00742036, -0.01328592, -0.00234016,  0.00084943,
         -0.00296614])
   message: b'CONVERGENCE: REL_REDUCTION_OF_F_<=_FACTR*EPSMCH'
      nfev: 18
       nit: 2
    status: 0
   success: True
         x: array([0.92561169, 1.11270421, 1.11857061, 0.22523347, 0.87966867,
        1.38149963, 0.69008367, 1.1192695 , 0.4763997 , 1.03227404,
        0.13868009])],
'10964.781961431874': [      fun: 0.2359072672634342
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
        jac: array([ 2.15621486e-02, -6.87266865e-03, -1.12517004e-02,  2.98851732e-01,
        -3.89685998e-03,  1.53479684e-02,  2.22668108e-02,  1.05352883e-02,
        -2.00298086e-02,  1.23229142e-05, -2.73844435e-02])
   message: b'CONVERGENCE: REL_REDUCTION_OF_F_<=_FACTR*EPSMCH'
      nfev: 12
       nit: 6
    status: 0
   success: True
         x: array([1.83305421, 0.70348502, 0.9210961 , 0.05652551, 0.80863995,
        1.76268801, 1.87748026, 1.77634249, 0.        , 1.00521479,
        0.29372138])],
'18620.871366628733': [      fun: 2.121233866182659
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
        jac: array([-1.29218519e-05,  3.88973278e-05,  2.01105915e-01,  4.50000873e-06,
        -1.72716996e-05,  3.71903569e-05, -2.25896464e-05, -3.64055511e-05,
        -3.24603310e-05, -7.52144959e-06,  4.15565569e-01])
   message: b'CONVERGENCE: REL_REDUCTION_OF_F_<=_FACTR*EPSMCH'
      nfev: 20
       nit: 18
    status: 0
   success: True
         x: array([0.99879112, 1.00161789, 0.        , 1.000225  , 0.99924919,
