In [1]:

```
import datetime
import os
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
from datlib.FRED import *
from datlib.plots import *
import pandas_datareader.data as web

%matplotlib inline

# Import Statsmodels

from statsmodels.tsa.api import VAR
from statsmodels.tsa.stattools import adfuller
from statsmodels.tools.eval_measures import rmse, aic
```

```
In [2]: #FRED.py
        #. . .
        def bil_to_mil(series):
            return series* 10**3
        # . . .
        #fedProject.py
        # . . .
        data_codes  = {# Assets
                       "Balance Sheet: Total Assets ($ Mil)": "WALCL",
                       "Balance Sheet Securities, Prem-Disc, Repos, and Loans ($ Mil)": "
                       "Balance Sheet: Securities Held Outright ($ Mil)": "WSHOSHO",
                       ### breakdown of securities holdings ###
                       "Balance Sheet: U.S. Treasuries Held Outright ($ Mil)":"WSHOTSL",
                       "Balance Sheet: Federal Agency Debt Securities ($ Mil)" : "WSHOFAD
                       "Balance Sheet: Mortgage-Backed Securities ($ Mil)": "WSHOMCB",
                       # other forms of lending
                       "Balance Sheet: Repos ($ Mil)": "WORAL",
                       "Balance Sheet: Central Bank Liquidity Swaps ($ Mil)" : "SWPT",
                       "Balance Sheet: Direct Lending ($ Mil)" : "WLCFLL",
                       # unamortized value of securities held (due to changes in interest
                       "Balance Sheet: Unamortized Security Premiums ($ Mil)": "WUPSHO",
                       # Liabilities
                       "Balance Sheet: Total Liabilities ($ Mil)" : "WLTLECL",
                       "Balance Sheet: Federal Reserve Notes Outstanding ($ Mil)" : "WLFN
                       "Balance Sheet: Reverse Repos ($ Mil)": "WLRRAL",
                       ### Major share of deposits
                       "Balance Sheet: Deposits from Dep. Institutions ($ Mil)":"WLODLL",
                       "Balance Sheet: U.S. Treasury General Account ($ Mil)": "WDTGAL",
                       "Balance Sheet: Other Deposits ($ Mil)": "WOTHLB",
                       "Balance Sheet: All Deposits ($ Mil)": "WLDLCL",
                       # Capital
                       "Balance Sheet: Total Capital": "WCTCL",
                       # Interest Rates
                       "Unemployment Rate": "UNRATE",
                       "Nominal GDP ($ Bil)":"GDP",
                       "Real GDP ($ Bil)":"GDPC1",
                       "GDP Deflator":"GDPDEF",
                       "CPI":"CPIAUCSL",
                       "Core PCE":"PCEPILFE",
                       "Private Investment":"GPDI",
                       "Base: Total ($ Mil)": "BOGMBASE",
                       "Base: Currency in Circulation ($ Bil)": "WCURCIR",
                       "1 Month Treasury Rate (%)": "DGS1MO",
                       "3 Month Treasury Rate (%)": "DGS3MO",
                       "1 Year Treasury Rate (%)": "DGS1",
                       "2 Year Treasury Rate (%)": "DGS2",
                       "10 Year Treasury Rate (%)": "DGS10",
                       "30 Year Treasury Rate (%)": "DGS30",
                       "Effective Federal Funds Rate (%)": "DFF",
                       "Federal Funds Target Rate (Pre-crisis)":"DFEDTAR",
                       "Federal Funds Upper Target":"DFEDTARU",
                       "Federal Funds Lower Target":"DFEDTARL",
                       "Interest on Reserves (%)": "IOER",
                       "VIX": "VIXCLS",
                        "5 Year Forward Rate": "T5YIFR"
                       }
```

```python

inflation_target = 2

unemployment_target = 4
# Select start and end dates
start = datetime.datetime(2000, 1, 1)
end = datetime.datetime.today()

## year variable automatically adjusts the numper of periods
#   per year in light of data frequency
annual_div = {"Q":4,
              "W":52,
              "M":12}
### choose frequency
freq = "M"
### set periods per year
year = annual_div[freq]
```

In [3]:

```
#data cleaning, importing

d_parser = lambda x: pd.datetime.strptime(x, '%m/%d/%Y')
df = pd.read_csv('M4-3.csv', parse_dates=['Date'], date_parser=d_parser)
df
```

```
C:\Users\HP\AppData\Local\Temp/ipykernel_6988/1110085206.py:3: FutureWarning: T
he pandas.datetime class is deprecated and will be removed from pandas in a fut
ure version. Import from datetime module instead.
  d_parser = lambda x: pd.datetime.strptime(x, '%m/%d/%Y')
```

Out[3]:

	Date	M4	Log Total Assets	Effective Federal Funds Rate (%)	Log Currency in Circulation ($ Bil)	Unemployment Rate	Inflation Rate
0	2010-01-31	7.07	14.63	0.11	6.83	9.8	2.62
1	2010-02-28	7.06	14.63	0.13	6.83	9.8	2.15
2	2010-03-31	7.05	14.65	0.17	6.84	9.9	2.29
3	2010-04-30	7.06	14.66	0.20	6.84	9.9	2.21
4	2010-05-31	7.06	14.66	0.20	6.84	9.6	2.00
...	...	...	...	...	...	...	...
115	2019-08-31	7.40	15.14	2.13	7.47	3.7	1.74
116	2019-09-30	7.40	15.15	2.04	7.47	3.5	1.72
117	2019-10-31	7.41	15.19	1.83	7.48	3.6	1.77
118	2019-11-30	7.42	15.21	1.55	7.49	3.6	2.04
119	2019-12-31	7.42	15.23	1.55	7.49	3.6	2.26

120 rows × 7 columns

In [4]:

```
df['Date_at_year_month'] = df['Date'].dt.strftime('%Y-%m')
```

In [5]:

```
column_names = {'Date_at_year_month':'DATE',
                'M4':'M4',
                'Log Total Assets': 'TA',
                'Log Currency in Circulation ($ Bil)':'CC',
                'Effective Federal Funds Rate (%)':'FFR',
               'Unemployment Rate': 'U',
               'Inflation Rate': 'I'}

# rename columns
df = df.rename(columns = column_names)

df
```

Out[5]:

	Date	M4	TA	FFR	CC	U	I	DATE
0	2010-01-31	7.07	14.63	0.11	6.83	9.8	2.62	2010-01
1	2010-02-28	7.06	14.63	0.13	6.83	9.8	2.15	2010-02
2	2010-03-31	7.05	14.65	0.17	6.84	9.9	2.29	2010-03
3	2010-04-30	7.06	14.66	0.20	6.84	9.9	2.21	2010-04
4	2010-05-31	7.06	14.66	0.20	6.84	9.6	2.00	2010-05
...	...	...	...	...	...	...	...	...
115	2019-08-31	7.40	15.14	2.13	7.47	3.7	1.74	2019-08
116	2019-09-30	7.40	15.15	2.04	7.47	3.5	1.72	2019-09
117	2019-10-31	7.41	15.19	1.83	7.48	3.6	1.77	2019-10
118	2019-11-30	7.42	15.21	1.55	7.49	3.6	2.04	2019-11
119	2019-12-31	7.42	15.23	1.55	7.49	3.6	2.26	2019-12

120 rows × 8 columns

In [6]:
```
df = df.set_index('DATE')
df
```

Out[6]:

	Date	M4	TA	FFR	CC	U	I
DATE							
2010-01	2010-01-31	7.07	14.63	0.11	6.83	9.8	2.62
2010-02	2010-02-28	7.06	14.63	0.13	6.83	9.8	2.15
2010-03	2010-03-31	7.05	14.65	0.17	6.84	9.9	2.29
2010-04	2010-04-30	7.06	14.66	0.20	6.84	9.9	2.21
2010-05	2010-05-31	7.06	14.66	0.20	6.84	9.6	2.00
...	...	...	...	...	...	...	...
2019-08	2019-08-31	7.40	15.14	2.13	7.47	3.7	1.74
2019-09	2019-09-30	7.40	15.15	2.04	7.47	3.5	1.72
2019-10	2019-10-31	7.41	15.19	1.83	7.48	3.6	1.77
2019-11	2019-11-30	7.42	15.21	1.55	7.49	3.6	2.04
2019-12	2019-12-31	7.42	15.23	1.55	7.49	3.6	2.26

