S-Curve-NetworkAdoption-Copy1

May 8, 2019

1 Stochastic Modelling of Cryptocurrency Network Adoption*

*** shared with the consent of project owner**

In [267]:
```
# Standard Library Imports
import math
import pandas as pd
import numpy as np
import scipy as sp
from scipy.ndimage import gaussian_filter1d
from scipy.stats import norm

import matplotlib as mpl
import matplotlib.pyplot as plt
from scipy import stats
import datetime as dt

%matplotlib inline
```

1.1 Dataset Import

Currently, only ethereum network is used for modelling.

In [268]:
```
gas_price = pd.read_csv('data/ethereum/AvgGasPrice.csv')
gas_used = pd.read_csv('data/ethereum/GasUsed.csv')
n_transactions = pd.read_csv('data/ethereum/TxGrowth.csv')
```

In [269]:
```
gas_price.columns = ['Date', 'TimeStamp', 'Value']
gas_used.columns = ['Date', 'TimeStamp', 'Value']
n_transactions.columns = ['Date', 'TimeStamp', 'Value']

gas_price.head()
```

Out[269]:

	Date	TimeStamp	Value
0	7/30/2015	1438214400	0
1	7/31/2015	1438300800	0
2	8/1/2015	1438387200	0
3	8/2/2015	1438473600	0
4	8/3/2015	1438560000	0

```
In [270]: gas_price.Date = pd.to_datetime(gas_price.Date, format = '%m/%d/%Y')
          gas_used.Date = pd.to_datetime(gas_used.Date, format = '%m/%d/%Y')
          n_transactions.Date = pd.to_datetime(n_transactions.Date, format = '%m/%d/%Y')

          gas_price.head()
```

```
Out[270]:         Date   TimeStamp  Value
          0 2015-07-30  1438214400      0
          1 2015-07-31  1438300800      0
          2 2015-08-01  1438387200      0
          3 2015-08-02  1438473600      0
          4 2015-08-03  1438560000      0
```

1.1.1 ADD EVERY TICKER NAME HERE!

```
In [271]: # order in both lists MUST MATCH
          tickers=['gas_price','gas_used', 'n_transactions']
          df_names = [gas_price,  gas_used, n_transactions]
          print(df_names)
```

```
[          Date   TimeStamp         Value
0    2015-07-30  1438214400             0
1    2015-07-31  1438300800             0
2    2015-08-01  1438387200             0
3    2015-08-02  1438473600             0
4    2015-08-03  1438560000             0
5    2015-08-04  1438646400             0
6    2015-08-05  1438732800             0
7    2015-08-06  1438819200             0
8    2015-08-07  1438905600  604684154870
9    2015-08-08  1438992000  322713574989
10   2015-08-09  1439078400  475467129048
11   2015-08-10  1439164800  421654904254
12   2015-08-11  1439251200   77838819162
13   2015-08-12  1439337600  444902379011
14   2015-08-13  1439424000  268683475202
15   2015-08-14  1439510400  193455494453
16   2015-08-15  1439596800  144368937208
17   2015-08-16  1439683200  120940093311
18   2015-08-17  1439769600  132149993345
19   2015-08-18  1439856000  146513014268
20   2015-08-19  1439942400  194583349948
21   2015-08-20  1440028800   99011782801
22   2015-08-21  1440115200   79543407701
23   2015-08-22  1440201600  552841333007
24   2015-08-23  1440288000   73439482806
25   2015-08-24  1440374400   92409814705
26   2015-08-25  1440460800   76432335617
```

```
27   2015-08-26  1440547200   60481160549
28   2015-08-27  1440633600   59307091958
29   2015-08-28  1440720000   92879907335
...         ...         ...           ...
1270 2019-01-20  1547942400   12387866392
1271 2019-01-21  1548028800   13567626739
1272 2019-01-22  1548115200   18561474026
1273 2019-01-23  1548201600   13308904468
1274 2019-01-24  1548288000   14394162195
1275 2019-01-25  1548374400   13857565780
1276 2019-01-26  1548460800   12616710414
1277 2019-01-27  1548547200   11788620538
1278 2019-01-28  1548633600   15213901906
1279 2019-01-29  1548720000   12439032644
1280 2019-01-30  1548806400   13051979777
1281 2019-01-31  1548892800   14209971121
1282 2019-02-01  1548979200   13234562600
1283 2019-02-02  1549065600   12000569516
1284 2019-02-03  1549152000   11637460620
1285 2019-02-04  1549238400   12082194503
1286 2019-02-05  1549324800   12593215644
1287 2019-02-06  1549411200   12593166346
1288 2019-02-07  1549497600   14057368181
1289 2019-02-08  1549584000   13310836398
1290 2019-02-09  1549670400   12390959208
1291 2019-02-10  1549756800   12847065310
1292 2019-02-11  1549843200   13977805236
1293 2019-02-12  1549929600   13012487105
1294 2019-02-13  1550016000   13713241302
1295 2019-02-14  1550102400   19148327564
1296 2019-02-15  1550188800   14753437258
1297 2019-02-16  1550275200   13510079150
1298 2019-02-17  1550361600   13757940835
1299 2019-02-18  1550448000   17094399315

[1300 rows x 3 columns],            Date   TimeStamp         Value
0    2015-07-30  1438214400          0
1    2015-07-31  1438300800          0
2    2015-08-01  1438387200          0
3    2015-08-02  1438473600          0
4    2015-08-03  1438560000          0
5    2015-08-04  1438646400          0
6    2015-08-05  1438732800          0
7    2015-08-06  1438819200          0
8    2015-08-07  1438905600   49353826
9    2015-08-08  1438992000  376006093
10   2015-08-09  1439078400   38863003
11   2015-08-10  1439164800   74070061
```

12	2015-08-11	1439251200	163481740
13	2015-08-12	1439337600	70102332
14	2015-08-13	1439424000	88234087
15	2015-08-14	1439510400	78746522
16	2015-08-15	1439596800	59565914
17	2015-08-16	1439683200	58241191
18	2015-08-17	1439769600	60515132
19	2015-08-18	1439856000	66816413
20	2015-08-19	1439942400	91746712
21	2015-08-20	1440028800	63112713
22	2015-08-21	1440115200	106379973
23	2015-08-22	1440201600	90744195
24	2015-08-23	1440288000	117802449
25	2015-08-24	1440374400	97648912
26	2015-08-25	1440460800	114480057
27	2015-08-26	1440547200	99511209
28	2015-08-27	1440633600	147888097
29	2015-08-28	1440720000	111903559
...	...	...	...
1270	2019-01-20	1547942400	33077247331
1271	2019-01-21	1548028800	33763981311
1272	2019-01-22	1548115200	34637145295
1273	2019-01-23	1548201600	31630703208
1274	2019-01-24	1548288000	31679636794
1275	2019-01-25	1548374400	30938949942
1276	2019-01-26	1548460800	33241053039
1277	2019-01-27	1548547200	31494607522
1278	2019-01-28	1548633600	33400327582
1279	2019-01-29	1548720000	32867605159
1280	2019-01-30	1548806400	32975674787
1281	2019-01-31	1548892800	35261654580
1282	2019-02-01	1548979200	32761450415
1283	2019-02-02	1549065600	30168904532
1284	2019-02-03	1549152000	28022576836
1285	2019-02-04	1549238400	28109457360
1286	2019-02-05	1549324800	27984580259
1287	2019-02-06	1549411200	28696360299
1288	2019-02-07	1549497600	29441176225
1289	2019-02-08	1549584000	30304669218
1290	2019-02-09	1549670400	29701599787
1291	2019-02-10	1549756800	26786193364
1292	2019-02-11	1549843200	27611571189
1293	2019-02-12	1549929600	28573833622
1294	2019-02-13	1550016000	29584055361
1295	2019-02-14	1550102400	29051955302
1296	2019-02-15	1550188800	30180437810
1297	2019-02-16	1550275200	29978364164
1298	2019-02-17	1550361600	29860882794

```
1299 2019-02-18  1550448000  31150438004

[1300 rows x 3 columns],            Date   TimeStamp   Value
0    2015-07-30  1438214400    8893
1    2015-07-31  1438300800       0
2    2015-08-01  1438387200       0
3    2015-08-02  1438473600       0
4    2015-08-03  1438560000       0
5    2015-08-04  1438646400       0
6    2015-08-05  1438732800       0
7    2015-08-06  1438819200       0
8    2015-08-07  1438905600    2050
9    2015-08-08  1438992000    2881
10   2015-08-09  1439078400    1329
11   2015-08-10  1439164800    2037
12   2015-08-11  1439251200    4963
13   2015-08-12  1439337600    2036
14   2015-08-13  1439424000    2842
15   2015-08-14  1439510400    3174
16   2015-08-15  1439596800    2284
17   2015-08-16  1439683200    2440
18   2015-08-17  1439769600    2512
19   2015-08-18  1439856000    2494
20   2015-08-19  1439942400    3246
21   2015-08-20  1440028800    2303
22   2015-08-21  1440115200    3919
23   2015-08-22  1440201600    3579
24   2015-08-23  1440288000    4190
25   2015-08-24  1440374400    4432
26   2015-08-25  1440460800    4487
27   2015-08-26  1440547200    4156
28   2015-08-27  1440633600    5590
29   2015-08-28  1440720000    4758
...         ...         ...     ...
1270 2019-01-20  1547942400  537705
1271 2019-01-21  1548028800  582751
1272 2019-01-22  1548115200  605558
1273 2019-01-23  1548201600  533819
1274 2019-01-24  1548288000  520130
1275 2019-01-25  1548374400  504903
1276 2019-01-26  1548460800  464380
1277 2019-01-27  1548547200  488814
1278 2019-01-28  1548633600  568564
1279 2019-01-29  1548720000  566026
1280 2019-01-30  1548806400  555347
1281 2019-01-31  1548892800  517057
1282 2019-02-01  1548979200  498856
1283 2019-02-02  1549065600  450314
```

```
1284 2019-02-03  1549152000  424378
1285 2019-02-04  1549238400  416394
1286 2019-02-05  1549324800  414815
1287 2019-02-06  1549411200  429065
1288 2019-02-07  1549497600  428676
1289 2019-02-08  1549584000  471952
1290 2019-02-09  1549670400  417129
1291 2019-02-10  1549756800  381151
1292 2019-02-11  1549843200  429007
1293 2019-02-12  1549929600  438111
1294 2019-02-13  1550016000  491354
1295 2019-02-14  1550102400  474782
1296 2019-02-15  1550188800  468599
1297 2019-02-16  1550275200  454309
1298 2019-02-17  1550361600  447945
1299 2019-02-18  1550448000  512455

[1300 rows x 3 columns]]
```

1.1.2 Set START DATE AND END DATE OF ANALYSIS

```
In [272]: # Y , M , D
          start = dt.datetime(2015, 7, 30)


          #Enter a specific date or today
          end = dt.datetime(2018, 12, 31)

          #end = dt.date.today()
          print(start)
```

```
2015-07-30 00:00:00
```

Make a dataframe starts and ends at Time specified, date as index, and columns the close price of assets in question

```
In [273]: df = pd.DataFrame()

          df['Date'] = pd.to_datetime([start + dt.timedelta(days=x) for x in range(0, (end-sta

          # df.Date = pd.to_datetime(df.Date, format = '%Y/%m/%d')
          # df = df[df.Date  >= start ]
          df = df.set_index('Date')

          for count, name in enumerate(df_names):
              df = df.join(name.set_index('Date').Value.rename(tickers[count]))
```