        1.0009307 , 0.99900096, 0.9976891 , 0.99742463, 1.00021436,
        0.        ])],
'31622.776601683792': [      fun: 2.121240883388302
  hess_inv: <11x11 LbfgsInvHessProduct with dtype=float64>
        jac: array([-1.67101568e-05,  3.64273548e-05,  2.01107742e-01,  4.50000873e-06,
        -1.65887541e-05,  3.01817308e-05, -2.15937226e-05, -4.02732365e-05,
        -3.96518551e-05, -3.25263196e-06,  4.15566634e-01])
   message: b'CONVERGENCE: REL_REDUCTION_OF_F_<=_FACTR*EPSMCH'
      nfev: 47
       nit: 1
    status: 0
   success: True
         x: array([0.99879112, 1.00161789, 0.        , 1.000225  , 0.99924919,
```

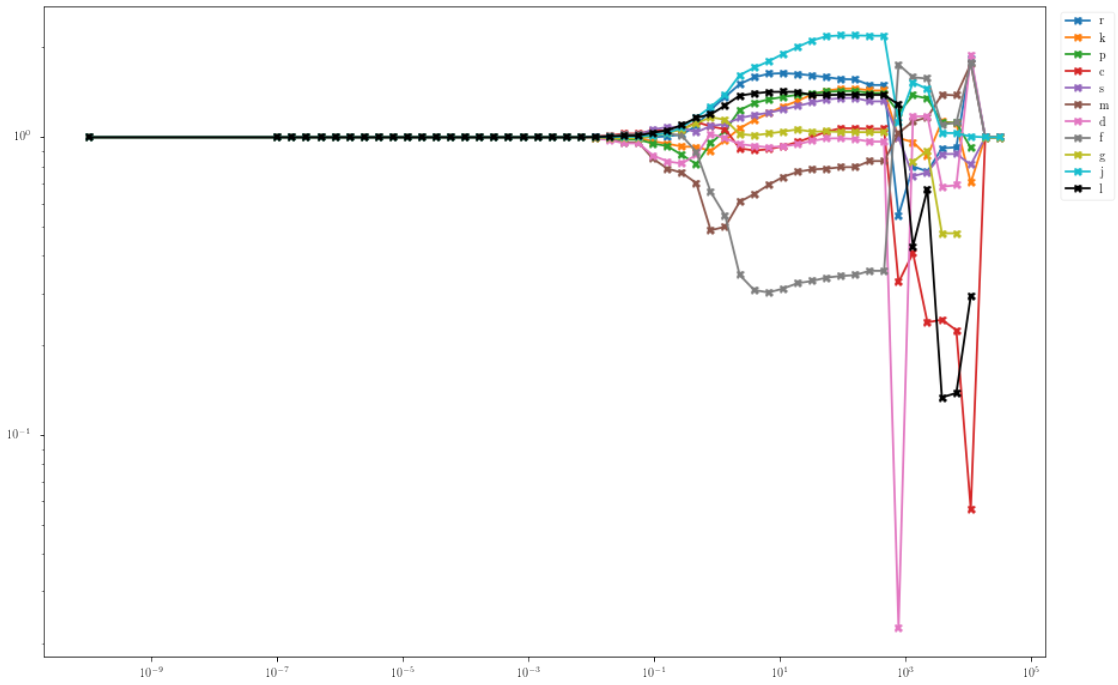
```
                1.0009307 , 0.99900096, 0.9976891 , 0.99742463, 1.00021436,
                0.        ])]}
```

In [11]:
```
outer_objective_values = np.array([[float(rho), val[0].fun] for rho, val in solver.solu
plt.loglog(*outer_objective_values.T, 'o')
plt.title("Outer Objective Function Values by Algorithm Parameter")
plt.xlabel(r"$\rho$, Model Weighting Parameter")
```

Out[11]:
```
Text(0.5, 0, '$\\rho$, Model Weighting Parameter')
```

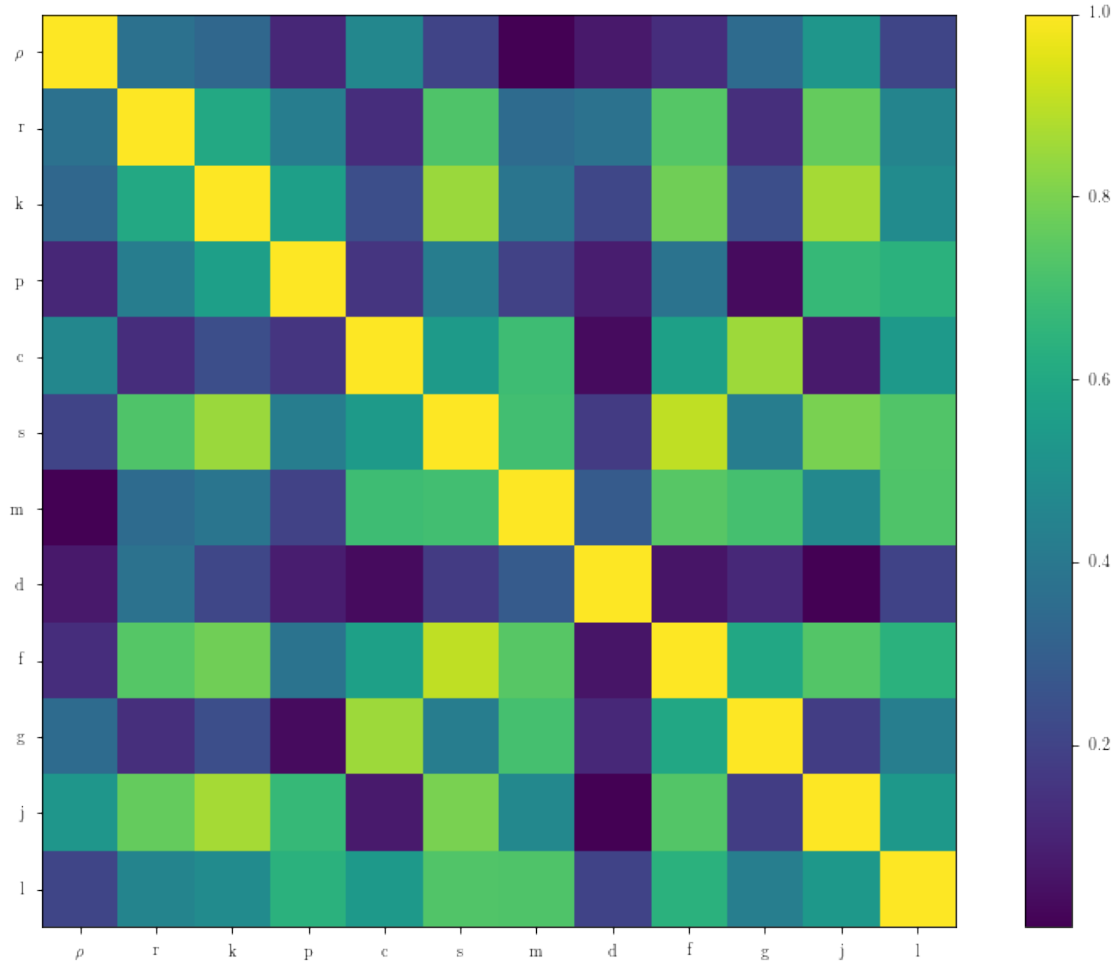


In [12]:
```
rhos = [float(rho) for rho in solver.solutions.keys()]
vals = [val[0].x for val in solver.solutions.values()]
plt.plot(rhos, vals, 'X-')
plt.legend("rkpcsmdfgjl", loc="best", bbox_to_anchor=(1.01, 1))
plt.xscale("log")
plt.yscale("log", nonposy="mask")
```

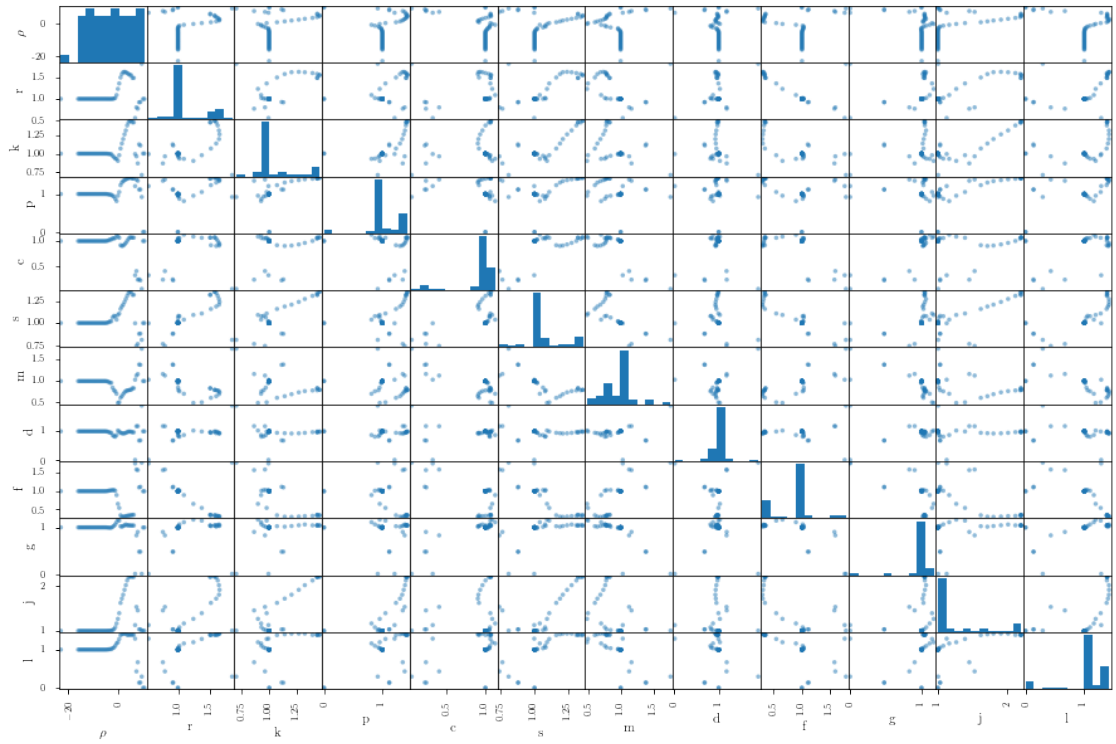


In [13]:
```
# generate a crude correlation plot