120 rows × 7 columns

In [7]:
```
df = df.drop(['Date'], axis = 1)
df
```

Out[7]:

	M4	TA	FFR	CC	U	I
DATE						
2010-01	7.07	14.63	0.11	6.83	9.8	2.62
2010-02	7.06	14.63	0.13	6.83	9.8	2.15
2010-03	7.05	14.65	0.17	6.84	9.9	2.29
2010-04	7.06	14.66	0.20	6.84	9.9	2.21
2010-05	7.06	14.66	0.20	6.84	9.6	2.00
...	...	...	...	...	...	...
2019-08	7.40	15.14	2.13	7.47	3.7	1.74
2019-09	7.40	15.15	2.04	7.47	3.5	1.72
2019-10	7.41	15.19	1.83	7.48	3.6	1.77
2019-11	7.42	15.21	1.55	7.49	3.6	2.04
2019-12	7.42	15.23	1.55	7.49	3.6	2.26

120 rows × 6 columns

In [8]:

```
data = df
data
```

Out[8]:

	M4	TA	FFR	CC	U	I
DATE						
2010-01	7.07	14.63	0.11	6.83	9.8	2.62
2010-02	7.06	14.63	0.13	6.83	9.8	2.15
2010-03	7.05	14.65	0.17	6.84	9.9	2.29
2010-04	7.06	14.66	0.20	6.84	9.9	2.21
2010-05	7.06	14.66	0.20	6.84	9.6	2.00
...	...	...	...	...	...	...
2019-08	7.40	15.14	2.13	7.47	3.7	1.74
2019-09	7.40	15.15	2.04	7.47	3.5	1.72
2019-10	7.41	15.19	1.83	7.48	3.6	1.77
2019-11	7.42	15.21	1.55	7.49	3.6	2.04
2019-12	7.42	15.23	1.55	7.49	3.6	2.26

120 rows × 6 columns

In [9]:

```
data.isnull().sum()
```

Out[9]:

```
M4     0
TA     0
FFR    0
CC     0
U      0
I      0
dtype: int64
```

In [10]:

```
## 1st diff
data_diff = data.diff().dropna()
data_diff
```

Out[10]:

	M4	TA	FFR	CC	U	I
DATE						
2010-02	-0.01	0.00	0.02	0.00	0.0	-0.47
2010-03	-0.01	0.02	0.04	0.01	0.1	0.14
2010-04	0.01	0.01	0.03	0.00	0.0	-0.08
2010-05	0.00	0.00	0.00	0.00	-0.3	-0.21
2010-06	-0.01	0.01	-0.02	0.01	-0.2	-0.88
...	...	...	...	...	...	...
2019-08	0.01	-0.01	-0.27	0.00	0.1	-0.08
2019-09	0.00	0.01	-0.09	0.00	-0.2	-0.02
2019-10	0.01	0.04	-0.21	0.01	0.1	0.05
2019-11	0.01	0.02	-0.28	0.01	0.0	0.27
2019-12	0.00	0.02	0.00	0.00	0.0	0.22

119 rows × 6 columns

In [11]:

```
#ADF test

X = data_diff["M4"].values
result = adfuller(X)
print('ADF Statistic: %f' % result[0])
print('p-value: %f' % result[1])
print('Critical Values:')
for key, value in result[4].items():
    print('\t%s: %.3f' % (key, value))

if result[0] < result[4]["5%"]:
    print ("Reject Ho - Time Series is Stationary")
else:
    print ("Failed to Reject Ho - Time Series is Non-Stationary")


X = data_diff["FFR"].values
result = adfuller(X)
print('ADF Statistic: %f' % result[0])
print('p-value: %f' % result[1])
print('Critical Values:')
for key, value in result[4].items():
    print('\t%s: %.3f' % (key, value))

if result[0] < result[4]["5%"]:
    print ("Reject Ho - Time Series is Stationary")
else:
    print ("Failed to Reject Ho - Time Series is Non-Stationary")


X = data_diff["TA"].values
result = adfuller(X)
print('ADF Statistic: %f' % result[0])
print('p-value: %f' % result[1])
print('Critical Values:')
for key, value in result[4].items():
    print('\t%s: %.3f' % (key, value))

if result[0] < result[4]["5%"]:
    print ("Reject Ho - Time Series is Stationary")
else:
    print ("Failed to Reject Ho - Time Series is Non-Stationary")


X = data_diff["CC"].values
result = adfuller(X)
print('ADF Statistic: %f' % result[0])
print('p-value: %f' % result[1])
print('Critical Values:')
for key, value in result[4].items():
    print('\t%s: %.3f' % (key, value))

if result[0] < result[4]["5%"]:
    print ("Reject Ho - Time Series is Stationary")
else:
    print ("Failed to Reject Ho - Time Series is Non-Stationary")
```

```
X = data_diff["U"].values
result = adfuller(X)
print('ADF Statistic: %f' % result[0])
print('p-value: %f' % result[1])
print('Critical Values:')
for key, value in result[4].items():
    print('\t%s: %.3f' % (key, value))

if result[0] < result[4]["5%"]:
    print ("Reject Ho - Time Series is Stationary")
else:
    print ("Failed to Reject Ho - Time Series is Non-Stationary")

X = data_diff["I"].values
result = adfuller(X)
print('ADF Statistic: %f' % result[0])
print('p-value: %f' % result[1])
print('Critical Values:')
for key, value in result[4].items():
    print('\t%s: %.3f' % (key, value))

if result[0] < result[4]["5%"]:
    print ("Reject Ho - Time Series is Stationary")
else:
    print ("Failed to Reject Ho - Time Series is Non-Stationary")
```

```
ADF Statistic: -15.211102
p-value: 0.000000
Critical Values:
        1%: -3.487
        5%: -2.886
        10%: -2.580
Reject Ho - Time Series is Stationary
ADF Statistic: -1.657520
p-value: 0.453122
Critical Values:
        1%: -3.492
        5%: -2.889
        10%: -2.581
Failed to Reject Ho - Time Series is Non-Stationary
ADF Statistic: -2.732047
p-value: 0.068655
Critical Values:
        1%: -3.490
        5%: -2.888
        10%: -2.581
Failed to Reject Ho - Time Series is Non-Stationary
ADF Statistic: -5.133268
p-value: 0.000012
Critical Values:
        1%: -3.490
        5%: -2.888
        10%: -2.581
Reject Ho - Time Series is Stationary
ADF Statistic: -1.758765
p-value: 0.401117
```

```
Critical Values:
	1%: -3.492
	5%: -2.889
	10%: -2.581
Failed to Reject Ho - Time Series is Non-Stationary
ADF Statistic: -4.729846
p-value: 0.000074
Critical Values:
	1%: -3.493
	5%: -2.889
	10%: -2.581
Reject Ho - Time Series is Stationary
```

In [12]:

```
##2nd diff
data_new = data_diff.diff().dropna()
data_new
```

Out[12]:

	M4	TA	FFR	CC	U	I
DATE						
2010-03	8.881784e-16	2.000000e-02	0.02	1.000000e-02	0.1	0.61
2010-04	2.000000e-02	-1.000000e-02	-0.01	-1.000000e-02	-0.1	-0.22
2010-05	-1.000000e-02	-1.000000e-02	-0.03	0.000000e+00	-0.3	-0.13
2010-06	-1.000000e-02	1.000000e-02	-0.02	1.000000e-02	0.1	-0.67
2010-07	2.000000e-02	-2.000000e-02	0.02	-1.000000e-02	0.2	1.10
...	...	...	...	...	...	...
2019-08	1.000000e-02	0.000000e+00	-0.29	-1.000000e-02	0.1	-0.20
2019-09	-1.000000e-02	2.000000e-02	0.18	0.000000e+00	-0.3	0.06
2019-10	1.000000e-02	3.000000e-02	-0.12	1.000000e-02	0.3	0.07
2019-11	0.000000e+00	-2.000000e-02	-0.07	-8.881784e-16	-0.1	0.22
2019-12	-1.000000e-02	-1.776357e-15	0.28	-1.000000e-02	0.0	-0.05