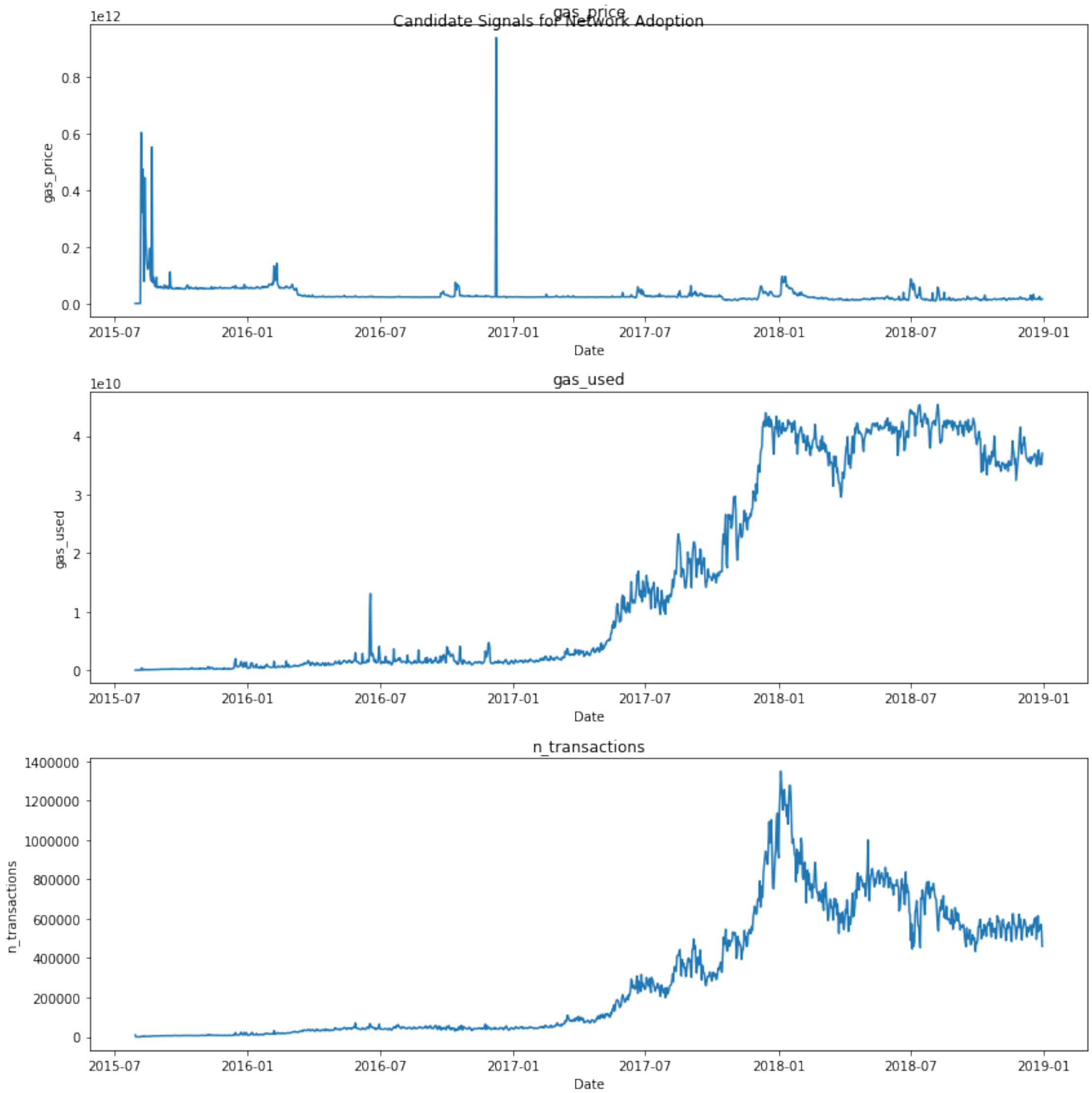
```
In [274]: df.head(10)
```

```
Out[274]:                gas_price   gas_used  n_transactions
          Date
          2015-07-30             0          0            8893
          2015-07-31             0          0               0
          2015-08-01             0          0               0
          2015-08-02             0          0               0
          2015-08-03             0          0               0
          2015-08-04             0          0               0
          2015-08-05             0          0               0
          2015-08-06             0          0               0
          2015-08-07  604684154870   49353826            2050
          2015-08-08  322713574989  376006093            2881
```

1.1.3 Daily Percent Change

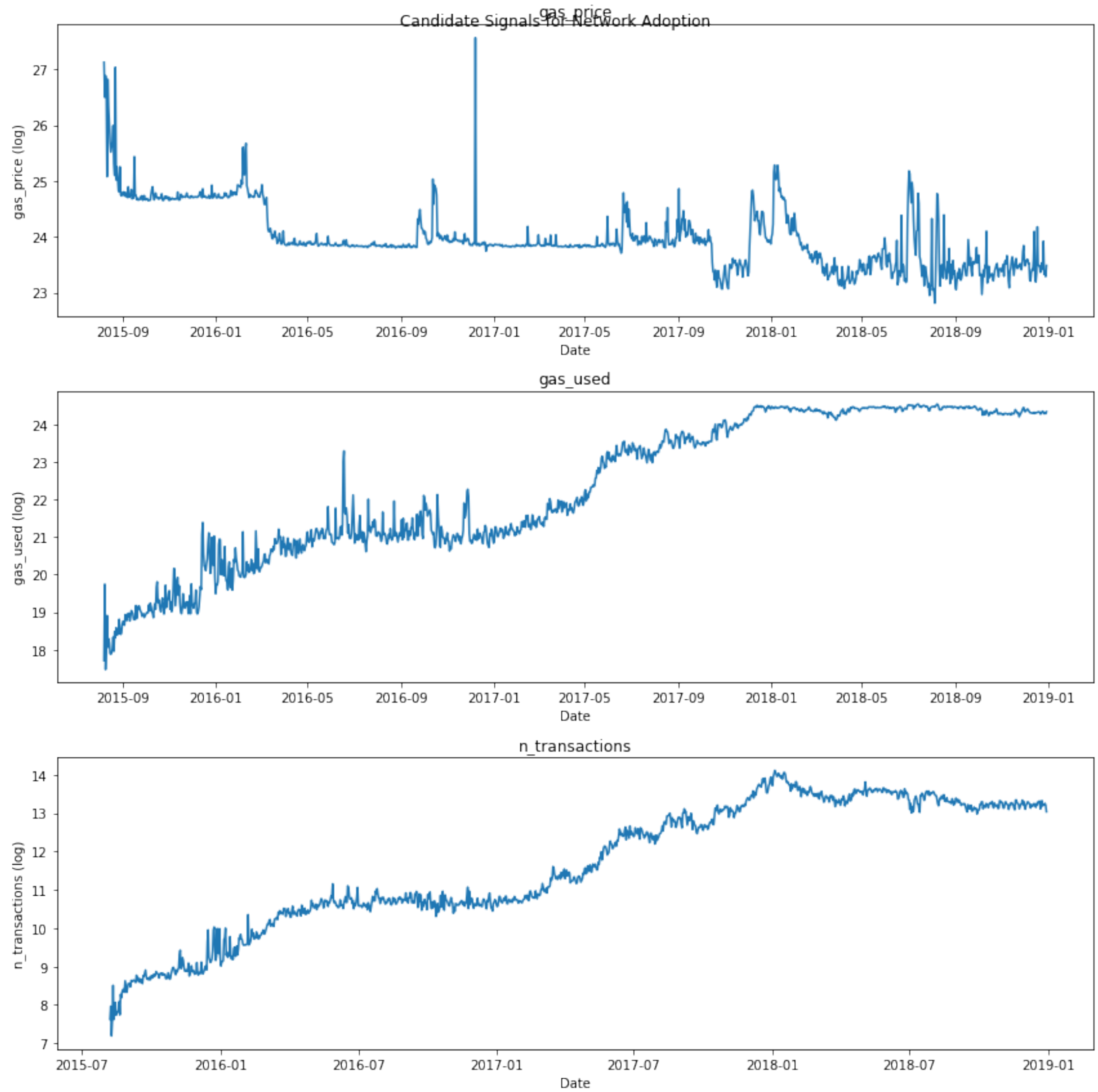
daily_df is a dataframe of daily returns

```
In [275]: plt.figure(figsize=(12,12))
          plt.suptitle('Candidate Signals for Network Adoption')
          for count, name in enumerate(tickers):
              plt.subplot(len(tickers),1,count+1)
              plt.plot(df.index, df[name]) #,legend=True,logy=True )
              plt.title(tickers[count])
              plt.xlabel('Date')
              plt.ylabel(name)

          plt.tight_layout()
```



In [276]:
```
plt.figure(figsize=(12,12))
plt.suptitle('Candidate Signals for Network Adoption')
for count, name in enumerate(tickers):
    plt.subplot(len(tickers),1,count+1)
    plt.plot(df.index, np.log(df[name])) #,legend=True,logy=True )
    plt.title(tickers[count])
    plt.xlabel('Date')
    plt.ylabel(name+' (log)')

plt.tight_layout()
```

```
/Users/hamedlayeghi/Work/General/Python/Python3.7-x64_Anaconda-2019.03/lib/python3.7/site-packa
  """
```

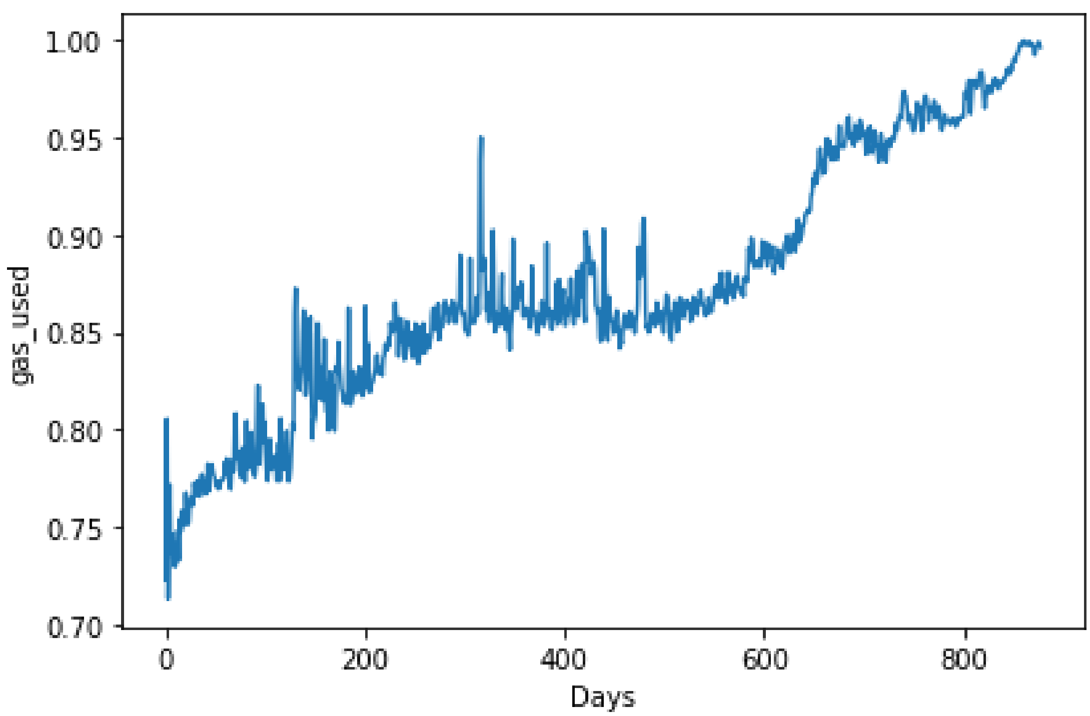


2 Regression

```
In [277]: c = 'gas_used'

          start_new = pd.Timestamp(2015,8,7)
          end_new = pd.Timestamp(2017,12,31)
          df_new = df[(start_new<=df.index) & (df.index<=end_new)]

          X = (df_new.index - start_new).days
          Y = np.log(df_new[c].values)
          Y = Y/max(Y)
```

```
plt.plot(X,Y)
plt.xlabel('Days')
plt.ylabel(c)
plt.tight_layout();
print(X)
```

```
Int64Index([  0,   1,   2,   3,   4,   5,   6,   7,   8,   9,
            ...
            868, 869, 870, 871, 872, 873, 874, 875, 876, 877],
           dtype='int64', name='Date', length=878)
```