import pandas as pd

results = pd.DataFrame({r"$\rho$": np.log(rhos)})
for idx, name in enumerate("rkpcsmdfgjl"):
    results[name] = [v[idx] for v in vals]
```

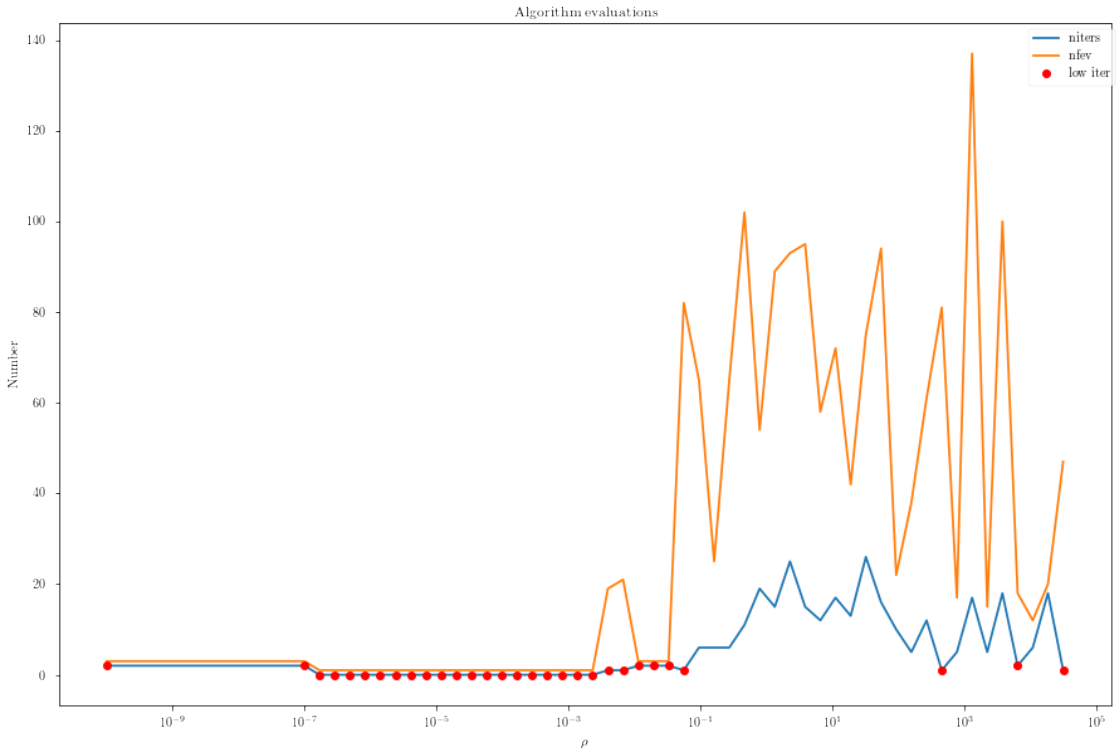
In [14]:
```
plt.imshow(np.abs(results.corr()))
plt.colorbar()
plt.xticks(range(12), [r"$\rho$"] + list("rkpcsmdfgjl"))
plt.yticks(range(12), [r"$\rho$"] + list("rkpcsmdfgjl"))
plt.grid(False)
```




```
In [15]: ax = pd.plotting.scatter_matrix(results)
         for a in ax.flatten():
             a.grid(False)
```



```
In [16]: iters_list = np.array([[float(key), value[0].nit] for key, value in solver.solutions.it
         fevs_list = np.array([[float(key), value[0].nfev] for key, value in solver.solutions.it
         plt.semilogx(*iters_list.T, *fevs_list.T)

         low_iters = np.array([[k,v] for k,v in iters_list if v < 5])
         plt.plot(*low_iters.T, 'ro')

         plt.legend(["niters", "nfev", "low iter"],
                    loc="best", bbox_to_anchor=(1.01, 1))
         plt.title("Algorithm evaluations")
         plt.xlabel(r"$\rho$")
         plt.ylabel("Number")

