

IXO Modelling

Objective

Determine if there is a feasible mechanism to tie the reserve of the market maker mechanism with the reserve of the brokerage mechanism, to maintain the peg stability during the period needed to bootstrap the system. Acknowledging the discussed assumptions, incentive mechanisms, and actors, in the system - the ultimate objective is to ensure actors are incentivized to supply their assets into the system in exchange for utility so that the system can be bootstrapped effectively.

Sprint 1 Scope

1. Customize and parameterize the existing augmented bonding curve model developed by BlockScience
2. Determine the most suitable mechanism for tying the two reserves together (using the Kyber network and Uniswap mechanisms as inspiration)
3. Determine what parameters we have available to stabilize the market maker peg (initial assumption - use the reserve ratio, and possible exit taxation to prime this mechanism)
4. Determine if the mechanism is theoretically feasible

Resources

1. Augmented bonding curve hatch_sim notebook: https://github.com/BlockScience/conviction/blob/master/hatch_sim.ipynb
2. Kyber network reserve types: <https://developer.kyber.network/docs/Reserves-Types/>

IXO Liquidity Mechanism

Uniswap notes:

Uniswap mechanism for liquidity provider / delegators brokerage:

- Uniswap liquidity pools are autonomous and use the Constant Product Market Maker ($x * y = k$)
- A small liquidity provider fee (0.3%) is taken out of each trade and added to the reserves
- Formal verification: <https://github.com/runtimeverification/verified-smart-contracts/blob/uniswap/uniswap/x-y-k.pdf>
- The invariant is that the ratio of $e:t:l$ is preserved and $k = e * t$ increases (e is ether, t is exchange tokens, and l is total liquidity / supply of uni tokens)
- By supplying and burning liquidity (uni tokens), the investor can exchange for their share of ether and tokens

Uni-token === IXO staking token If you stake you're delegating, and delegators receive a proportion of the networks fees, block rewards/inflation, service fees from oracles

Terminology:

- c_{-} - IXO-Cosmos equivalent of Ethereum tokens
- native - native to IXO-Cosmos network
- $cIXOS$ - staking tokens
- $cIXO$ - utility tokens

Actor flow:

1. Participant buys into market maker with Dai, and is given Ethereum based IXO tokens.
2. Participant stakes IXO into the brokerage mechanism in exchange for IXOS. The IXO stake is backed by a proportion of the DAI collateral pool.
3. The IXO and IXOS pools are mirrored on the IXO-Cosmos network, and backed by DAI - post IBC these assets can be made native to the IXO-Cosmos network.
4. $cIXO$ become utility tokens that can be spent in IXO-Cosmos network, and minted through block rewards to be rewarded to actors in the system. The utility comes from the asset backing of the $cIXO$ tokens in the brokerage.

Working example:

1. Participant purchases 100 IXO tokens @ 0.1 DAI per IXO for a total of 10 DAI.

2. Participant provides liquidity in brokerage contract by depositing 50 IXO, retaining 50 IXO for the time being. The asset backing is provided by the bonding curve Dai collateral pool.
3. Participant is rewarded with 50 IXOS tokens to represent the proportion of the liquidity provided.
4. These IXOS tokens are mirrored and can be used within the IXO-Cosmos network as equivalent cIXOS tokens, these are low velocity and are essentially staked for IXO-Cosmos incentive rewards.
5. Participants within the IXO-Cosmos network, who are incentivized/rewarded with cIXO tokens for supporting the network roles, may atomic swap/mirror their cIXO tokens for IXO tokens and in effect DAI via the bonding curve.

Observations:

- Based on last two actions - what is the best way to couple the cIXO token value to the DAI reserve to maintain the cross blockchain peg?
- Objective - make the cIXO utility token stable.
- cIXOS staked on IXO-Cosmos side for various incentive rewards.