118 rows × 6 columns

In [13]:

```
#ADF test

X = data_new["M4"].values
result = adfuller(X)
print('ADF Statistic: %f' % result[0])
print('p-value: %f' % result[1])
print('Critical Values:')
for key, value in result[4].items():
    print('\t%s: %.3f' % (key, value))

if result[0] < result[4]["5%"]:
    print ("Reject Ho - Time Series is Stationary")
else:
    print ("Failed to Reject Ho - Time Series is Non-Stationary")


X = data_new["FFR"].values
result = adfuller(X)
print('ADF Statistic: %f' % result[0])
print('p-value: %f' % result[1])
print('Critical Values:')
for key, value in result[4].items():
    print('\t%s: %.3f' % (key, value))

if result[0] < result[4]["5%"]:
    print ("Reject Ho - Time Series is Stationary")
else:
    print ("Failed to Reject Ho - Time Series is Non-Stationary")


X = data_new["TA"].values
result = adfuller(X)
print('ADF Statistic: %f' % result[0])
print('p-value: %f' % result[1])
print('Critical Values:')
for key, value in result[4].items():
    print('\t%s: %.3f' % (key, value))

if result[0] < result[4]["5%"]:
    print ("Reject Ho - Time Series is Stationary")
else:
    print ("Failed to Reject Ho - Time Series is Non-Stationary")


X = data_new["CC"].values
result = adfuller(X)
print('ADF Statistic: %f' % result[0])
print('p-value: %f' % result[1])
print('Critical Values:')
for key, value in result[4].items():
    print('\t%s: %.3f' % (key, value))

if result[0] < result[4]["5%"]:
    print ("Reject Ho - Time Series is Stationary")
else:
    print ("Failed to Reject Ho - Time Series is Non-Stationary")
```

```
X = data_new["U"].values
result = adfuller(X)
print('ADF Statistic: %f' % result[0])
print('p-value: %f' % result[1])
print('Critical Values:')
for key, value in result[4].items():
    print('\t%s: %.3f' % (key, value))

if result[0] < result[4]["5%"]:
    print ("Reject Ho - Time Series is Stationary")
else:
    print ("Failed to Reject Ho - Time Series is Non-Stationary")

X = data_new["I"].values
result = adfuller(X)
print('ADF Statistic: %f' % result[0])
print('p-value: %f' % result[1])
print('Critical Values:')
for key, value in result[4].items():
    print('\t%s: %.3f' % (key, value))

if result[0] < result[4]["5%"]:
    print ("Reject Ho - Time Series is Stationary")
else:
    print ("Failed to Reject Ho - Time Series is Non-Stationary")
```

```
ADF Statistic: -8.381034
p-value: 0.000000
Critical Values:
        1%: -3.491
        5%: -2.888
        10%: -2.581
Reject Ho - Time Series is Stationary
ADF Statistic: -3.943879
p-value: 0.001735
Critical Values:
        1%: -3.492
        5%: -2.889
        10%: -2.581
Reject Ho - Time Series is Stationary
ADF Statistic: -6.016185
p-value: 0.000000
Critical Values:
        1%: -3.490
        5%: -2.887
        10%: -2.581
Reject Ho - Time Series is Stationary
ADF Statistic: -6.497273
p-value: 0.000000
Critical Values:
        1%: -3.494
        5%: -2.889
        10%: -2.582
Reject Ho - Time Series is Stationary
ADF Statistic: -7.922465
p-value: 0.000000
```

```
Critical Values:
        1%: -3.492
        5%: -2.889
        10%: -2.581
Reject Ho - Time Series is Stationary
ADF Statistic: -4.617794
p-value: 0.000120
Critical Values:
        1%: -3.494
        5%: -2.889
        10%: -2.582
Reject Ho - Time Series is Stationary
```

In [14]:

```
## Partial Correlation

import statsmodels.api as sm

residuals = {}
for y_var in df.keys():
    X_vars = list(df.keys())
    X_vars.remove(y_var)
    X = df[X_vars]
    # Initial estimate should include constant
    #   This won't be the case we regress the errors
    X["Constant"] = 1
    # pass y_var as list for consistent structure
    y = df[[y_var]]
    model = sm.OLS(y, X)
    results = model.fit()
    residuals[y_var] = results.resid
residuals = pd.DataFrame(residuals)
residuals
```

Out[14]:

	M4	TA	FFR	CC	U	I
DATE						
2010-01	0.028805	0.021011	-0.095218	-0.038911	-0.233974	0.653826
2010-02	0.018289	0.009285	0.007696	-0.028268	-0.192946	0.135538
2010-03	0.004676	0.015828	0.135208	-0.007922	0.005185	-0.110117
2010-04	0.015403	0.050207	0.159963	-0.017603	0.046161	-0.217561
2010-05	0.014376	0.012834	0.119665	-0.028901	-0.233021	0.029664
...	...	...	...	...	...	...
2019-08	0.006053	-0.037344	-0.165353	0.005289	0.070490	-0.423017
2019-09	0.007440	-0.065067	-0.264839	-0.003043	-0.119374	-0.078433
2019-10	0.018458	-0.029945	-0.404117	-0.000360	0.110977	-0.168943
2019-11	0.027866	-0.039496	-0.709277	-0.000349	0.168700	0.235383
2019-12	0.030180	-0.022017	-0.672719	-0.003016	0.188046	0.400705

120 rows × 6 columns

In [15]:
```
residuals.corr()[residuals.corr().abs() < 1].mul(-1).fillna(1).round(2)
```

Out[15]:

	M4	TA	FFR	CC	U	I
M4	1.00	-0.46	0.20	0.72	-0.05	-0.04
TA	-0.46	1.00	-0.60	0.31	-0.52	0.18
FFR	0.20	-0.60	1.00	0.10	-0.17	0.30
CC	0.72	0.31	0.10	1.00	-0.55	0.21
U	-0.05	-0.52	-0.17	-0.55	1.00	0.39
I	-0.04	0.18	0.30	0.21	0.39	1.00

In [16]:
```
# !pip install pingouin
import pingouin
df.pcorr().round(2)
```

Out[16]:

	M4	TA	FFR	CC	U	I
M4	1.00	-0.46	0.20	0.72	-0.05	-0.04
TA	-0.46	1.00	-0.60	0.31	-0.52	0.18
FFR	0.20	-0.60	1.00	0.10	-0.17	0.30
CC	0.72	0.31	0.10	1.00	-0.55	0.21
U	-0.05	-0.52	-0.17	-0.55	1.00	0.39
I	-0.04	0.18	0.30	0.21	0.39	1.00

In [17]:
```
from datlib.plots import *
corr_matrix_heatmap(df.corr(),
                    save_fig = False,
                    pp = None)
corr_matrix_heatmap(df.pcorr(), save_fig = False, pp = None)
```

In [18]:

```
pcorr_pvalues = {}
for y, Y in residuals.items():
    pcorr_pvalues[y] = {}
    for x, X in residuals.items():
        if x != y:
            pcorr_pvalues[y][x] = sm.OLS(Y,X).fit().pvalues[x]

        else:
            pcorr_pvalues[y][x] = np.NaN
pd.DataFrame(pcorr_pvalues).round(2)
```

Out[18]:

	M4	TA	FFR	CC	U	I
M4	NaN	0.00	0.03	0.00	0.59	0.63
TA	0.00	NaN	0.00	0.00	0.00	0.05
FFR	0.03	0.00	NaN	0.26	0.07	0.00
CC	0.00	0.00	0.26	NaN	0.00	0.02
U	0.59	0.00	0.07	0.00	NaN	0.00
I	0.63	0.05	0.00	0.02	0.00	NaN

In [19]:

```
##DAG

import pingouin
from pgmpy.estimators import PC
import matplotlib.pyplot as plt
from matplotlib.patches import ArrowStyle
from networkx.drawing.nx_agraph import graphviz_layout
import warnings
warnings.filterwarnings("ignore")
from matplotlib.backends.backend_pdf import PdfPages
import networkx as nx
```