Out[16]: Text(0, 0.5, 'Number')
```

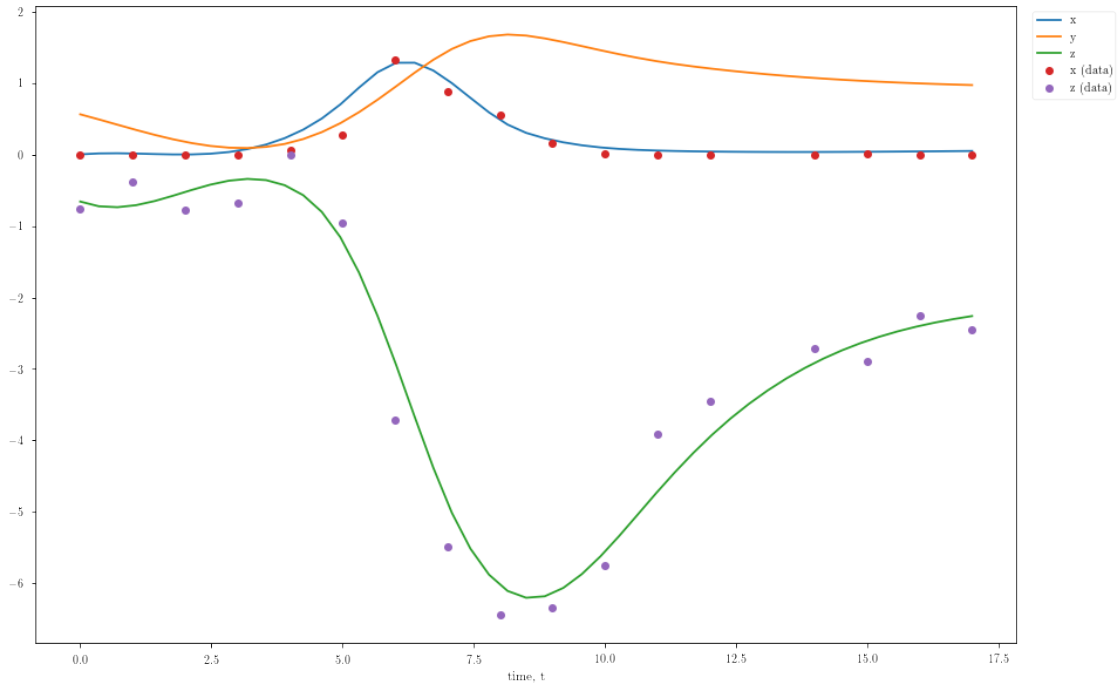



```
In [17]: def tokey(rho, ps):
             return f"{'y'.join(map(str,ps))}r{rho}"
         getx = fitter.ca.Function("getx", [model.ts, *model.cs], model.xs)
```