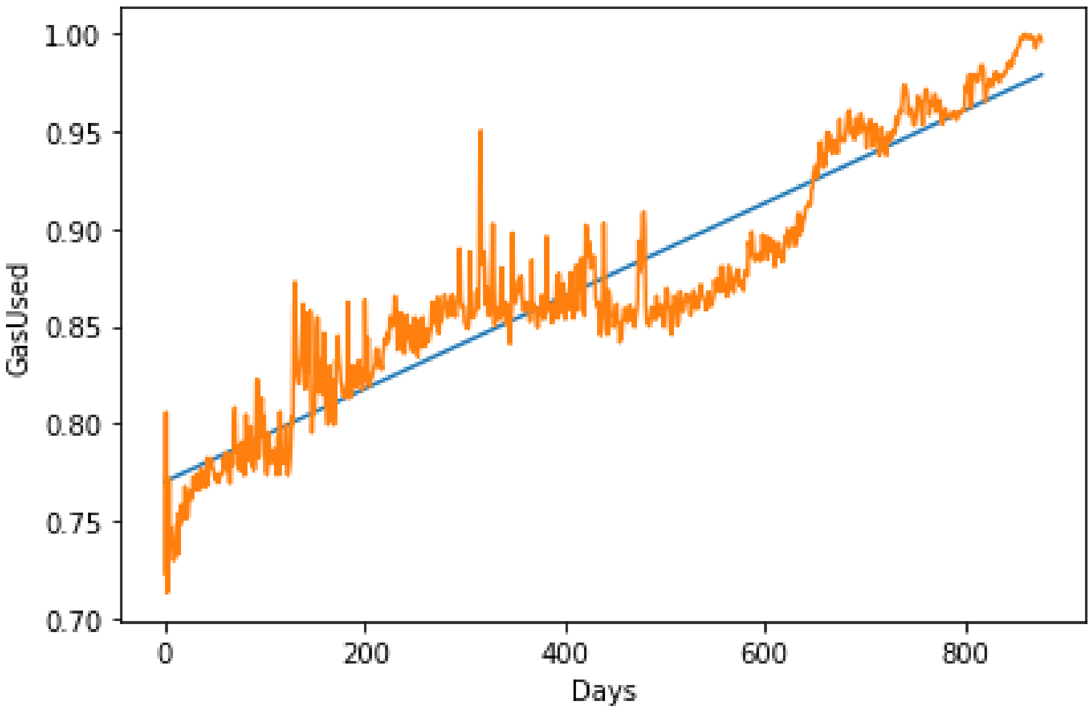



```
In [278]: print(str(len(Y)), str(len(X)))
```

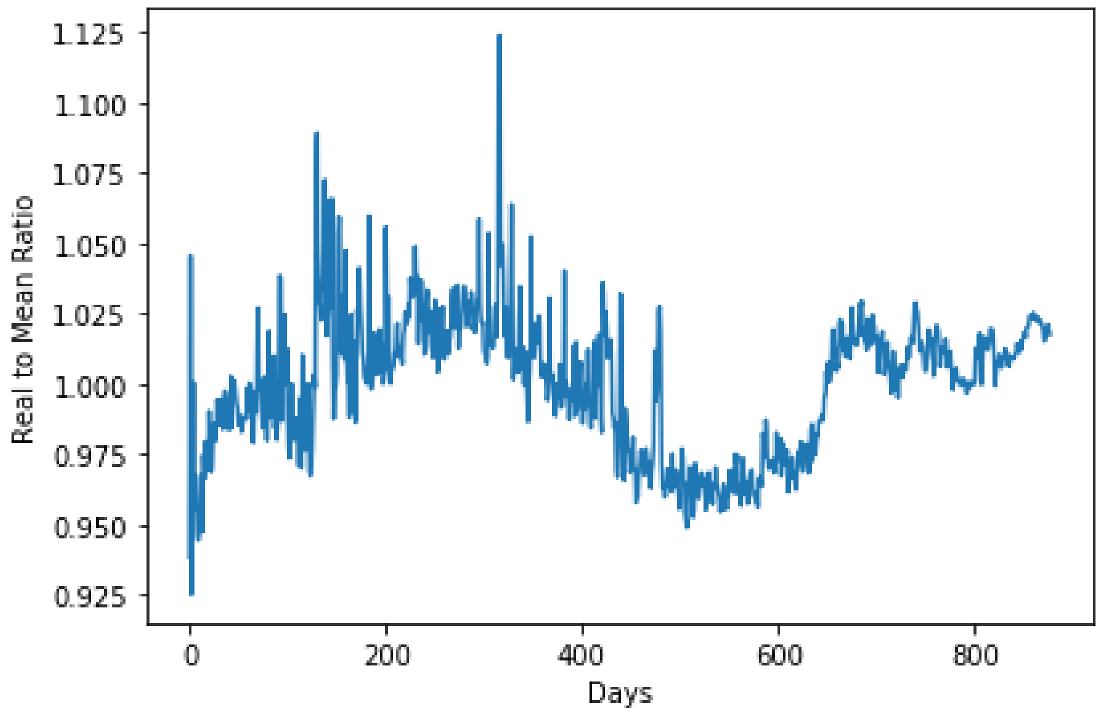
```
878 878
```

```
In [279]: slope, intercept, r_value, p_value, std_err = sp.stats.linregress(X,Y)
          Y_hat = slope * X + intercept
          plt.plot(X, Y_hat)
          plt.plot(X, Y)
          plt.xlabel('Days')
          plt.ylabel('GasUsed')
          plt.tight_layout()

          print('slope = %s, intercept = %s' % (str(slope), str(intercept)))
```

```
slope = 0.00023825758480799708, intercept = 0.7702545314392375
```

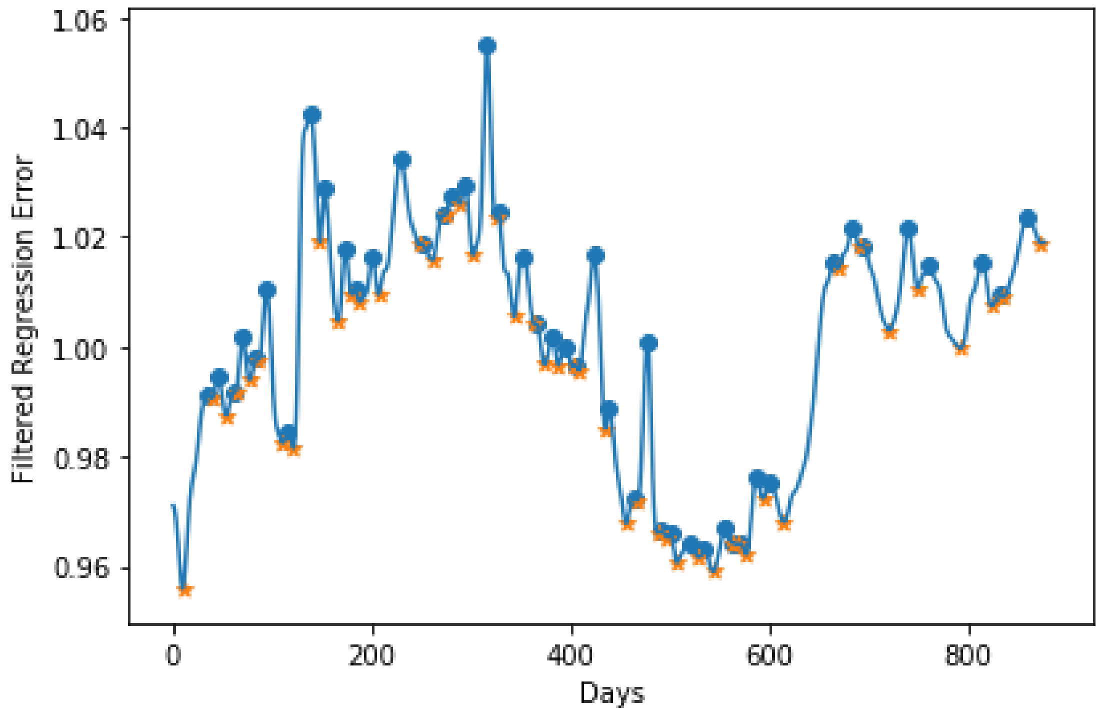



```
In [280]: error = Y / Y_hat
          plt.plot(X, error)
          plt.xlabel('Days')
          plt.ylabel('Real to Mean Ratio')
          plt.tight_layout()
```



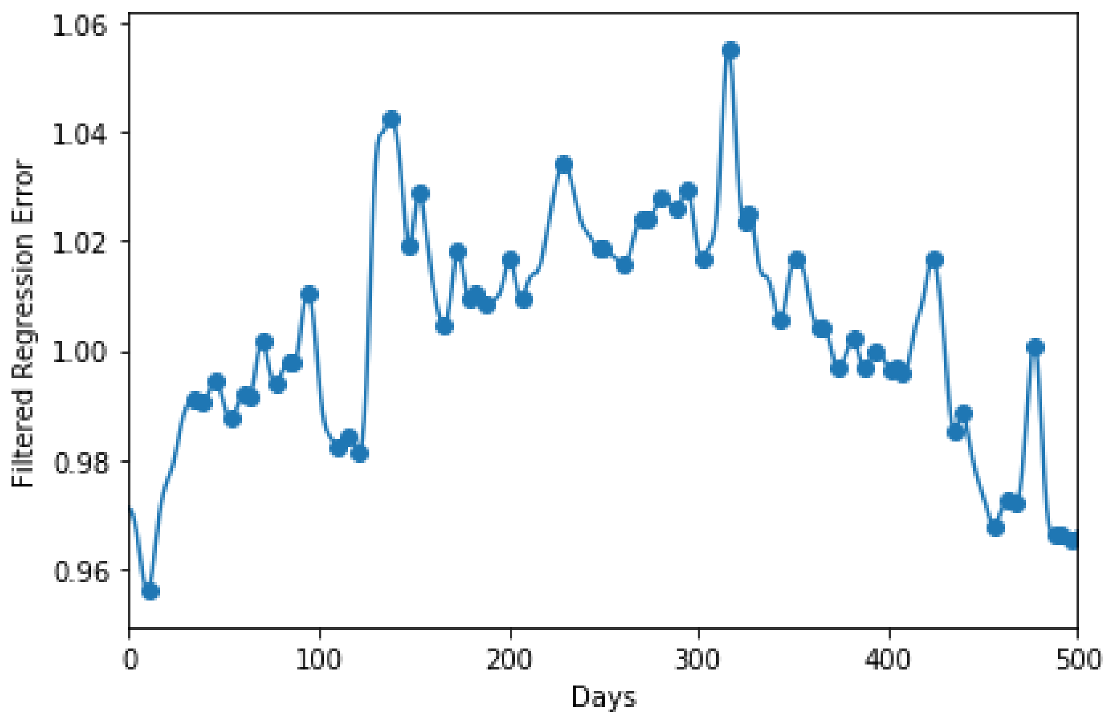
3 Smoothing with Gaussian Kernel

In [281]:
```
error_filtered = gaussian_filter1d(error, 3)
margin = 0
local_max = np.r_[False, error_filtered[1:] > (error_filtered[:-1]+margin)] & np.r_[
                                                                                 >
local_max_indices = np.where(local_max == True)
local_max_indices = local_max_indices[0]
local_min = np.r_[False, error_filtered[1:] < (error_filtered[:-1]-margin)] & np.r_[
                                                                                 <
local_min_indices = np.where(local_min == True)
local_min_indices = local_min_indices[0]
# plot
plt.plot(X, error_filtered)
plt.scatter(local_max_indices, error_filtered[local_max_indices])
plt.scatter(local_min_indices, error_filtered[local_min_indices],marker='*')

plt.xlabel('Days')
plt.ylabel('Filtered Regression Error')
plt.tight_layout()
```



In [282]:
```
local_extremum_indices = np.concatenate((local_min_indices, local_max_indices))
print(local_extremum_indices)
local_extremum_indices= np.sort(local_extremum_indices, kind='mergesort')
# plot
plt.plot(X, error_filtered)
plt.scatter(local_extremum_indices, error_filtered[local_extremum_indices])
plt.xlim(0,500)
plt.xlabel('Days')
plt.ylabel('Filtered Regression Error')
plt.tight_layout()
```

```
[ 10  39  54  63  77  86 110 121 148 166 180 188 207 248 261 274 289 302
 325 343 364 374 388 402 408 435 456 467 488 497 507 529 544 563 568 577
 594 615 669 692 721 750 793 824 836 874  35  45  61  70  84  94 116 138
 153 173 183 201 229 250 271 281 294 316 327 352 366 382 394 405 424 439
 464 477 491 501 521 535 556 564 571 587 601 665 684 695 740 761 815 832
 860]
```