In [20]:

```
## Estimating a Directed Acyclic Graph
p_val = .01
from pgmpy.estimators import PC
c = PC(df)
max_cond_vars = len(df.keys())-2


model = c.estimate(return_type = "dag",variant= "parallel",#"orig", "stable"
                   significance_level = p_val,
                   max_cond_vars = max_cond_vars, ci_test = "pearsonr")
edges = model.edges()
```

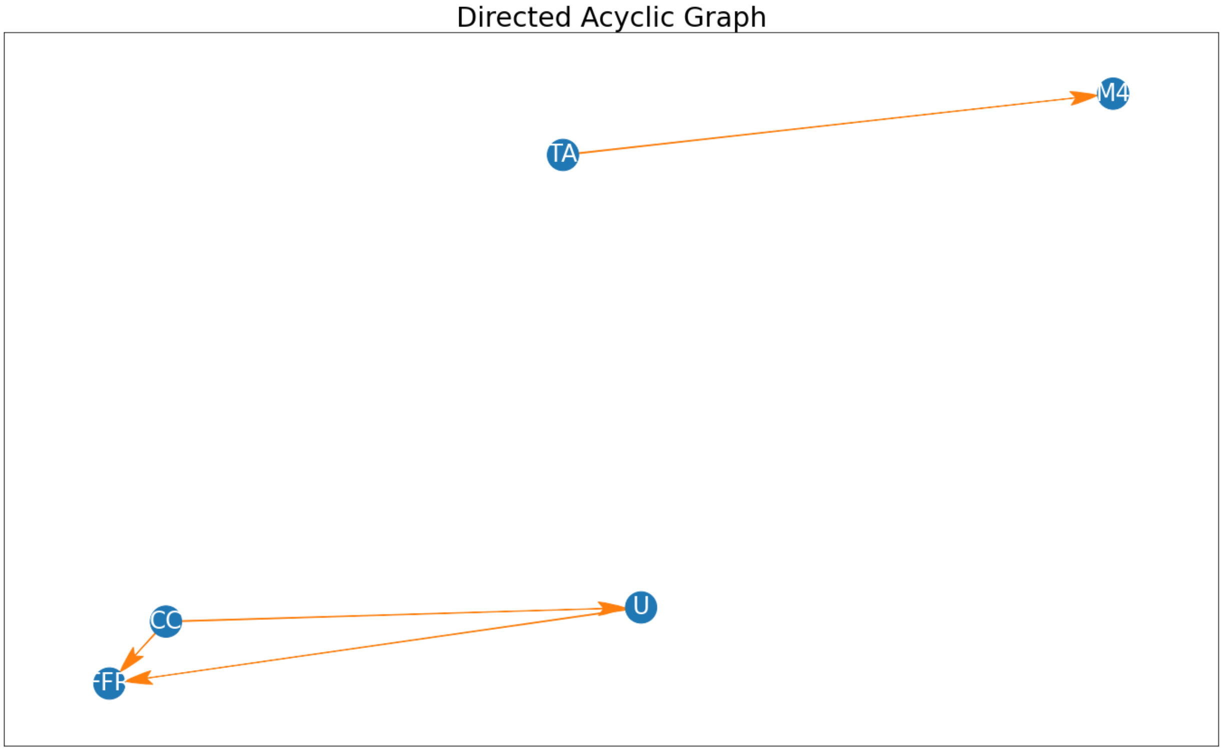
```
  0%|          | 0/4 [00:00<?, ?it/s]
```

In [21]:

```
from matplotlib.patches import ArrowStyle

def graph_DAG(edges, df, title = ""):
    graph = nx.DiGraph()
    graph.add_edges_from(edges)
    color_map = ["C0" for g in graph]

    fig, ax = plt.subplots(figsize = (20,12))
    graph.nodes()
    plt.tight_layout()
    pos = nx.spring_layout(graph)#, k = 5/(len(sig_corr.keys())**.5))

    plt.title(title, fontsize = 30)
    nx.draw_networkx(graph, pos, node_color=color_map, node_size = 1200,
                     with_labels=True,  arrows=True,
                     font_color = "white",
                     font_size = 26, alpha = 1,
                     width = 1, edge_color = "C1",
                     arrowstyle=ArrowStyle("Fancy, head_length=3, head_width=1.5,

graph_DAG(edges, df, title = "Directed Acyclic Graph")
edges
```

Out[21]:

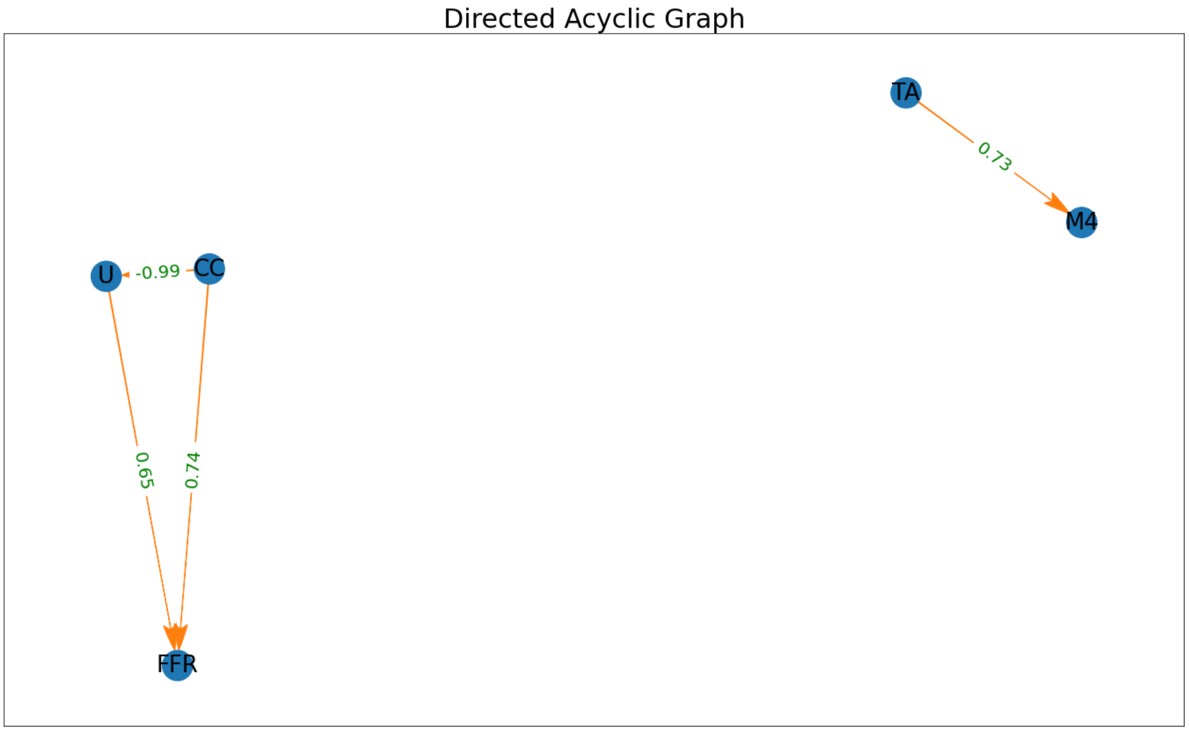
```
OutEdgeView([('TA', 'M4'), ('U', 'FFR'), ('CC', 'FFR'), ('CC', 'U')])
```