```
In [18]: target_rho = 93.32543007969925
         c_end = solver.problems[0].cache.results[tokey(target_rho, solver.solutions[str(target_
         print(solver.solutions[str(target_rho)][0].x)
         xs_end = np.array([np.array(i) for i in getx(model.observation_times,
                                                      *fitter.argsplit(c_end,
                                                                       3)
                                                     )])
         print(xs_end[:,0].T)
         plt.plot(model.observation_times, np.hstack([xs_end[0], xs_end[1], xs_end[2]]),
                  context.datasets[0]['t'], context.datasets[0]['x'], 'o',
                  context.datasets[0]['t'], context.datasets[0]['z'], 'o')
         plt.legend(list("xyz") + ["x (data)", "z (data)"], loc="best", bbox_to_anchor=(1.01, 1)
         plt.xlabel("time, t")
```

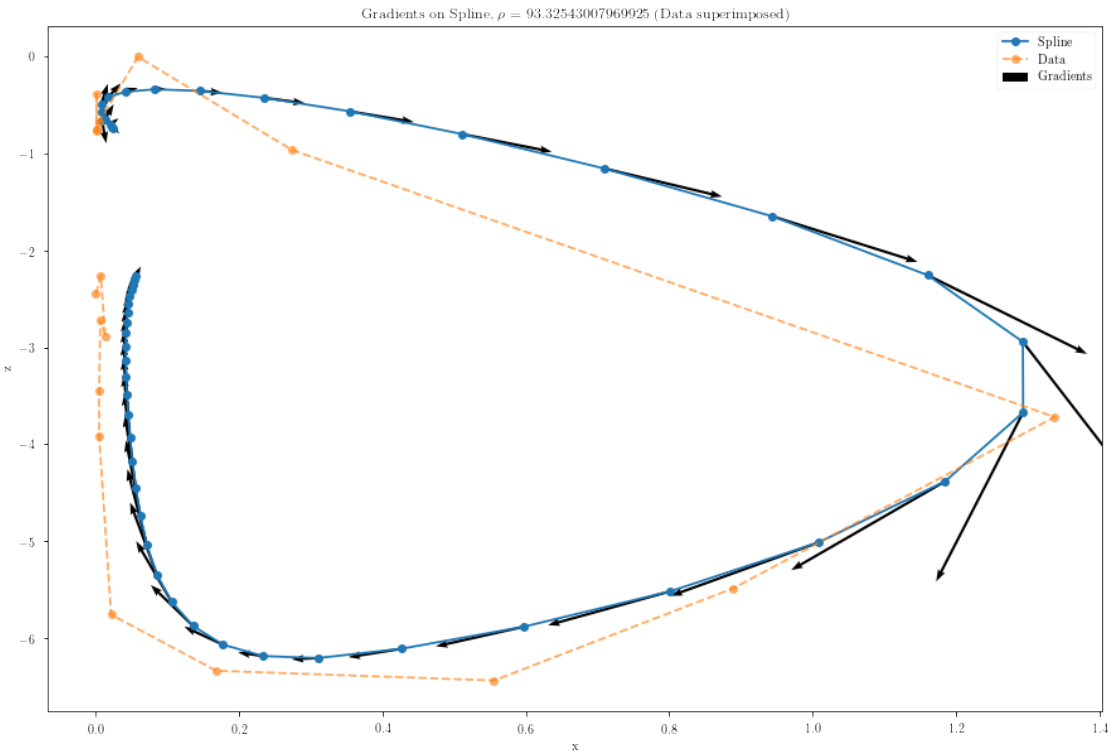
```
[1.56699576 1.4540872  1.42766417 1.07226737 1.35245872 0.79361168
 0.99170435 0.34236754 1.04212202 2.19501619 1.38906843]
[[ 0.00871347  0.57011703 -0.65294932]]
```

Out[18]: Text(0.5, 0, 'time, t')

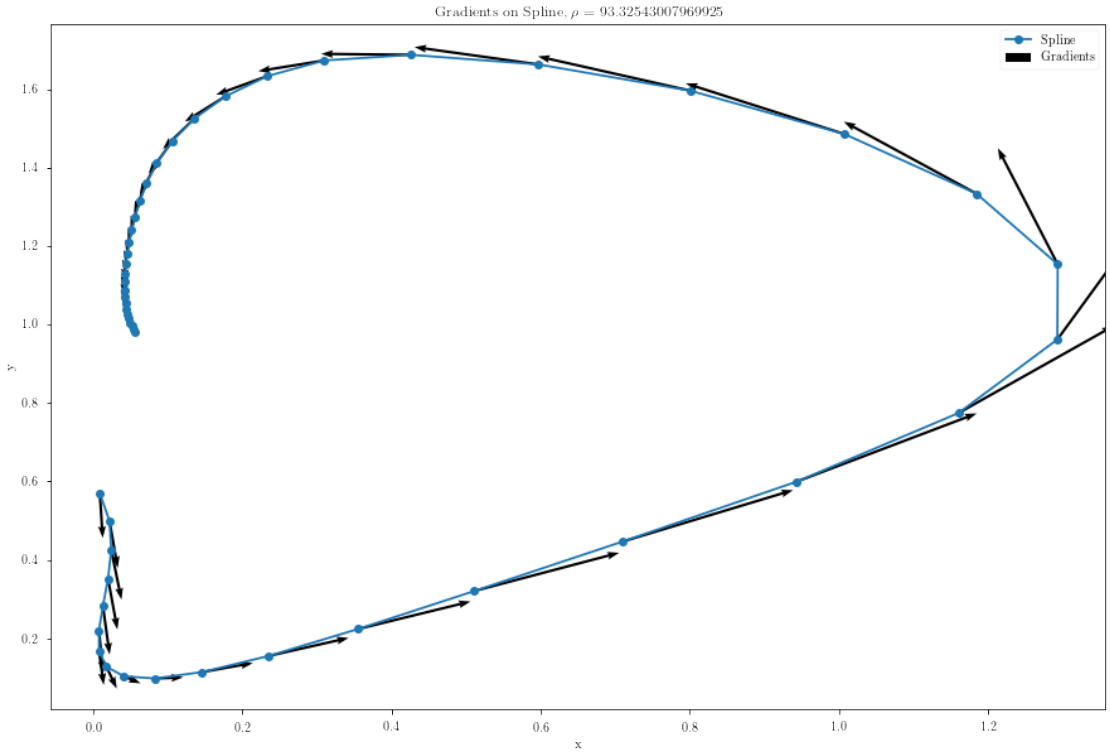


In [19]:
```
spline_dfield = np.array([context.model(t, xs_end[:,i], solver.solutions[str(target_rho
                    for i,t in enumerate(model.observation_times)])

spline_dfield = spline_dfield.reshape(spline_dfield.shape[:2])

plt.plot(xs_end[0], xs_end[2], 'o-')
plt.plot(context.datasets[0]['x'], context.datasets[0]['z'], 'o--', alpha=0.65)
plt.quiver(xs_end[0], xs_end[2], spline_dfield[:,0], spline_dfield[:,2],
           scale=None, angles='xy', headwidth=3, headlength=4.5, headaxislength=4, widt
plt.title(f"Gradients on Spline, $\\rho$ = {target_rho} (Data superimposed)")
plt.xlabel("x")
plt.ylabel("z")
plt.legend(["Spline", "Data", "Gradients"])
```

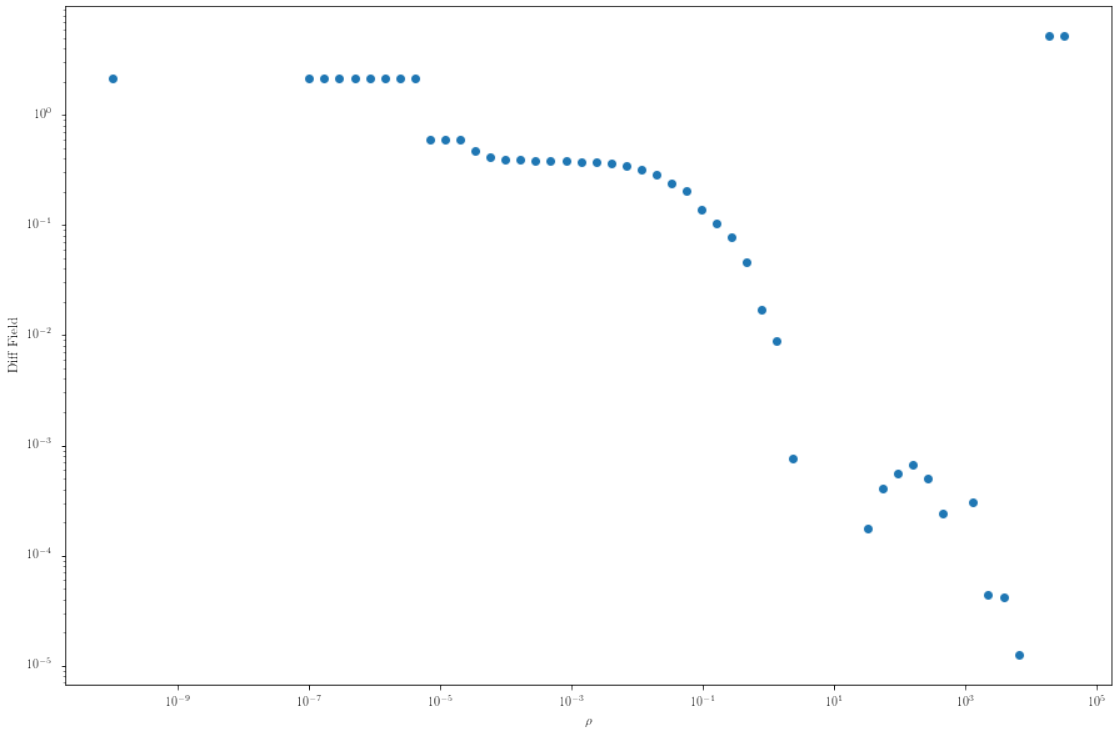
Out[19]: <matplotlib.legend.Legend at 0x7fc97bbf6438>