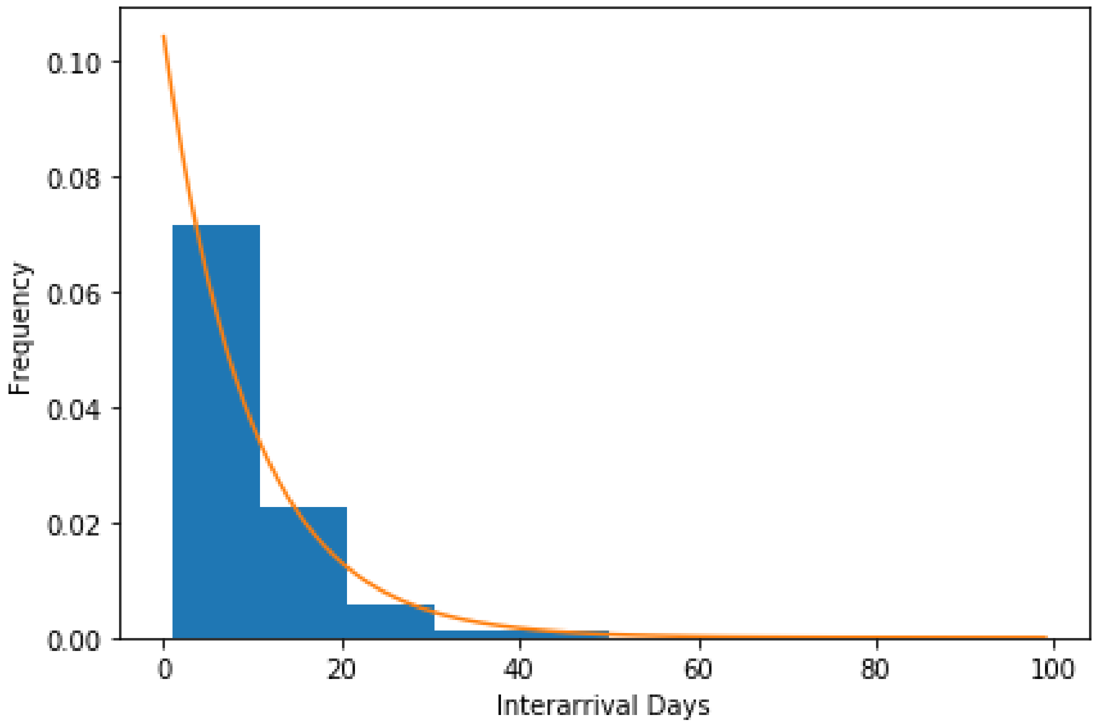
4 Developing the stochastic model

4.0.1 Interarrival times

```
In [283]: arrival_times = np.diff(local_extremum_indices)
          lambda_hat = 1/np.mean(arrival_times)
          print(arrival_times, lambda_hat)
          plt.hist(arrival_times, bins =5, density =True)
          x = np.arange(100)
          plt.plot(x, lambda_hat*np.exp(-lambda_hat*x))
          plt.tight_layout()
          plt.xlabel('Interarrival Days')
          plt.ylabel('Frequency')
```

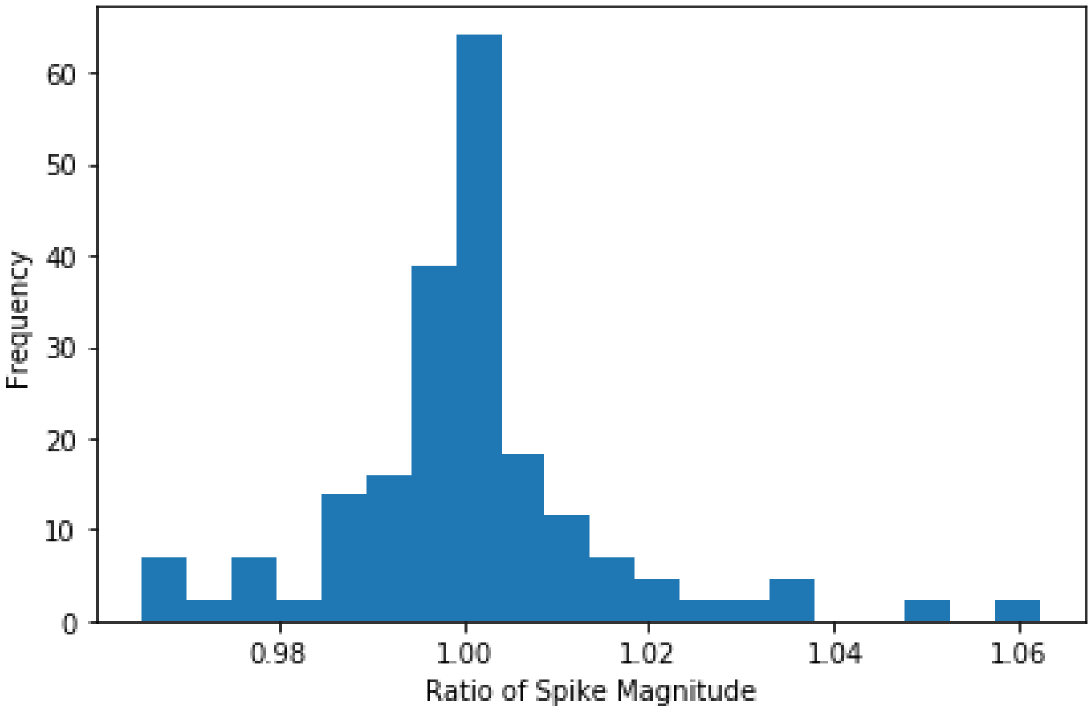
```
[25  4  6  9  7  2  7  7  7  2  8 16  6  5 17 10  5 13  7  7  3  5 13  6
 22 19  2 11 10  3  7  8  5  8 14  9  2 16  9 12  2  8  8  6  6  8  3  3
 16 11  4 17  8  3 10 11  3  6  4  6 14  8  6  9 12  7  1  4  3  6 10  7
  7 14 50  4 15  8  3 26 19 10 11 32 22  9  8  4 24 14] 0.10416666666666667
```

```
Out[283]: Text(20.875, 0.5, 'Frequency')
```

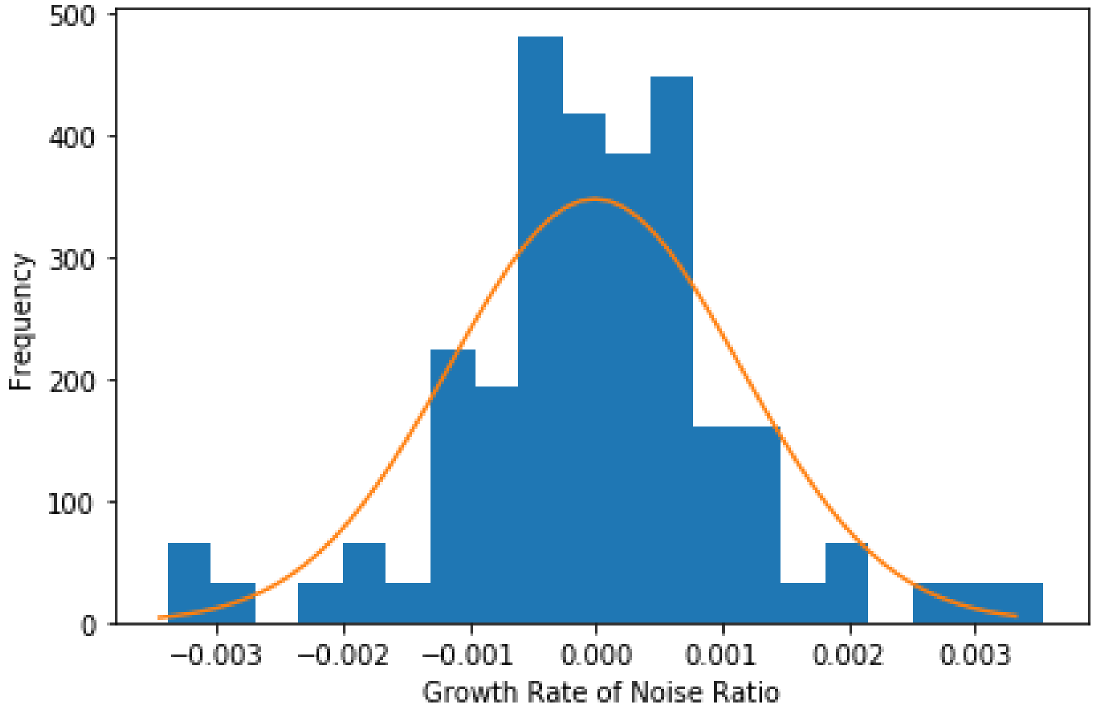


4.0.2 Spike Magnitudes

```
In [284]: local_extrema = error_filtered[local_extremum_indices]
          spike_magnitudes = local_extrema[1:]/local_extrema[:-1]
          plt.hist(spike_magnitudes, bins=20, density=True)
          plt.ylabel('Frequency')
          plt.xlabel('Ratio of Spike Magnitude')
          plt.tight_layout()
```




```
In [285]: growth = np.log(spike_magnitudes)/arrival_times
          mu_growth = np.mean(growth)
          var_growth = np.var(growth)
          std_growth = np.sqrt(var_growth)
          plt.hist(growth, bins=20, density=True)
          print('maximum growth rate: %s times standard deviation' % str(max(abs(growth))/std_g
          range_factor = 3
          x = np.arange(mu_growth - range_factor * std_growth, mu_growth +range_factor *std_gro
          plt.plot(x, norm.pdf(x, loc=mu_growth, scale=std_growth))
          plt.ylabel('Frequency')
          plt.xlabel('Growth Rate of Noise Ratio')
          plt.tight_layout()

          print(mu_growth, std_growth)

maximum growth rate: 3.0919468995062718 times standard deviation
-4.8316421292355e-06 0.0011479527780770898
```



5 Random Generator Class for Network Adoption

In [286]:
```
def update_mean_ema(mu_p, x_n, alpha):
    return alpha * x_n + (1-alpha) * mu_p


class PoissonWithExponentialJumpSignalGenerator:
    def __init__(self, slope_log=0.0002382576, intercept_log=0.770254531, max_log_ado
                 mu_noise_log=-4.8316e-06, std_noise_log=0.00115, max_noise_ratio_gro
                 return_contraction_threshold = None, return_contraction_ema_alpha =
                 return_contraction_const = None
                ):
        self._rng = np.random.RandomState(seed=rng_seed)
        self._slope_log = slope_log
        self._intercept_log = intercept_log
        self._max_log_adoption = max_log_adoption
        self._start_noise_ratio = 1.0
        self._time_last_event = 0
        self._lambda_event = lambda_event
        self._time_next_event = int(np.random.exponential(scale = 1/self._lambda_even
        self._direction = 1
        self._mu_noise_log = mu_noise_log
        self._std_noise_log = std_noise_log
```

```python
        self._max_noise_ratio_growth_rate = max_noise_ratio_growth_rate
        self._noise_ratio_growth_rate = self._direction*abs(np.random.normal(loc=mu_
        self._average_log_adoption = None
        self._adoption = None
        self._return_ema = 0.0
        self._adoption = math.exp(intercept_log)
        if (return_contraction_threshold is not None) or (return_contraction_ema_alph
            assert return_contraction_threshold is not None, "missing value for retu
            assert return_contraction_ema_alpha is not None, "missing value for retu
            assert return_contraction_const is not None, "missing value for return_c
        self._return_contraction_threshold = return_contraction_threshold
        self._return_contraction_const = return_contraction_const
        self._return_contraction_ema_alpha = return_contraction_ema_alpha


    def _update_adoption(self):
        self._adoption = math.exp(self._noise_ratio * self._average_log_adoption)
        assert self._adoption >= 0, "adoption cannot be negative"

    def _update_average_adoption(self, time: float):
        x = self._slope_log * time + self._intercept_log
        self._average_log_adoption = min(x, self._max_log_adoption)

    def _update_noise_ratio(self, time: float):
        self._noise_ratio = self._start_noise_ratio*math.exp(self._noise_ratio_growt
        # print('noise_ratio_growth_rate = %s' % str(self._noise_ratio_growth_rate))
        # print('noise_ratio = %s' % str(self._noise_ratio))

    def _update_event(self, time: float):
#         print('time = %s and time_from_last = %s' % (str(time),str(time-self._time_
        if (time-self._time_last_event) >= self._time_next_event:
            t_tmp = self._time_next_event
            self._time_next_event = int(np.random.exponential(scale = 1/self._lambda_
            self._time_last_event = time
            self._direction *= -1
            self._start_noise_ratio = self._noise_ratio
            self._noise_ratio_growth_rate = self._direction*np.clip(abs(self._rng.no
                                                                    scale=self._std_noise_log)), 0, \
                                                                    self._max_noise_ratio_growth_rat
        if self._return_contraction_threshold is not None:
            # contraction
            if self._return_ema > self._return_contraction_threshold:
                _delta = self._return_ema - self._return_contraction_threshold
                # print(f"compressing at time {time}: delta = ", _delta)
                self._noise_ratio_growth_rate -=  self._return_contraction_const * _
                # print("_noise_ratio_growth_rate = ", self._noise_ratio_growth_rate
            # print("t_next = %s" % str(self._time_next_event))
            if self._return_ema < - self._return_contraction_threshold:
```