In [22]:

```
## D-separation

def graph_DAG(edges, df, title = ""):
    graph = nx.DiGraph()
    edge_labels = {}
    ############ Add ############
    for edge in edges:
        controls = [key for key in df.keys() if key not in edge]
        controls = list(set(controls))
        keep_controls = []
        for control in controls:
            control_edges = [ctrl_edge for ctrl_edge in edges if control == ctrl_
            if (control, edge[1]) in control_edges:
                print("keep control:", control)
                keep_controls.append(control)
        print(edge, keep_controls)
        pcorr = df[[edge[0], edge[1]]+keep_controls].pcorr()
#         corr_matrix_heatmap(pcorr, save_fig = False, pp = None, title = "Parti
        edge_labels[edge] = str(round(pcorr[edge[0]].loc[edge[1]],2))
    graph.add_edges_from(edges)
    color_map = ["C0" for g in graph]

    fig, ax = plt.subplots(figsize = (20,12))
    graph.nodes()
    plt.tight_layout()
    pos = nx.spring_layout(graph)#, k = 5/(len(sig_corr.keys())**.5))

    plt.title(title, fontsize = 30)
    nx.draw_networkx(graph, pos, node_color=color_map, node_size = 1200,
                     with_labels=True,  arrows=True,
                     # turn text black for larger variable names in homework
                     font_color = "k",
                     font_size = 26, alpha = 1,
                     width = 1, edge_color = "C1",
                     arrowstyle=ArrowStyle("Fancy, head_length=3, head_width=1.5,
    ############ Add ############
    nx.draw_networkx_edge_labels(graph,pos,
                                edge_labels=edge_labels,
                                font_color='green',
                                font_size=20)

graph_DAG(edges, df, title = "Directed Acyclic Graph")
```

```
('TA', 'M4') []
keep control: CC
('U', 'FFR') ['CC']
keep control: U
('CC', 'FFR') ['U']
('CC', 'U') []
```



In [23]:

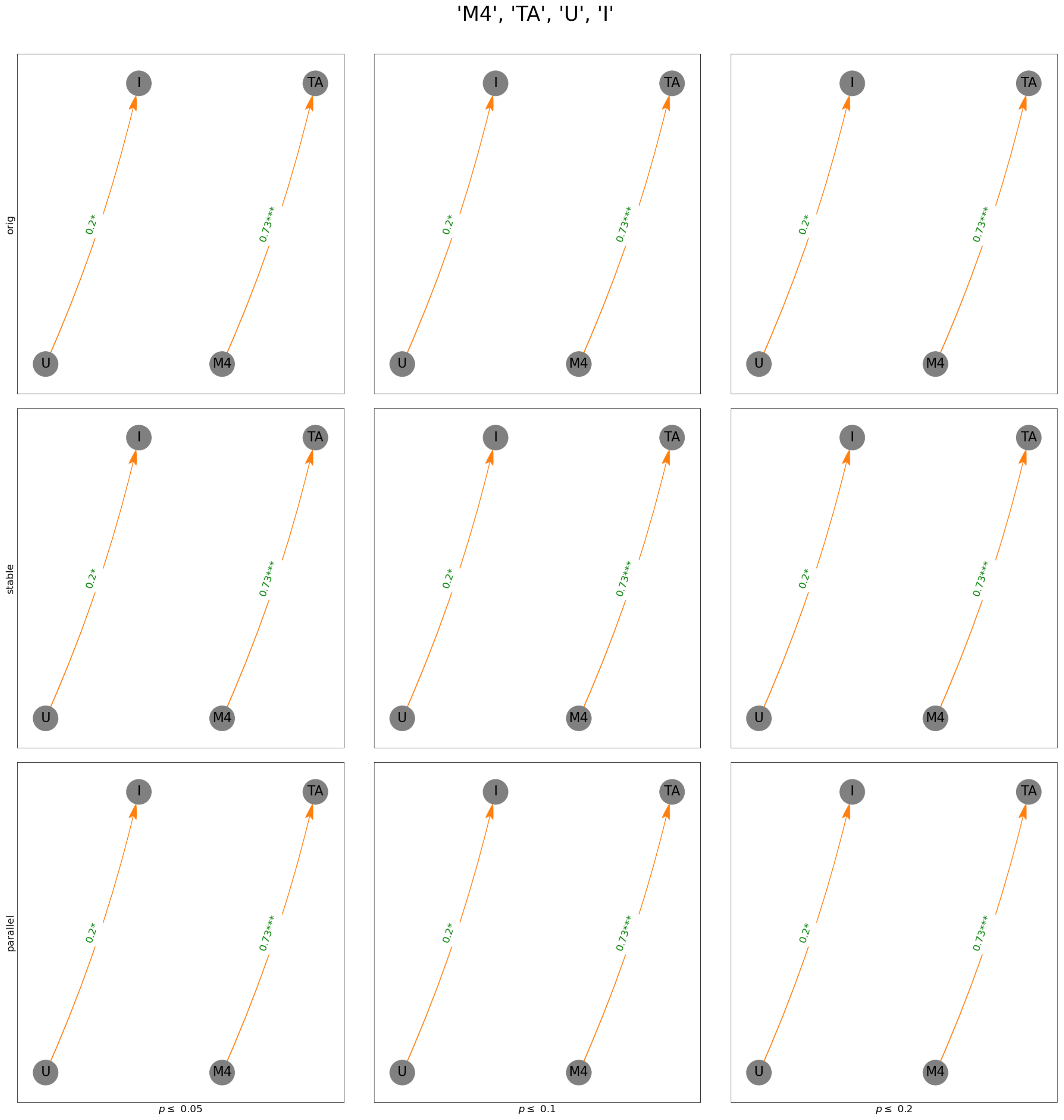
```python
data = df
def firstLetterWord(str, num_chars = 3):

    result = ""

    # Traverse the string.
    v = True
    for i in range(len(str)):

        # If it is space, set v as true.
        if (str[i] == ' '):
            v = True

        # Else check if v is true or not.
        # If true, copy character in output
        # string and set v as false.
        elif (str[i] != ' ' and v == True):
            result += (str[i:i+num_chars])
            v = False

    return result
```

In [26]:

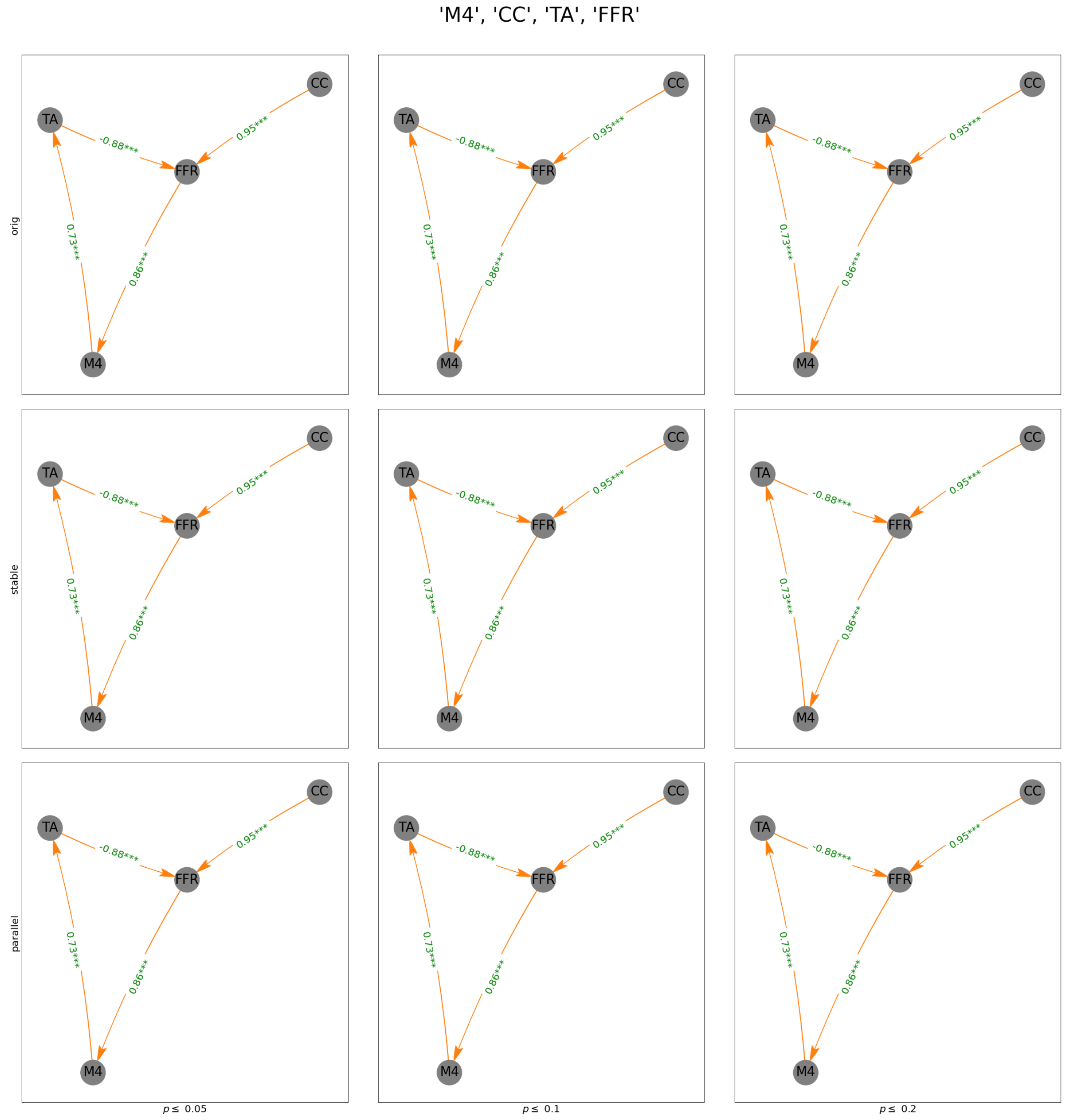
```
def graph_DAG(edges, data_reg, title = "",
              fig = False, ax = False,
              edge_labels = False,sig_vals = [0.05, 0.01, 0.001]):
    pcorr = data_reg.pcorr()
    graph = nx.DiGraph()
    def build_edge_labels(edges, df, sig_vals):
        edge_labels = {}
        for edge in edges:
            controls = [key for key in df.keys() if key not in edge]
            controls = list(set(controls))
            keep_controls = []
            for control in controls:
                control_edges = [ctrl_edge for ctrl_edge in edges if control == c
                if (control, edge[1]) in control_edges:
                    keep_controls.append(control)
#             print(edge, keep_controls)
            pcorr = df.partial_corr(x = edge[0], y = edge[1], covar=keep_controls
                                  method = "pearson")
            label = str(round(pcorr["r"][0],2))
            pvalue = pcorr["p-val"][0]
#             pcorr = df[[edge[0], edge[1]]+keep_controls].pcorr()
#             label = pcorr[edge[0]].loc[edge[1]]

            for sig_val in sig_vals:
                if pvalue < sig_val:
                    label = label + "*"

            edge_labels[edge] = label
        return edge_labels

    if edge_labels == False:
        edge_labels = build_edge_labels(edges,
                                        data_reg,
                                        sig_vals=sig_vals)
    graph.add_edges_from(edges)
    color_map = ["grey" for g in graph]

    if fig == False and ax == False: fig, ax = plt.subplots(figsize = (20,12))
    graph.nodes()
    plt.tight_layout()
    #pos = nx.spring_layout(graph)
    pos = graphviz_layout(graph)

    edge_labels2 = []
    for u, v, d in graph.edges(data=True):
        if pos[u][0] > pos[v][0]:
            if (v,u) in edge_labels.keys():
                edge_labels2.append(((u, v,), f'{edge_labels[u,v]}\n\n\n{edge_lab
        if (v,u) not in edge_labels.keys():
            edge_labels2.append(((u,v,), f'{edge_labels[(u,v)]}'))
    edge_labels = dict(edge_labels2)

    nx.draw_networkx(graph, pos, node_color=color_map, node_size = 2500,
                     with_labels=True,  arrows=True,
                     font_color = "black",
                     font_size = 26, alpha = 1,
                     width = 1, edge_color = "C1",
                     arrowstyle=ArrowStyle("Fancy, head_length=3, head_width=1.5,
                     connectionstyle='arc3, rad = 0.05',
                     ax = a)
    nx.draw_networkx_edge_labels(graph,pos,
                                 edge_labels=edge_labels,
                                 font_color='green',
                                 font_size=20,
                                ax = a)



DAG_models_vars = {0:["M4", "TA", "U","I"],
                  1:["M4", "CC", "TA","FFR"],
                  2:["M4", "FFR", "TA", "CC", "U"],
                  3:["TA", "U", "FFR", "M4"],
                  4:["TA", "U","I", "FFR", "CC"],
                  5:["TA", "U", "FFR", "CC","M4", "I"],}
# link_sigs = [0.05, 0.1, 0.2]
link_sigs = [0.05, .1, .2]
algorithms = ["orig", "stable", "parallel"]
for keys in DAG_models_vars.values():
    fig, ax = plt.subplots(len(algorithms), len(link_sigs), figsize = (30,30))
    max_cond_vars = len(keys) - 2
    data_reg = data[keys].dropna()
    data_reg.rename(columns = {col:firstLetterWord(col) for col in keys}, inplace
    keys = data_reg.keys()
    c = PC(data_reg[keys].dropna())
    max_cond_vars = len(keys) - 2
    i,j = 0,0
    for sig in link_sigs:
        for algorithm in algorithms:
            model = c.estimate(return_type = "pdag", variant = algorithm,
                               significance_level = sig,
                               max_cond_vars = max_cond_vars, ci_test = "pearsonr
            edges = model.edges()
            pcorr = data_reg.pcorr()
            weights = {}
            a = ax[i][j]
            graph_DAG(edges, data_reg, fig = fig, ax = a)

            if j == 0:
                a.set_ylabel(algorithm, fontsize = 20)
            if i == len(algorithms) - 1:
                a.set_xlabel("$p \leq$ "+ str(sig), fontsize = 20)
            i += 1
        j += 1
        i = 0
    plt.suptitle(str(list(keys)).replace("[","").replace("]",""), fontsize = 40,
    plt.show()
    plt.close()
edges
```

```
  0%|          | 0/2 [00:00<?, ?it/s]

  0%|          | 0/2 [00:00<?, ?it/s]

  0%|          | 0/2 [00:00<?, ?it/s]
```

```
0%|          | 0/2 [00:00<?, ?it/s]
0%|          | 0/2 [00:00<?, ?it/s]
0%|          | 0/2 [00:00<?, ?it/s]
0%|          | 0/2 [00:00<?, ?it/s]
0%|          | 0/2 [00:00<?, ?it/s]
0%|          | 0/2 [00:00<?, ?it/s]
```

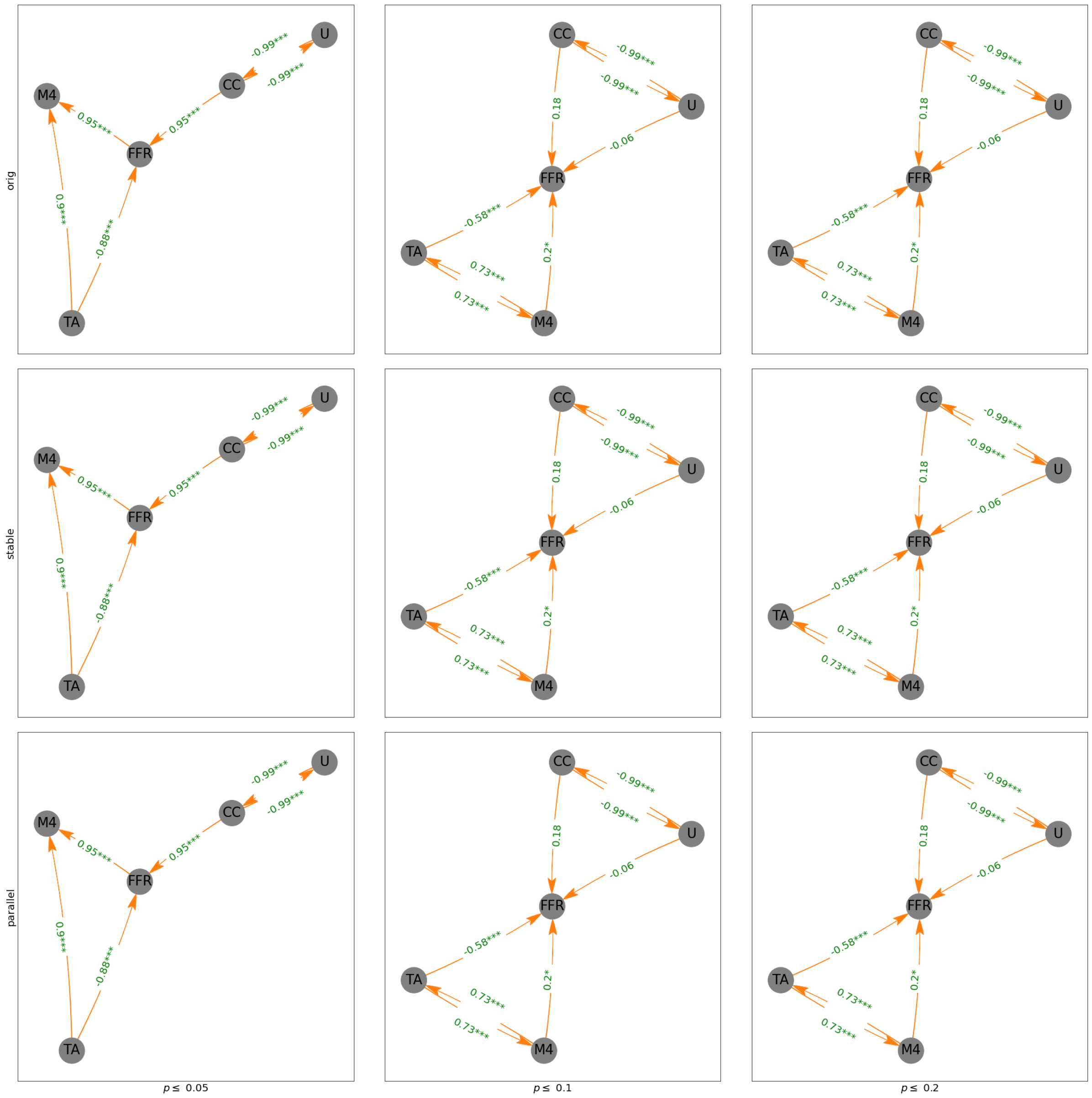


```
0%|          | 0/2 [00:00<?, ?it/s]
0%|          | 0/2 [00:00<?, ?it/s]
0%|          | 0/2 [00:00<?, ?it/s]
0%|          | 0/2 [00:00<?, ?it/s]
0%|          | 0/2 [00:00<?, ?it/s]
0%|          | 0/2 [00:00<?, ?it/s]
0%|          | 0/2 [00:00<?, ?it/s]
0%|          | 0/2 [00:00<?, ?it/s]
0%|          | 0/2 [00:00<?, ?it/s]
```