```
In [20]: plt.plot(xs_end[0], xs_end[1], 'o-')
         plt.quiver(xs_end[0], xs_end[1], spline_dfield[:,0], spline_dfield[:,1],
                    scale=None, angles='xy', headwidth=3, headlength=4.5, headaxislength=4, widt
         plt.title(f"Gradients on Spline, $\\rho$ = {target_rho}")
         plt.xlabel("x")
         plt.ylabel("y")
         plt.legend(["Spline", "Gradients"])

Out[20]: <matplotlib.legend.Legend at 0x7fc97bb5cf60>
```

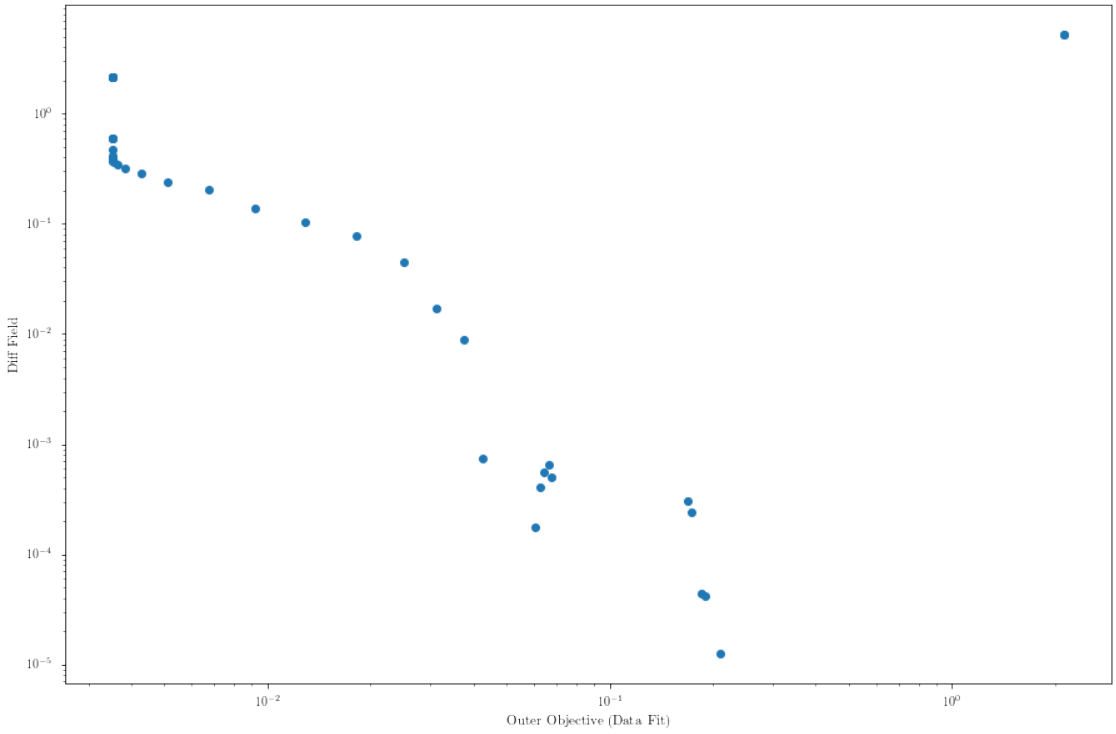



```
In [21]: inner_objective_values = np.array([[r, solver.problems[0].cache.results[tokey(r, v)].fu
         dfield = np.hstack([np.array(rhos).reshape(-1,1),
                             ((inner_objective_values - outer_objective_values)[:,1] / rhos).res

In [22]: plt.loglog(*dfield.T, 'o')
         plt.xlabel(r"$\rho$")
         plt.ylabel("Diff Field")