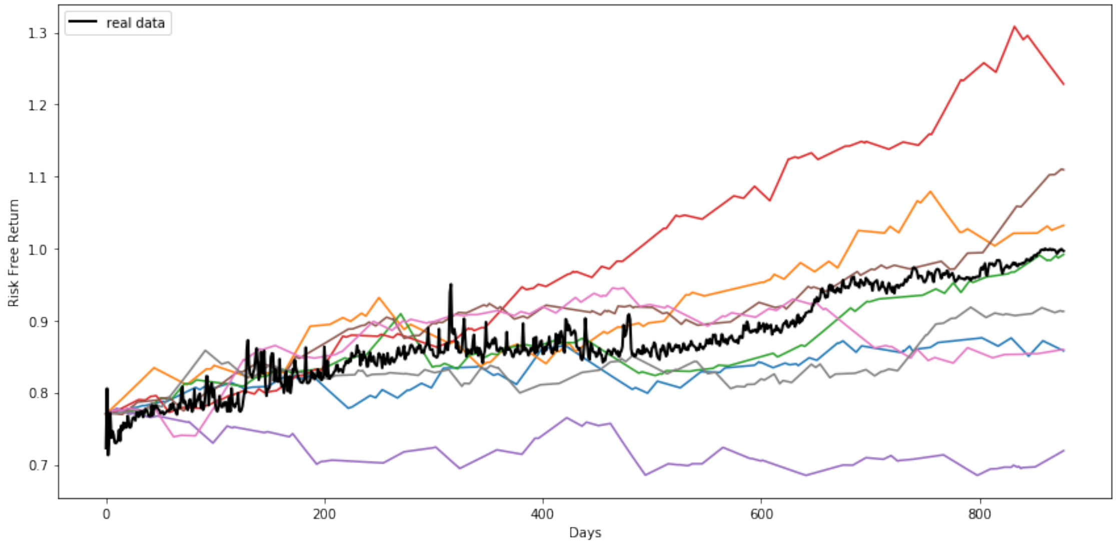
```
                _delta = self._return_ema + self._return_contraction_threshold
                # print(f"compressing at time {time}: delta = ", _delta)
                self._noise_ratio_growth_rate += self._return_contraction_const * _de
                # print("_noise_ratio_growth_rate = ", self._noise_ratio_growth_rate
            # print("t_next = %s" % str(self._time_next_event))

    def update_adoption(self, time: float):
        prev_adoption = self._adoption
        # print('average_adoption before = %s at t = %s '% (str(self._average_log_ado

        self._update_average_adoption(time)
        # print('average_adoption after = %s' %str(self._average_log_adoption))

        self._update_noise_ratio(time)

        self._update_adoption()
        # print('adoption = %s' %str(self._adoption))

        self._update_event(time)

        if self._return_contraction_ema_alpha is not None:
            _return = (self._adoption - prev_adoption) / prev_adoption
            self._return_ema = update_mean_ema(self._return_ema, _return, self._retur
        # print("return: ", self._return_ema)

        return self

    def get_signal(self):
        return self._adoption
```

In [287]:
```
syn_data_x = np.arange(int(np.max(X.values)) + 1)

N = 8
syn_data_y = []
for j in range(N):
    print(f"Starting run {j}\n=======================")
    gen = PoissonWithExponentialJumpSignalGenerator(rng_seed=np.random.randint(low=0
    syn_data_y.append(np.array([gen.update_adoption(i).get_signal() for i in syn_data
    print("")

# print(syn_data_y)
```

```
Starting run 0
=======================

Starting run 1
```

```
=======================

Starting run 2
=======================

Starting run 3
=======================

Starting run 4
=======================

Starting run 5
=======================

Starting run 6
=======================

Starting run 7
=======================
```

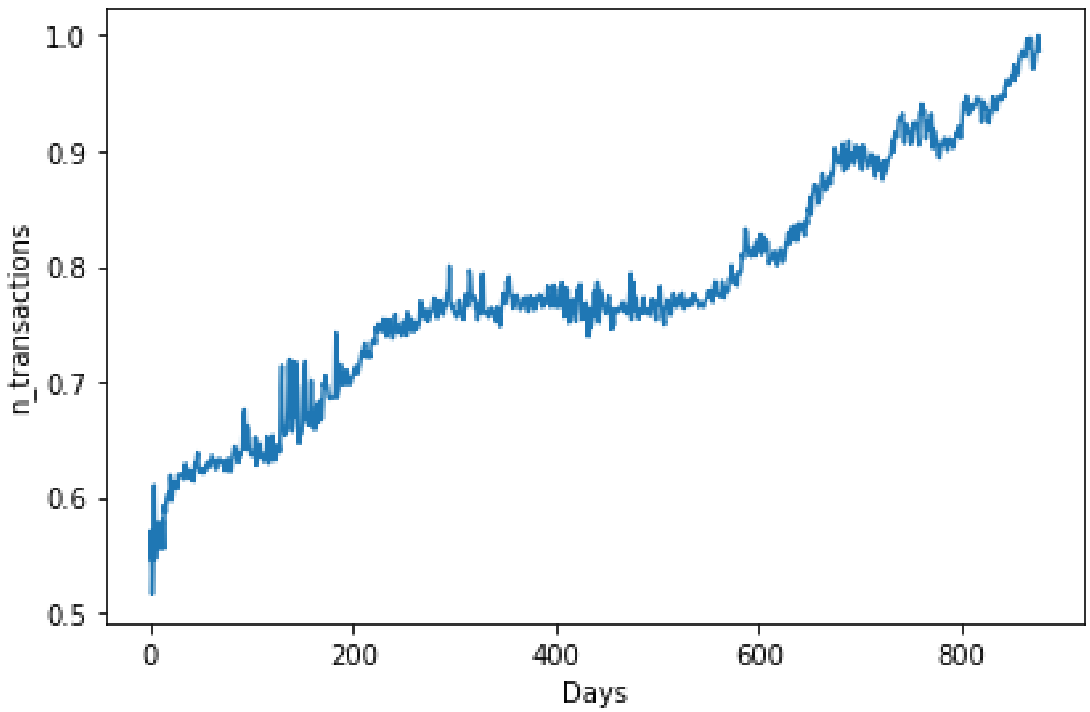
In [288]:
```
real_normalized_price = np.log(df_new[c].values)
real_normalized_price /= max(real_normalized_price)

plt.figure(figsize=(12,6));
for _r, _y in enumerate(syn_data_y):
    plt.plot(syn_data_x, np.log(_y))
plt.plot(X, real_normalized_price, label = 'real data', linewidth=2, color="black")
# plt.plot(min[X], max[X])
plt.xlabel('Days')
plt.ylabel('Risk Free Return')
plt.legend()
# plt.ylim(0, 1e-4)
plt.tight_layout();
```



6 Number of Transactions

6.1 Regression

```
In [289]: c = 'n_transactions'

          start_new = pd.Timestamp(2015,8,7)
          end_new = pd.Timestamp(2017,12,31)
          df_new = df[(start_new<=df.index) & (df.index<=end_new)]

          X = (df_new.index - start_new).days
          Y = np.log(df_new[c].values)
          Y = Y/max(Y)

          plt.plot(X,Y)
          plt.xlabel('Days')
          plt.ylabel(c)
          plt.tight_layout()
```

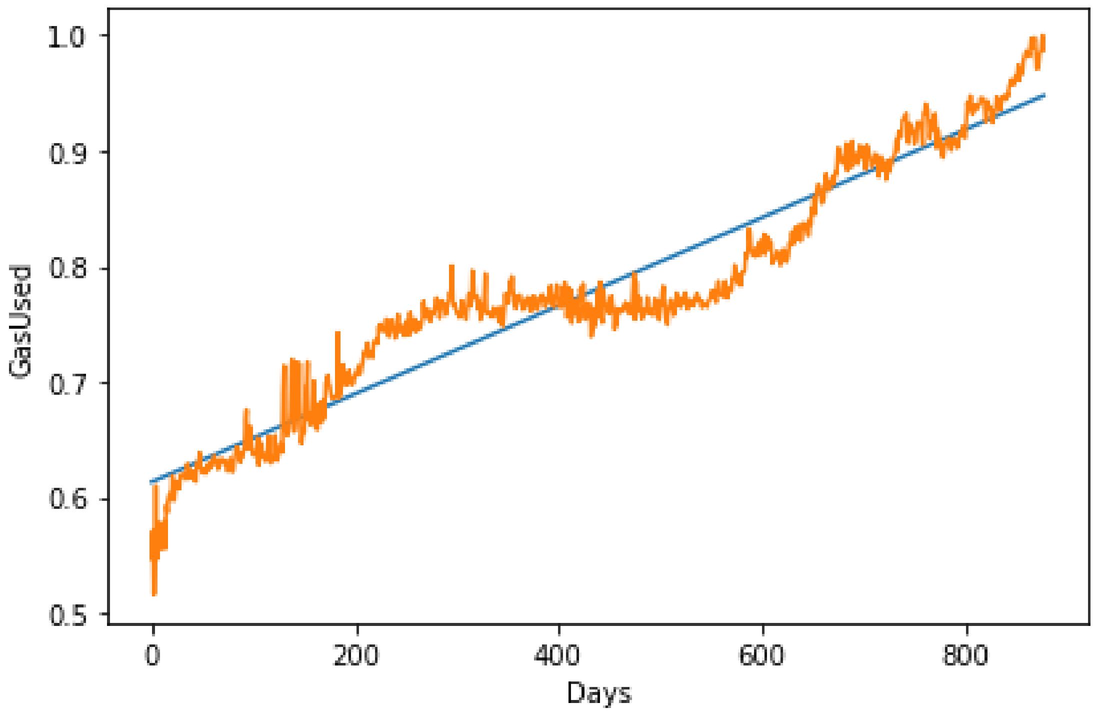



```
In [290]: print(str(len(Y)), str(len(X)))
```

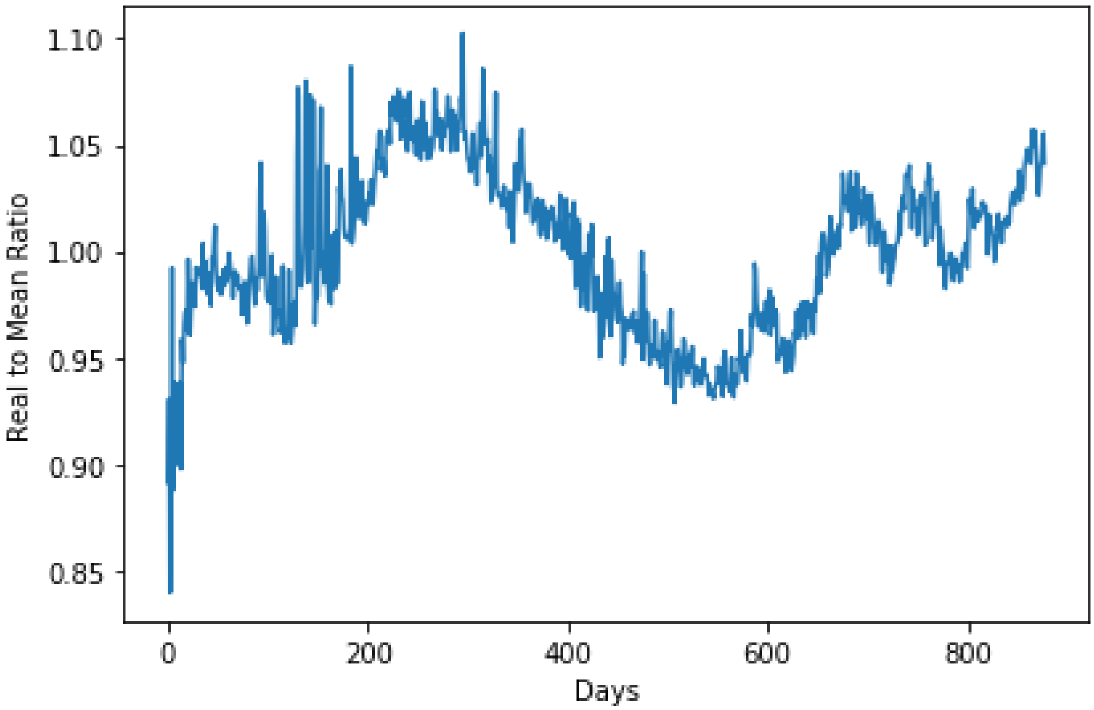
```
878 878
```

```
In [291]: slope, intercept, r_value, p_value, std_err = sp.stats.linregress(X,Y)
          Y_hat = slope * X + intercept
          plt.plot(X, Y_hat)
          plt.plot(X, Y)
          plt.xlabel('Days')
          plt.ylabel('GasUsed')
          plt.tight_layout()

          print('slope_log = %s, intercept_log = %s' % (str(slope), str(intercept)))
```

```
slope_log = 0.0003811951192898479, intercept_log = 0.6134434756157009
```