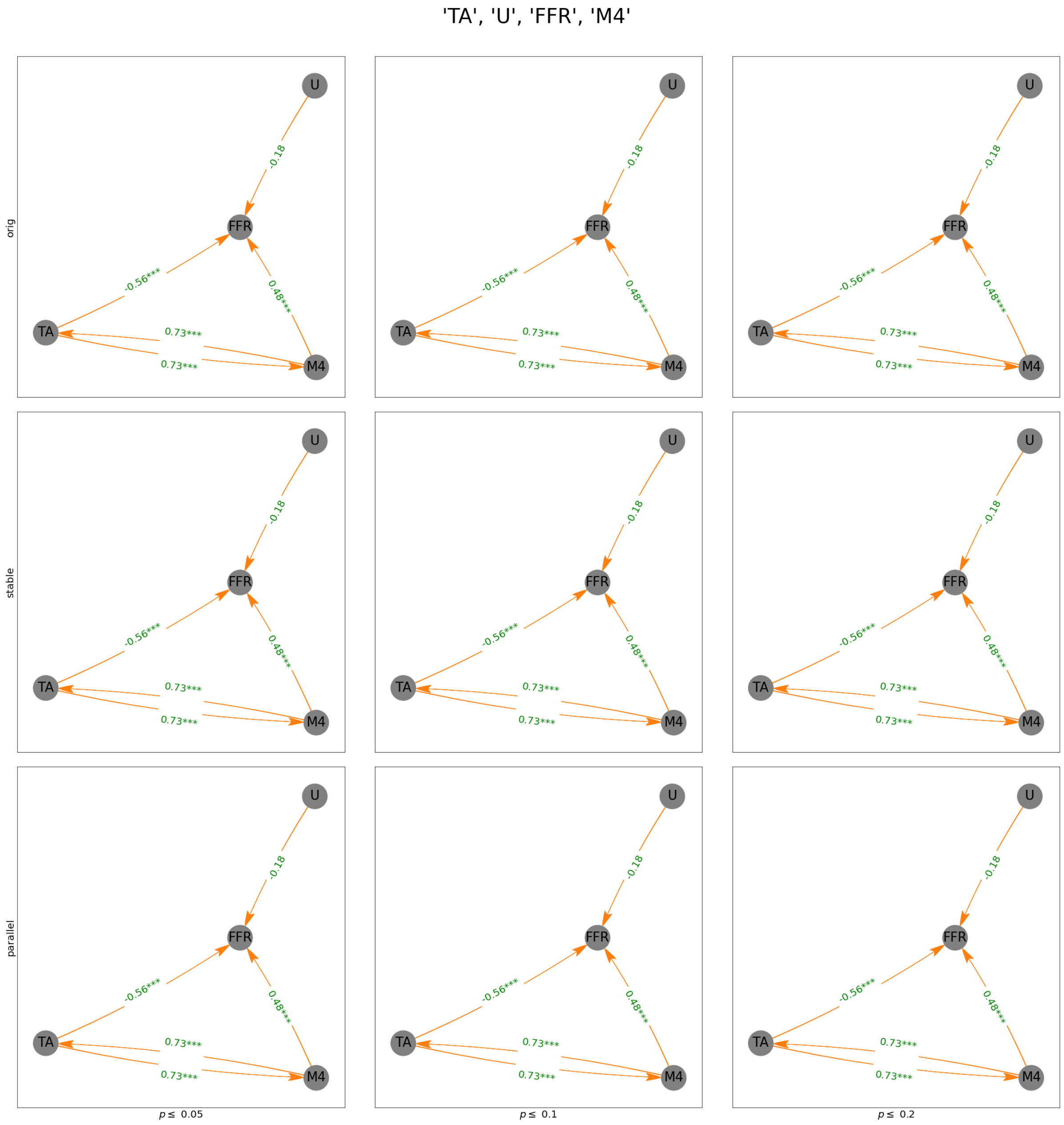


```
0%|          | 0/3 [00:00<?, ?it/s]

0%|          | 0/3 [00:00<?, ?it/s]

0%|          | 0/3 [00:00<?, ?it/s]

0%|          | 0/3 [00:00<?, ?it/s]

0%|          | 0/3 [00:00<?, ?it/s]

0%|          | 0/3 [00:00<?, ?it/s]

0%|          | 0/3 [00:00<?, ?it/s]

0%|          | 0/3 [00:00<?, ?it/s]

0%|          | 0/3 [00:00<?, ?it/s]
```

'M4', 'FFR', 'TA', 'CC', 'U'