Out[22]: Text(0, 0.5, 'Diff Field')
```



In [23]:
```
plt.loglog(outer_objective_values[:,1], dfield[:,1], 'o')
plt.xlabel("Outer Objective (Data Fit)")
plt.ylabel("Diff Field")
```

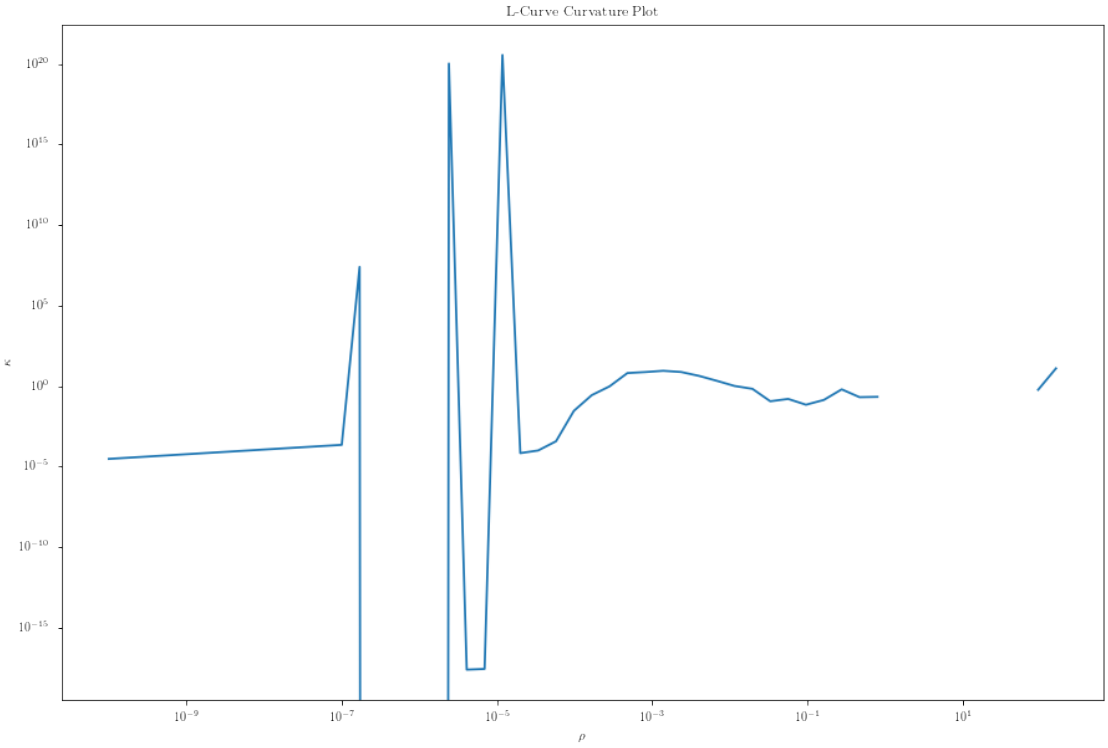
Out[23]:
```
Text(0, 0.5, 'Diff Field')
```




```
In [24]: curv_dx = np.gradient(np.log(outer_objective_values[:,1]))
         curv_dy = np.gradient(np.log(dfield[:,1]))
         curv_dx2 = np.gradient(curv_dx)
         curv_dy2 = np.gradient(curv_dy)

         kappa = np.abs(curv_dx*curv_dy2 - curv_dy*curv_dx2)/(curv_dx**2 + curv_dy**2)**(3/2)

         plt.loglog(rhos, kappa)
         plt.title("L-Curve Curvature Plot")
         plt.xlabel(r"$\rho$")
         plt.ylabel(r"$\kappa$")
```

```
/home/dwu402/.virtualenvs/scider/lib/python3.6/site-packages/ipykernel_launcher.py:2: RuntimeWar
```

```
Out[24]: Text(0, 0.5, '$\\kappa$')
```

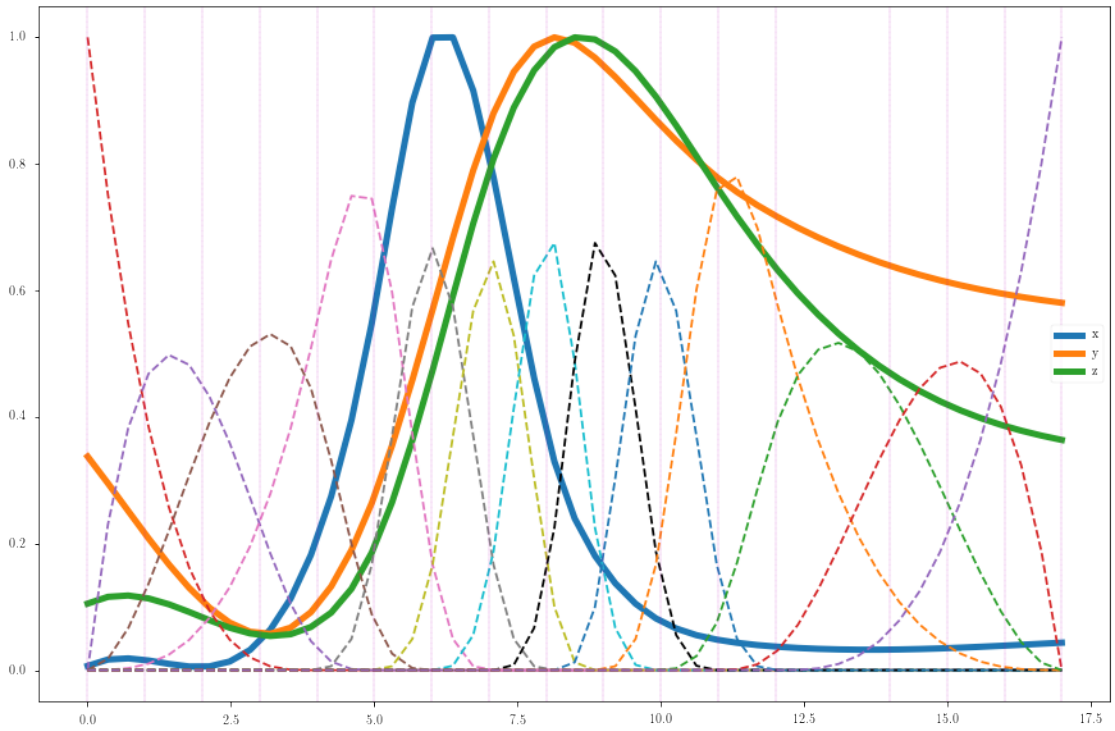