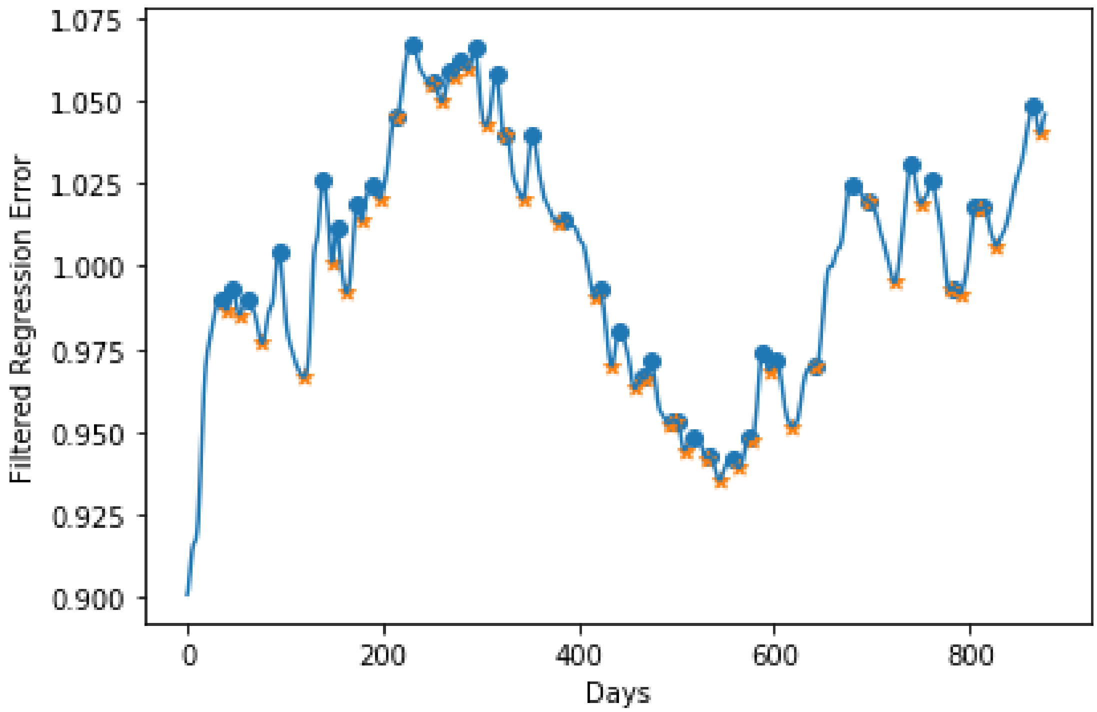


In [292]:
```
error = Y / Y_hat
plt.plot(X, error)
plt.xlabel('Days')
plt.ylabel('Real to Mean Ratio')
plt.tight_layout()
```



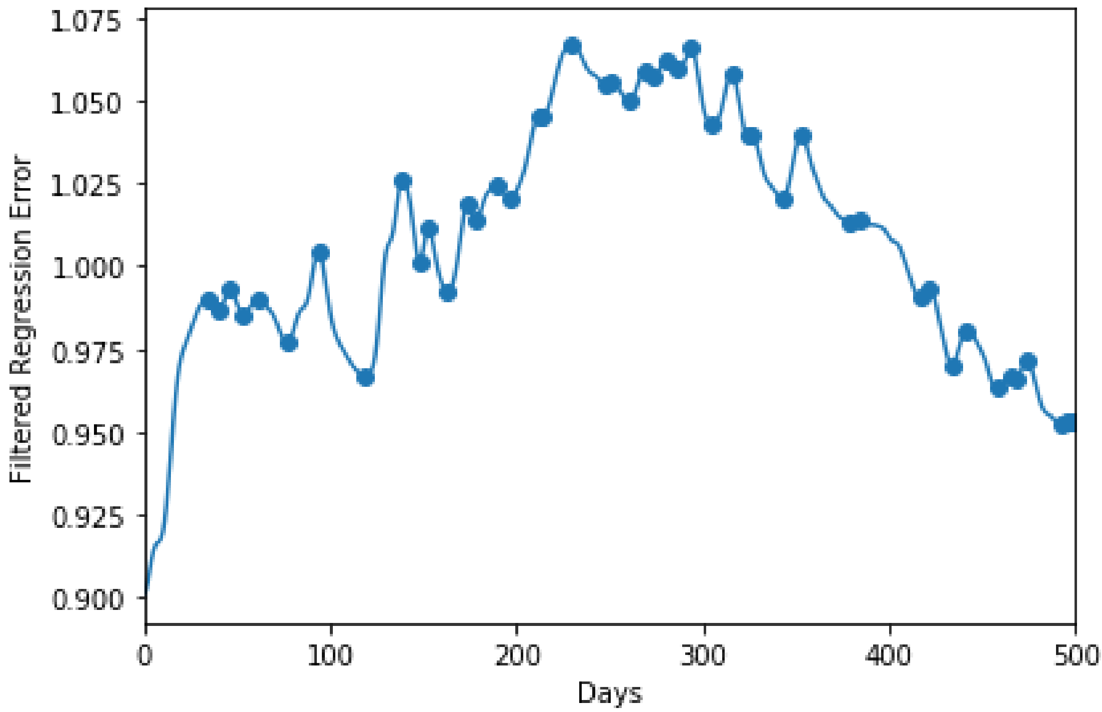
6.2 Smoothing with Gaussian Kernel

In [293]:
```
error_filtered = gaussian_filter1d(error, 3)
margin = 0
local_max = np.r_[False, error_filtered[1:] > (error_filtered[:-1]+margin)] & np.r_[
                                                                                   >
local_max_indices = np.where(local_max == True)
local_max_indices = local_max_indices[0]
local_min = np.r_[False, error_filtered[1:] < (error_filtered[:-1]-margin)] & np.r_[
                                                                                   <
local_min_indices = np.where(local_min == True)
local_min_indices = local_min_indices[0]
# plot
plt.plot(X, error_filtered)
plt.scatter(local_max_indices, error_filtered[local_max_indices])
plt.scatter(local_min_indices, error_filtered[local_min_indices],marker='*')

plt.xlabel('Days')
plt.ylabel('Filtered Regression Error')
plt.tight_layout()
```




```
In [294]: local_extremum_indices = np.concatenate((local_min_indices, local_max_indices))
          print(local_extremum_indices)
          local_extremum_indices= np.sort(local_extremum_indices, kind='mergesort')
          # plot
          plt.plot(X, error_filtered)
          plt.scatter(local_extremum_indices, error_filtered[local_extremum_indices])
          plt.xlim(0,500)
          plt.xlabel('Days')
          plt.ylabel('Filtered Regression Error')
          plt.tight_layout()
```

```
[ 40  53  77 119 148 163 178 197 214 248 260 273 287 305 325 343 379 417
 434 458 468 492 498 508 532 544 564 577 595 619 642 695 723 750 780 790
 810 827 872  34  46  61  94 139 153 174 189 213 230 251 269 280 294 316
 326 353 384 422 442 465 474 496 501 518 534 557 574 588 601 641 679 696
 740 761 783 806 814 865]
```



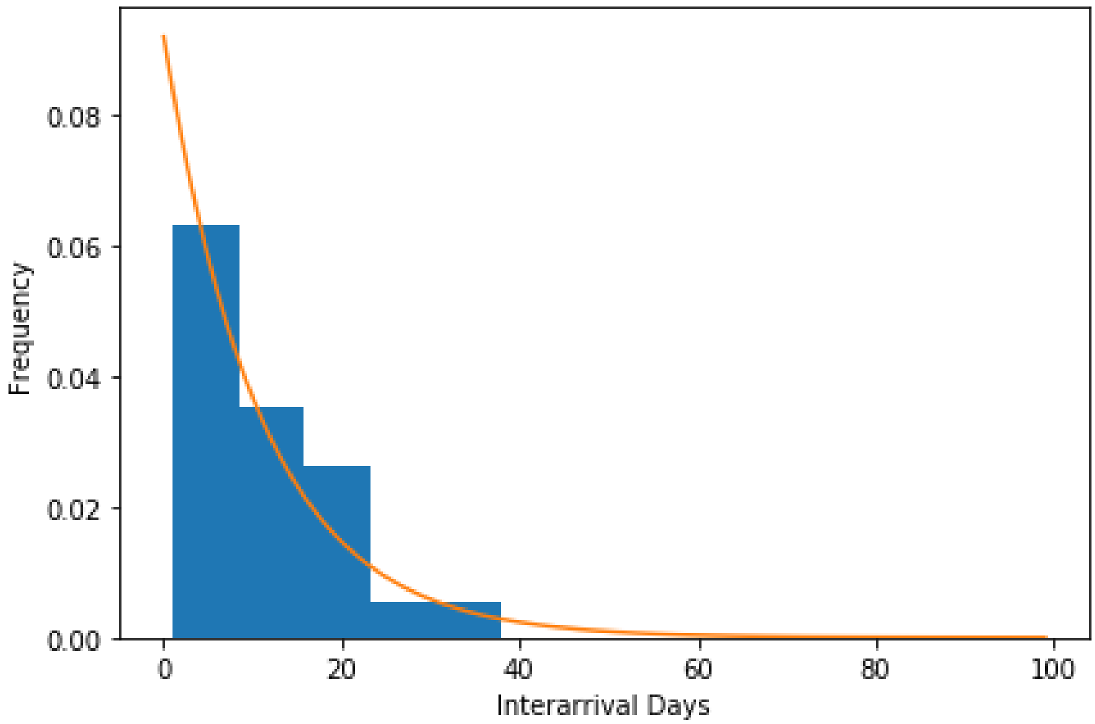
6.3 Developing the stochastic model

6.3.1 Interarrival times

```
In [295]: arrival_times = np.diff(local_extremum_indices)
          lambda_hat = 1/np.mean(arrival_times)
          print('%s = ' % chr(955), lambda_hat)
          plt.hist(arrival_times, bins =5, density =True)
          x = np.arange(100)
          plt.plot(x, lambda_hat*np.exp(-lambda_hat*x))
          plt.tight_layout()
          plt.xlabel('Interarrival Days')
          plt.ylabel('Frequency')
```

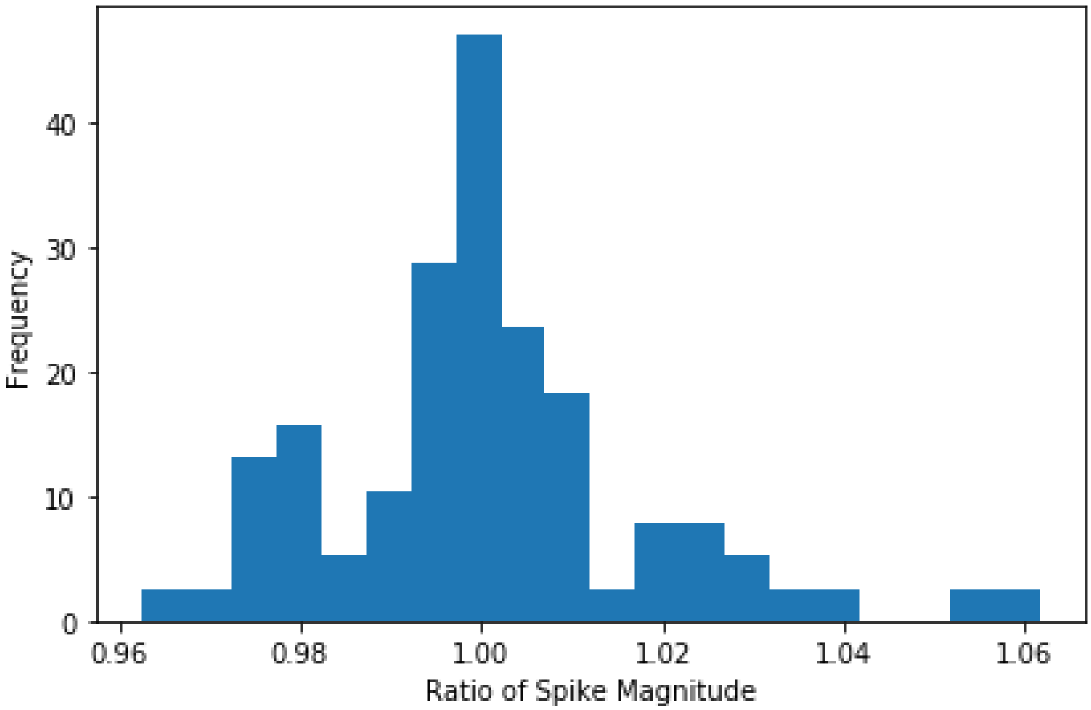
```
 =  0.0918854415274463
```

```
Out[295]: Text(20.875, 0.5, 'Frequency')
```