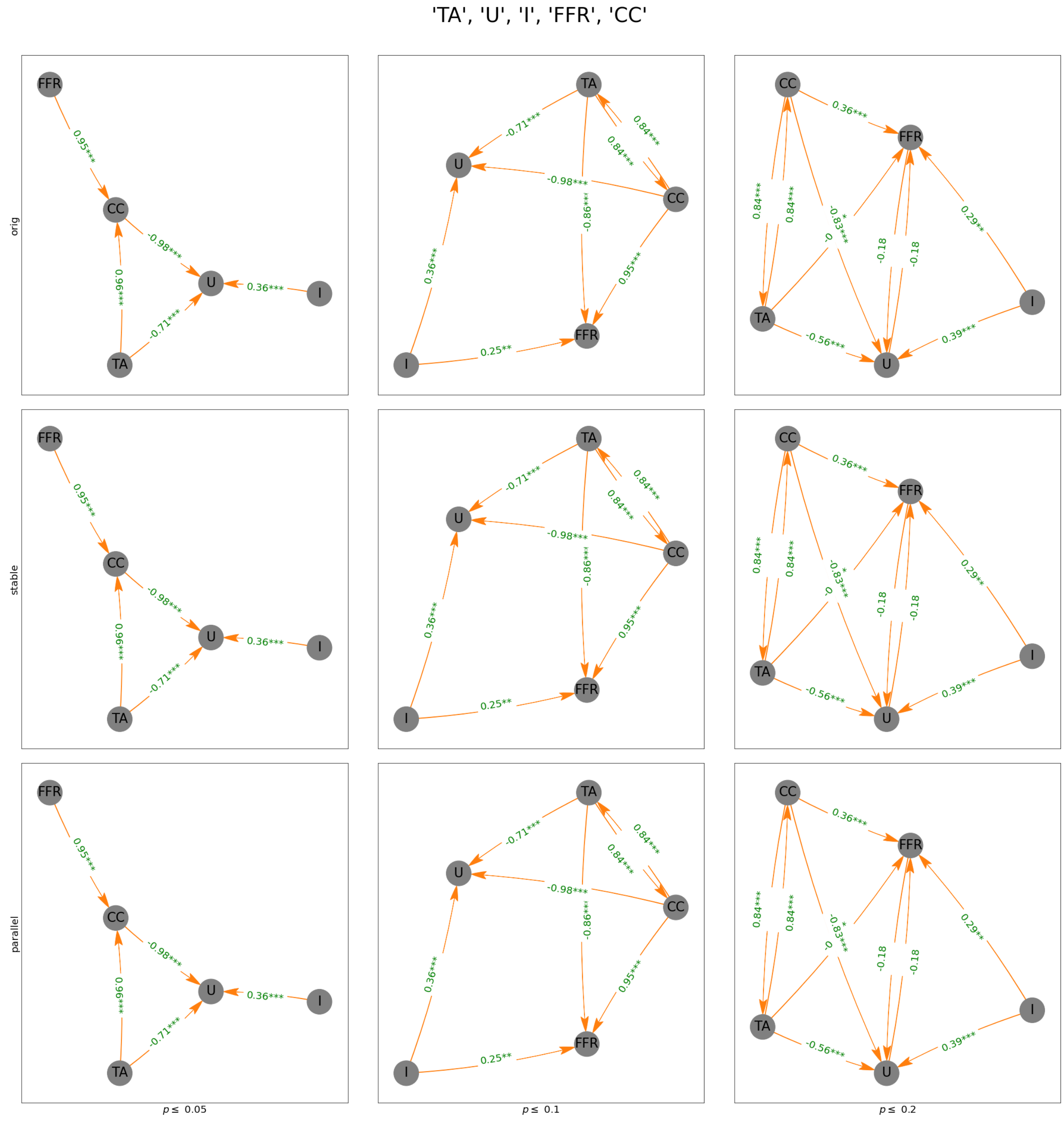


```
0%|          | 0/2 [00:00<?, ?it/s]
0%|          | 0/2 [00:00<?, ?it/s]
0%|          | 0/2 [00:00<?, ?it/s]
0%|          | 0/2 [00:00<?, ?it/s]
0%|          | 0/2 [00:00<?, ?it/s]
0%|          | 0/2 [00:00<?, ?it/s]
0%|          | 0/2 [00:00<?, ?it/s]
0%|          | 0/2 [00:00<?, ?it/s]
0%|          | 0/2 [00:00<?, ?it/s]
```



```
0%|          | 0/3 [00:00<?, ?it/s]

0%|          | 0/3 [00:00<?, ?it/s]

0%|          | 0/3 [00:00<?, ?it/s]
```

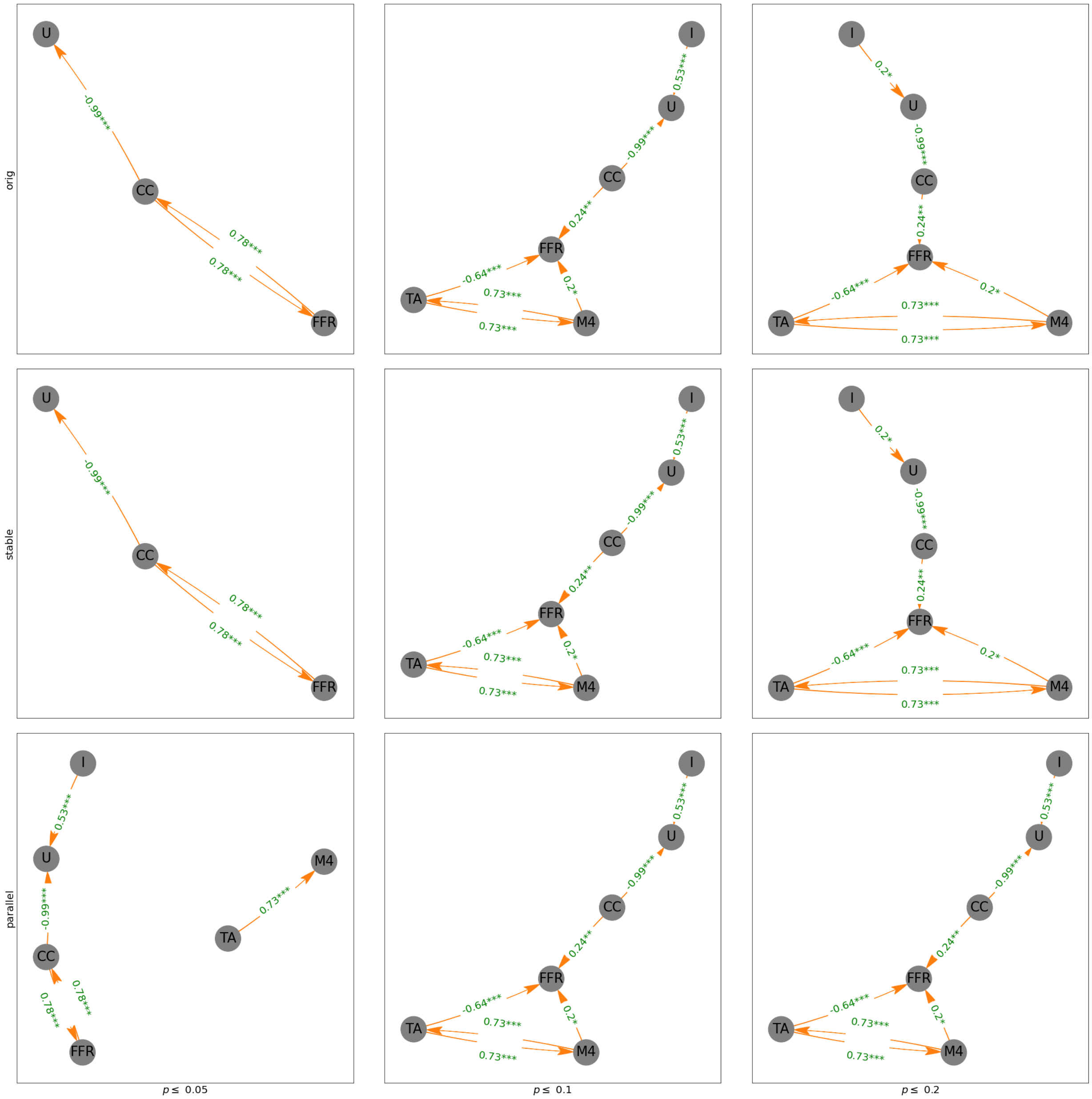
```
0%|          | 0/3 [00:00<?, ?it/s]
0%|          | 0/3 [00:00<?, ?it/s]
0%|          | 0/3 [00:00<?, ?it/s]
0%|          | 0/3 [00:00<?, ?it/s]
0%|          | 0/3 [00:00<?, ?it/s]
0%|          | 0/3 [00:00<?, ?it/s]
```



```
0%|          | 0/4 [00:00<?, ?it/s]
0%|          | 0/4 [00:00<?, ?it/s]
```

```
0%|          | 0/4 [00:00<?, ?it/s]
0%|          | 0/4 [00:00<?, ?it/s]

0%|          | 0/4 [00:00<?, ?it/s]

0%|          | 0/4 [00:00<?, ?it/s]

0%|          | 0/4 [00:00<?, ?it/s]

0%|          | 0/4 [00:00<?, ?it/s]

0%|          | 0/4 [00:00<?, ?it/s]
```

'TA', 'U', 'FFR', 'CC', 'M4', 'I'



```
Out[26]: OutEdgeView([('TA', 'FFR'), ('TA', 'M4'), ('CC', 'U'), ('CC', 'FFR'), ('I',
         'U'), ('M4', 'FFR'), ('M4', 'TA')])
```

```
In [ ]:
```

```
In [ ]:
```

```
In [ ]:
```