```
In [25]: rhos
```

```
Out[25]: [1e-10,
          1e-07,
          1.6982436524617461e-07,
          2.8840315031266057e-07,
          4.897788193684466e-07,
          8.317637711026709e-07,
          1.4125375446227554e-06,
          2.3988329190194897e-06,
          4.073802778041131e-06,
          6.9183097091893625e-06,
          1.1748975549395302e-05,
          1.995262314968883e-05,
          3.3884415613920276e-05,
          5.7543993733715664e-05,
          9.772372209558111e-05,
          0.00016595869074375615,
          0.0002818382931264455,
          0.00047863009232263854,
          0.0008128305161640995,
          0.0013803842646028866,
          0.0023442288153199225,
```

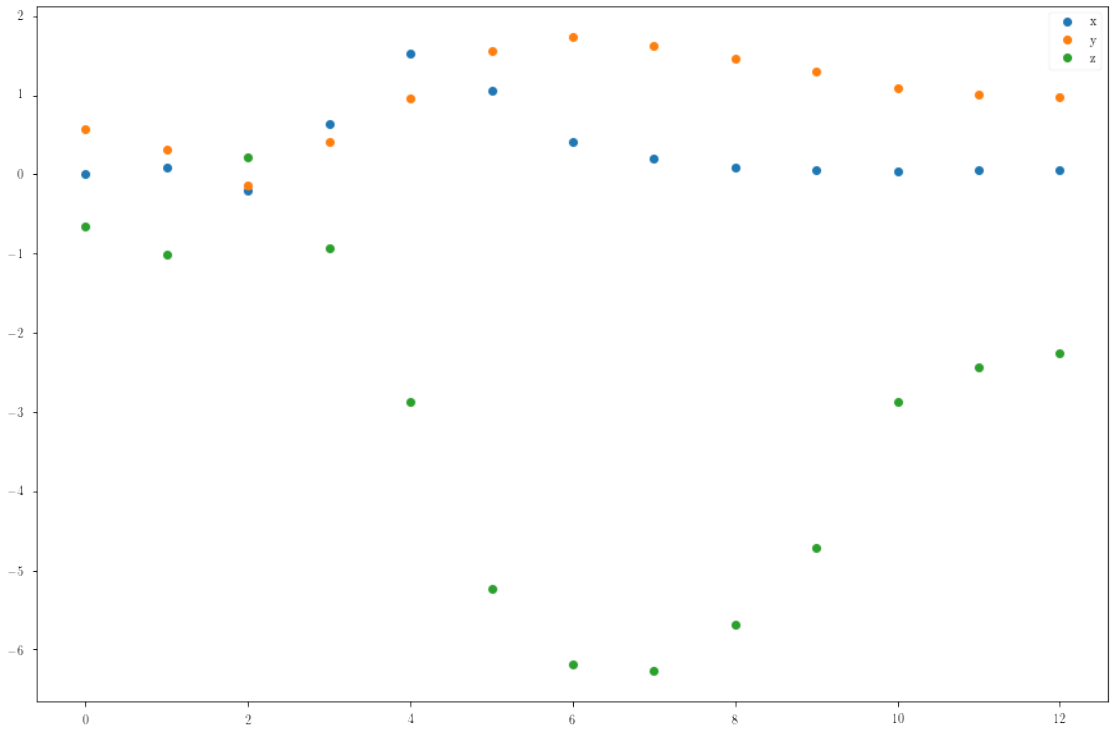
```
 0.003981071705534978,
 0.006760829753919818,
 0.01148153621496884,
 0.019498445997580455,
 0.03311311214825914,
 0.05623413251903491,
 0.09549925860214369,
 0.16218100973589297,
 0.2754228703338169,
 0.4677351412871981,
 0.7943282347242822,
 1.3489628825916533,
 2.290867652767775,
 3.890451449942813,
 6.606934480075965,
 11.220184543019652,
 19.054607179632523,
 32.35936569296281,
 54.954087385762485,
 93.32543007969925,
 158.48931924611173,
 269.1534803926914,
 457.0881896148752,
 776.2471166286928,
 1318.25673855641,
 2238.7211385683377,
 3801.8939632056126,
 6456.542290346562,
 10964.781961431874,
 18620.871366628733,
 31622.776601683792]
```

In [26]:
```
bfn = modeller.ca.Function('basis_fns', [model.ts], [model.basis])
plt.plot(model.observation_times, np.abs(np.hstack([xs_end[0]/max(abs(xs_end[0])),
                                                    xs_end[1]/max(abs(xs_end[1])),
                                                    xs_end[2]/max(abs(xs_end[2]))])),
         linewidth=5)
plt.plot(model.observation_times, bfn(model.observation_times), '--')
plt.legend('xyz')
[plt.axvline(x=i, color='m', linewidth=0.25, linestyle='--') for i in context.datasets[
print("")
```



In [27]:
```
plt.plot(range(model.K), np.array(fitter.argsplit(c_end, 3)).T, 'o')
plt.legend('xyz')
```

Out[27]:
```
<matplotlib.legend.Legend at 0x7fc97b6c0940>
```


x
y
z
2
1
0
−1
−2
−3
−4
−5
−6
0
2
4
6
8
10
12