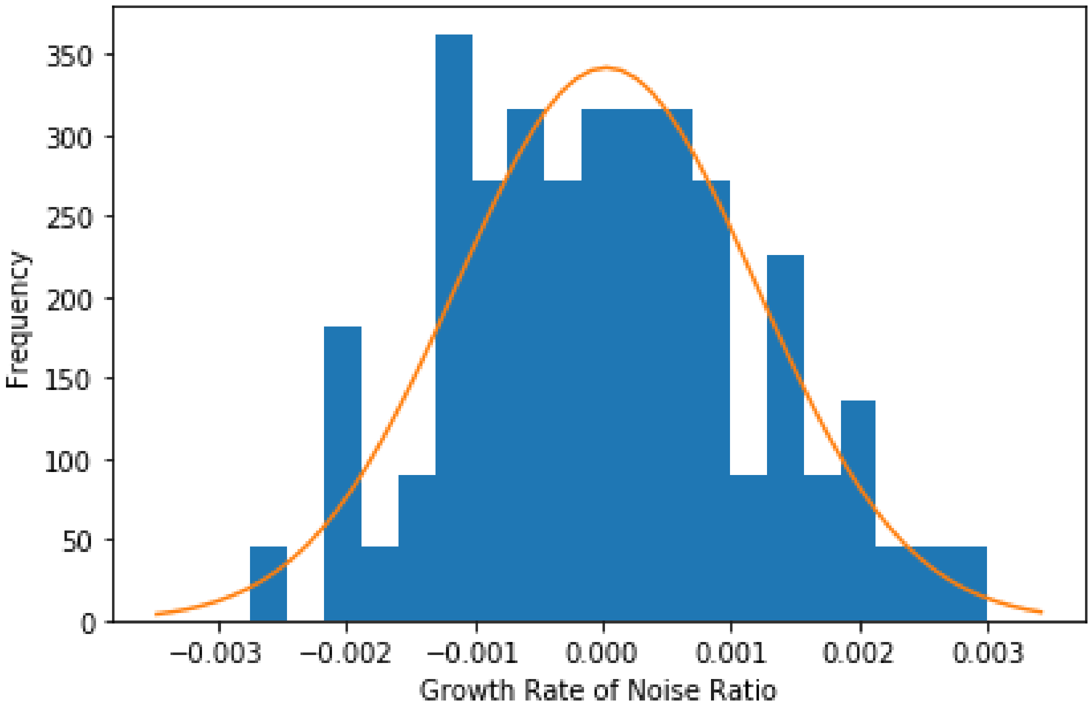
6.3.2 Spike Magnitudes

In [296]:
```
local_extrema = error_filtered[local_extremum_indices]
spike_magnitudes = local_extrema[1:]/local_extrema[:-1]
plt.hist(spike_magnitudes, bins=20, density=True)
plt.ylabel('Frequency')
plt.xlabel('Ratio of Spike Magnitude')
plt.tight_layout()
```




```
In [297]: growth = np.log(spike_magnitudes)/arrival_times
          mu_growth = np.mean(growth)
          var_growth = np.var(growth)
          std_growth = np.sqrt(var_growth)
          plt.hist(growth, bins=20, density=True)
          print('maximum growth rate: %s times standard deviation' % str(max(abs(growth))/std_g
          range_factor = 3
          x = np.arange(mu_growth - range_factor * std_growth, mu_growth +range_factor *std_gro
          plt.plot(x, norm.pdf(x, loc=mu_growth, scale=std_growth))
          plt.ylabel('Frequency')
          plt.xlabel('Growth Rate of Noise Ratio')
          plt.tight_layout()

          print(mu_growth, std_growth)
```

```
maximum growth rate: 2.567651500667173 times standard deviation
3.119052688325233e-05 0.0011669980060804665
```



7 Random Generator Class for Network Adoption

In [298]:
```
def update_mean_ema(mu_p, x_n, alpha):
    return alpha * x_n + (1-alpha) * mu_p

"""
class PoissonWithExponentialJumpSignalGenerator:
    def __init__(self, slope_log=0.000381195119289848, intercept_log=0.6134434756157
                 lambda_event=0.0919, mu_noise_log=3.12e-05, std_noise_log=0.001167,
                 max_noise_ratio_growth_rate = 2.57, rng_seed=None,
                 return_contraction_threshold = None, return_contraction_ema_alpha =
                 return_contraction_const = None
                ):
        self._rng = np.random.RandomState(seed=rng_seed)
        self._slope_log = slope_log
        self._intercept_log = intercept_log
        self._max_log_adoption = max_log_adoption
        self._start_noise_ratio = 1.0
        self._time_last_event = 0
        self._lambda_event = lambda_event
        self._time_next_event = int(np.random.exponential(scale = 1/self._lambda_eve
        self._direction = 1
        self._mu_noise_log = mu_noise_log
```

```
        self._std_noise_log = std_noise_log
        self._max_noise_ratio_growth_rate = max_noise_ratio_growth_rate
        self._noise_ratio_growth_rate = self._direction*abs(np.random.normal(loc=mu_
        self._average_log_adoption = None
        self._adoption = None
        self._return_ema = 0.0
        self._adoption = math.exp(intercept_log)
        if (return_contraction_threshold is not None) or (return_contraction_ema_alp
            assert return_contraction_threshold is not None, "missing value for retu
            assert return_contraction_ema_alpha is not None, "missing value for retu
            assert return_contraction_const is not None, "missing value for return_c
        self._return_contraction_threshold = return_contraction_threshold
        self._return_contraction_const = return_contraction_const
        self._return_contraction_ema_alpha = return_contraction_ema_alpha


    def _update_adoption(self):
        self._adoption = math.exp(self._noise_ratio * self._average_log_adoption)
        assert self._adoption >= 0, "adoption cannot be negative"

    def _update_average_adoption(self, time: float):
        x = self._slope_log * time + self._intercept_log
        self._average_log_adoption = min(x, self._max_log_adoption)

    def _update_noise_ratio(self, time: float):
        self._noise_ratio = self._start_noise_ratio*math.exp(self._noise_ratio_growt
        print('noise_ratio_growth_rate = %s' % str(self._noise_ratio_growth_rate))
        print('noise_ratio = %s' % str(self._noise_ratio))

    def _update_event(self, time: float):
#         print('time = %s and time_from_last = %s' % (str(time),str(time-self._time_
        if (time-self._time_last_event) >= self._time_next_event:
            t_tmp = self._time_next_event
            self._time_next_event = int(np.random.exponential(scale = 1/self._lambda_
            self._time_last_event = time
            self._direction *= -1
            self._start_noise_ratio = self._noise_ratio
            self._noise_ratio_growth_rate = self._direction*np.clip(abs(self._rng.no
                                                    scale=self._std_noise_log)), 0,
                                                    self._max_noise_ratio_growth_rat
        if self._return_contraction_threshold is not None:
            # contraction
            if self._return_ema > self._return_contraction_threshold:
                _delta = self._return_ema - self._return_contraction_threshold
                print(f"compressing at time {time}: delta = ", _delta)
                self._noise_ratio_growth_rate -=  self._return_contraction_const * _
                print("_noise_ratio_growth_rate = ", self._noise_ratio_growth_rate)
            # print("t_next = %s" % str(self._time_next_event))
```

```
            if self._return_ema < - self._return_contraction_threshold:
                _delta = self._return_ema + self._return_contraction_threshold
                print(f"compressing at time {time}: delta = ", _delta)
                self._noise_ratio_growth_rate += self._return_contraction_const * _d
                print("_noise_ratio_growth_rate = ", self._noise_ratio_growth_rate)
            # print("t_next = %s" % str(self._time_next_event))

    def update_adoption(self, time: float):
        prev_adoption = self._adoption
        print('average_adoption before = %s at t = %s '% (str(self._average_log_adop

        self._update_average_adoption(time)
        print('average_adoption after = %s' %str(self._average_log_adoption))

        self._update_noise_ratio(time)

        self._update_adoption()
        print('adoption = %s' %str(self._adoption))

        self._update_event(time)

        if self._return_contraction_ema_alpha is not None:
            _return = (self._adoption - prev_adoption) / prev_adoption
            self._return_ema = update_mean_ema(self._return_ema, _return, self._retu
        print("return: ", self._return_ema)

        return self

    def get_signal(self):
        return self._adoption

"""
class PoissonWithExponentialJumpSignalGenerator:
    def __init__(self, slope_log=0.000381195119289848, intercept_log=0.61344347561570
                 lambda_event=0.0919, mu_noise_log=3.12e-05, std_noise_log=0.001167,
                 max_noise_ratio_growth_rate = 2.57,
                 rng_seed=None,
                 return_contraction_threshold=None,
                 return_contraction_ema_alpha=None,
                 return_contraction_const=None
                 ):
        self._rng = np.random.RandomState(seed=rng_seed)
        self._slope_log = slope_log
        self._intercept_log = intercept_log
        self._max_log_adoption = max_log_adoption
        self._start_noise_ratio = 1.0
        self._time_last_event = 0
        self._lambda_event = lambda_event
```

```
        self._time_next_event = int(np.random.exponential(scale=1 / self._lambda_even
        self._direction = 1
        self._mu_noise_log = mu_noise_log
        self._std_noise_log = std_noise_log
        self._max_noise_ratio_growth_rate = max_noise_ratio_growth_rate
        self._noise_ratio_growth_rate = self._direction * abs(np.random.normal(loc=mu
        self._average_log_adoption = None
        self._adoption = math.exp(intercept_log)
        self._adoption_last = math.exp(intercept_log)

        self._return_ema = 0.0
        self._adoption = math.exp(intercept_log)
        if (return_contraction_threshold is not None) or (return_contraction_ema_alph
            assert return_contraction_threshold is not None,"missing value for return
            assert return_contraction_ema_alpha is not None,"missing value for return
            assert return_contraction_const is not None,"missing value for return_con
        self._return_contraction_threshold = return_contraction_threshold
        self._return_contraction_const = return_contraction_const
        self._return_contraction_ema_alpha = return_contraction_ema_alpha

    def _update_adoption(self):
        self._adoption = math.exp(self._noise_ratio * self._average_log_adoption)
        assert self._adoption >= 0, "adoption cannot be negative"

    def _update_log_baseline(self, step: float):
        x = self._slope_log * step + self._intercept_log
        self._average_log_adoption = min(x, self._max_log_adoption)

    def _apply_contraction(self):
        """
        Applies contractive force when exceeding limits, and provided limits are giv
        Force is proportional to squared distance from respective limit.
        """
        if self._return_contraction_threshold is not None:
            # contraction
            if self._return_ema > self._return_contraction_threshold:
                _delta = self._return_ema - self._return_contraction_threshold
                self._noise_ratio_growth_rate -= self._return_contraction_const * _de
                return
            if self._return_ema < - self._return_contraction_threshold:
                _delta = self._return_ema + self._return_contraction_threshold
                self._noise_ratio_growth_rate += self._return_contraction_const * _de

    def _update_noise_ratio(self, step: int):
        self._noise_ratio = self._start_noise_ratio * math.exp(self._noise_ratio_grow

    def _update_event(self, step: int):
        if (step - self._time_last_event) >= self._time_next_event:
```

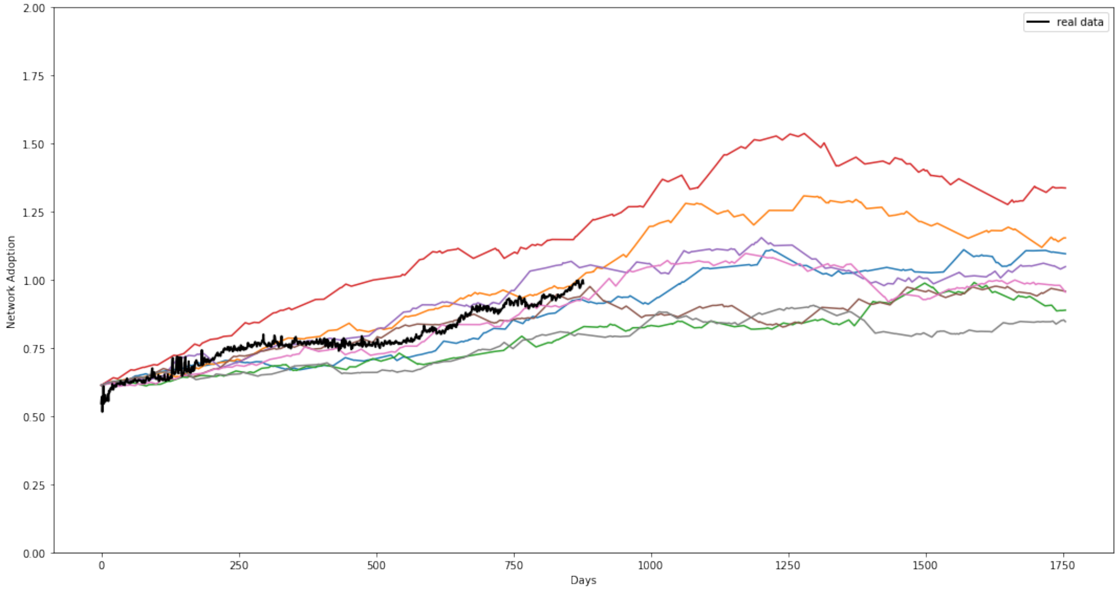
```
                self._time_next_event = int(np.random.exponential(scale=1 / self._lambda_
                # ToDo: predict noise ratio and don't let it drop beyond some point
                self._time_last_event = step
                self._direction *= -1
                self._start_noise_ratio = self._noise_ratio
                self._noise_ratio_growth_rate = self._direction * np.clip(abs(self._rng.r

                                                                          0, self._max_no

        def update_adoption(self, step: int):
            self._adoption_last = self._adoption
            self._update_log_baseline(step)
            self._apply_contraction()
            self._update_noise_ratio(step)
            self._update_adoption()
            self._update_event(step)
            #
            if self._return_contraction_ema_alpha is not None:
                _return = (self._adoption - self._adoption_last) / self._adoption_last
                self._return_ema = update_mean_ema(self._return_ema,_return,self._return_

            return self

        def get_signal(self):
            return self._adoption

        def get_signal_change(self):
            return self._adoption - self._adoption_last
```

```
In [299]: syn_data_x = np.arange(2*int(np.max(X.values)) + 1)

          N = 8
          syn_data_y = []
          for j in range(N):
              print(f"Starting run {j}\n======================")
              gen = PoissonWithExponentialJumpSignalGenerator(rng_seed=np.random.randint(low=0
              syn_data_y.append(np.array([gen.update_adoption(i).get_signal() for i in syn_data
              print("")

          print(syn_data_y)
```

```
Starting run 0
======================

Starting run 1
```

```
=======================

Starting run 2
=======================

Starting run 3
=======================

Starting run 4
=======================

Starting run 5
=======================

Starting run 6
=======================

Starting run 7
=======================

[array([1.8467798 , 1.84850746, 1.85023893, ..., 2.99374501, 2.99287749,
       2.99201044]), array([1.8467798 , 1.84860068, 1.85042585, ..., 3.17121058, 3.17118603,
       3.17116148]), array([1.8467798 , 1.84776882, 1.84875879, ..., 2.43159997, 2.43211768,
       2.43263563]), array([1.8467798 , 1.84905865, 1.85134445, ..., 3.81007662, 3.80958694,
       3.80909736]), array([1.8467798 , 1.84839694, 1.85001736, ..., 2.84831443, 2.85114538,
       2.85398183]), array([1.8467798 , 1.84797687, 1.84917553, ..., 2.60922634, 2.60817137,
       2.60711728]), array([1.8467798 , 1.8474975 , 1.8482155 , ..., 2.61247464, 2.60611051,
       2.59977799]), array([1.8467798 , 1.8480119 , 1.84924573, ..., 2.34179924, 2.33705063,
       2.33232294])]
```

```
In [300]: real_normalized_price = np.log(df_new[c].values)
          real_normalized_price /= max(real_normalized_price)

          plt.figure(figsize=(15,8));
          for _r, _y in enumerate(syn_data_y):
              plt.plot(syn_data_x, np.log(_y))
          plt.plot(X, real_normalized_price, label = 'real data', linewidth=2, color="black")
          # plt.plot(min[X], max[X])
          plt.xlabel('Days')
          plt.ylabel('Network Adoption')
          plt.legend()
          plt.ylim(0, 2)
          plt.tight_layout();
```



In [ ]:

7.1 Results

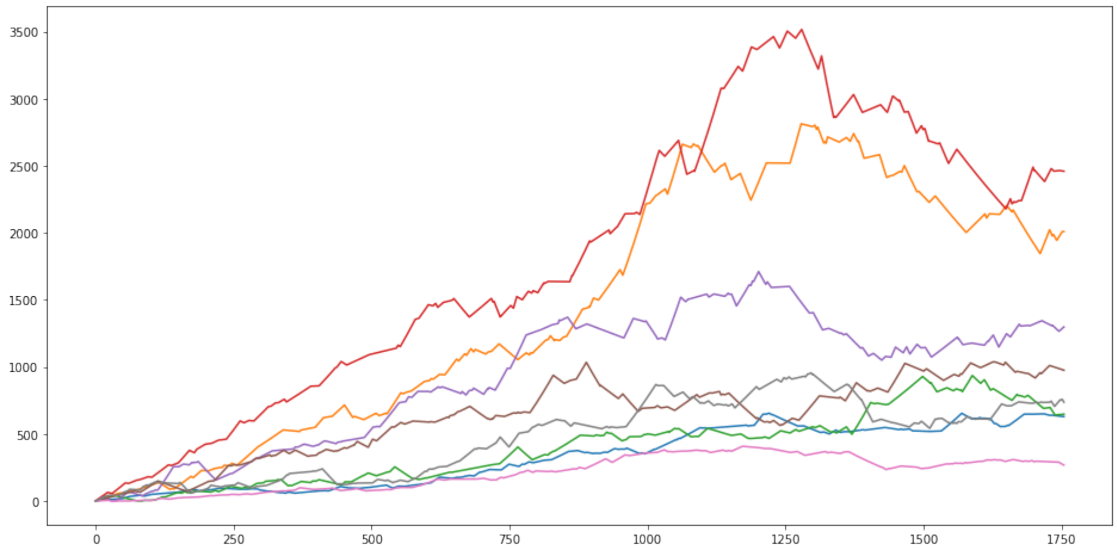
The following table show the paramaters of the random number generator class for both gas count and number of transactions:

Data	Slope	Intercept	λ	μ	σ	saturation limit
Gas count values	0.00024	0.770	0.10417	-4.83e-06	0.00115	3.1
N_transction values	0.00038	0.613	0.0919	3.12e-05	0.00117	2.6

8 Mapping to a desired interval

In [301]:
```
slope_log = 0.000381195119289848
intercept_log = 0.6134434756157009
max_log_adoption=1.0

current_initial = math.exp(intercept_log)
current_saturation = math.exp(max_log_adoption)
# Saturation time x = self._slope_log * time + self._intercept_log
desired_initial = 0.0
desired_saturation = 1000.0

# slopes
slope_mapping = (desired_saturation - desired_initial) / (current_saturation - curre
mapping = lambda x: np.maximum(0.0, np.random.normal(1.0, .3) *(slope_mapping * (x-cu
```

```
In [302]: plt.figure(figsize=(16,8));
          for _r, _y in enumerate(syn_data_y):
              plt.plot(syn_data_x, mapping(_y))
```



9 Network Adoption for Consumers (Early Adopters and Laggards)

behaviour type	time they join network	time to inflection	saturation budget as % of total	initial coins
Users	20% Early Adopters, t=1yrs	2yrs	13.5%	0, join later
Users	80% Laggards, t=6yrs	infinite	16%	0, join later

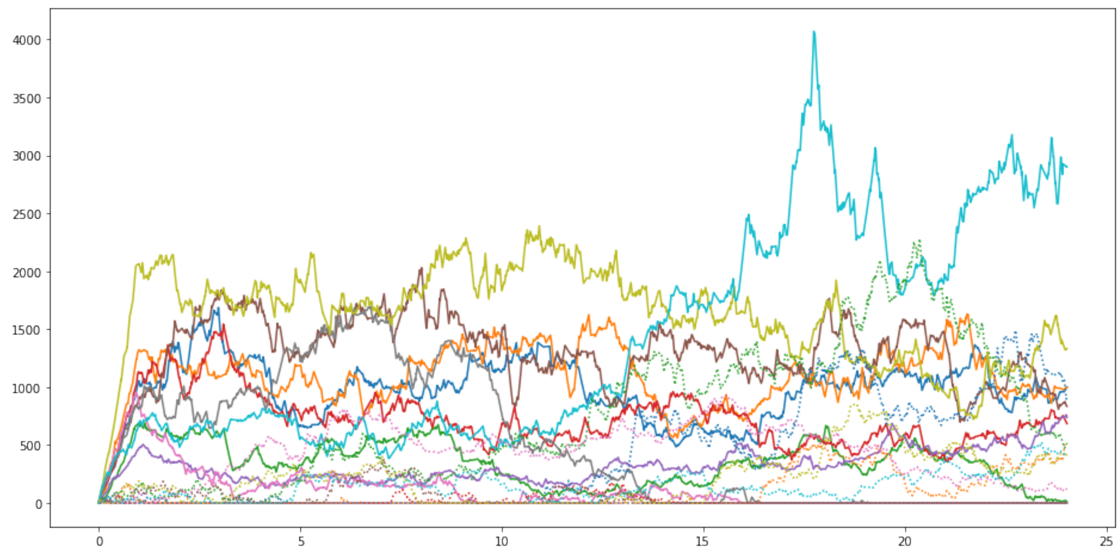
```
In [303]: intercept_log=0.6134434756157009
          max_log_adoption=1.0
          slope_log_early_adopters = (max_log_adoption - intercept_log)/((2-1)*365)  # (max_lo
          slope_log_laggards = (max_log_adoption - intercept_log)//((10-6)*365)
          syn_data_x = np.arange(10*int(np.max(X.values)) + 1)

          N = 10
          syn_data_y_early_adopters = []
          syn_data_y_laggards = []
          for j in range(N):
              print(f"Starting run {j}\n======================")
```

```
        gen_early_adopters = PoissonWithExponentialJumpSignalGenerator(slope_log=slope_lo
        gen_laggards = PoissonWithExponentialJumpSignalGenerator(slope_log=slope_log_lagg
        syn_data_y_early_adopters.append(np.array([gen_early_adopters.update_adoption(i)
        syn_data_y_laggards.append(np.array([gen_laggards.update_adoption(i).get_signal()

        print("")

    print(syn_data_y_laggards)
```

```
Starting run 0
=======================

Starting run 1
=======================

Starting run 2
=======================

Starting run 3
=======================

Starting run 4
=======================

Starting run 5
=======================

Starting run 6
=======================

Starting run 7
=======================

Starting run 8
=======================

Starting run 9
=======================

[array([1.8467798 , 1.84699887, 1.84603741, ..., 2.41452249, 2.41655744,
       2.41859606]), array([1.8467798 , 1.84787033, 1.84896255, ..., 2.22840441, 2.22882828,
       2.22925233]), array([1.8467798 , 1.84653506, 1.8462904 , ..., 2.23404135, 2.23720108,
       2.24037083]), array([1.8467798 , 1.84691132, 1.84704286, ..., 1.81522017, 1.81377548,
       1.81233387]), array([1.8467798 , 1.84689886, 1.84701793, ..., 1.72404049, 1.72526191,
       1.72648578]), array([1.8467798 , 1.84704986, 1.84732002, ..., 1.48974554, 1.49017178,
       1.49059844]), array([1.8467798 , 1.84856994, 1.85036464, ..., 2.01534893, 2.01618096,
       2.01701382]), array([1.8467798 , 1.84729784, 1.84781625, ..., 1.58288474, 1.5836617 ,
       1.58443986]), array([1.8467798 , 1.8493214 , 1.85187221, ..., 2.16761813, 2.17042969,
```

```
2.17038888]), array([1.8467798 , 1.84686891, 1.84695802, ..., 2.28246899, 2.28335752,
2.28424682])]
```

```
In [304]: plt.figure(figsize=(16,8));
          for _r, _y in enumerate(syn_data_y_early_adopters):
              plt.plot(syn_data_x/365, mapping(_y))
          for _r, _y in enumerate(syn_data_y_laggards):
              plt.plot(syn_data_x/365, mapping(_y), linestyle=':')

          # plt.ylim(0, 100)
```




```
In [ ]:
```