To reduce invariance:

- Introduce arbitrage rebalancing
- Introduce algorithmic binding
- Introduce capacitor like smoothing of binding - treat the pool like a capacitor and the variance as AC electricity, determine the RC ratio necessary to filter out noise. The smoothing capacitor acts smooths the ripple current, to an appropriate level of stability. It does this by storing charge (perhaps tax), and discharging when necessary.

Dependancies

```
import sys
sys.path.append("../..../venv/lib/python3.7/site-packages" )

import matplotlib.pyplot as plt
import numpy as np
import pandas as pd
import seaborn as sns
import networkx as nx
from scipy.stats import expon
import math
import pickle

from cadCAD.configuration.utils import config_sim #env_trigger, var_substep_trigger, config_sim, psub_list
from cadCAD.engine import ExecutionMode, ExecutionContext, Executor
from cadCAD.configuration import append_configs

%matplotlib inline

from helpers import *
from bonding_curve_eq import *
```

Liquidity Mechanisms and Actors Overview

```
from enum import Enum, auto
class Nodes(Enum):
    POOL = auto() # Pool of specific token / collateral
    # Mechanisms
    MARKET_MAKER = auto() # Issues IXO tokens in exchange for DAI
    BROKERAGE = auto() # Issues IXOS / staking tokens to delegators
    # Actors
    SERVICE_PROVIDER = auto() # makes claims about contributions and state of project
    EVALUATOR = auto() # validates claims
    DELEGATOR = auto() # stakes into the brokerage to provide liquidity
```

```

PARTICIPANT = auto() # generic type for any user of IXO-Cosmos utility tokens

class Edges(Enum):
    BALANCE = auto()
    BRIDGE = auto() # IBC style mirror

# IBC Ethereum Peg-Zone:
# 1. IXO from AMM and DAI staked into reserve pool by delegators in exchange for IXOS
# 2. cIXO and cIXOS matched on IXO-Cosmos network
# 3. This mechanism can be spun down, while maintaining the liquidity created, when the IBC mechanism is o

Global Parameters

liquidity_provider_fee = .03 # percent
tax = 0 # exit tax - introduces friction and possibly funds to prime stability mechanisms
theta = 0 #.35 # Funding pool taxation - 0 implies all contributions allocated to market

# From scenario spreadsheet
initial_ixo_supply = 2e9
initial_ixo_price = .02
initial_ixo_reserve = initial_ixo_supply * initial_ixo_price

founders_stake = .1 # percent
initial_ixos_supply = initial_ixo_supply * founders_stake # initial supply of staking vouchers

initial_ixo_price = .10 # average IXO price from ixo.world Euro cents
initial_ixos_price = .20 # staking voucher price from AMM in Euro cents

ixo_delegation_distribution_reserve = 1e6
ixo_delegation_distribution_supply = 1e6/initial_ixo_price #200e6 # 5 strategic delegations worth Euro 1 M

# Augmented bonding curve parameters
# Hatch state
d0 = initial_ixo_reserve/1e6 # million DAI
p0 = initial_ixo_price # DAI per tokens

R0 = d0*(1-theta) # million DAI
S0 = d0/p0

kappa = 1 # Bonding curve curvature - using an initial kappa value of 1 we can keep a constant token price

# Brokerage - Kyber Fed Price Reserve
# Policy to bound proposed conversion rate
sanity_rate = 10 # 1 DAI = 10 IXO
reasonable_difference = .1 # percent

# Target portfolio
# 50% DAI / 50% IXO

# Rebalancing
# Or: auto_instant - rebalance performed after every trade
time_spacing = 1 # time period after which to perform another rebalance
price_spacing_diff = .5 # percentage difference from last rebalance after which to perform another rebalan

# Pricing
maximum_spread = 0.02 # dictated by for example Kyber
minimum_spread = 0.005

```

```

spread = 0.01 # dependant on liquidity
quoted_price = 0 # TODO

# cadCAD configuration
time_steps = 24 # months, use days for more granularity

amm_initial_reserve, amm_initial_invariant, amm_initial_spot_price = initialize_bonding_curve(initial_ixo_

# cadCAD Parameter Sets
#####

# amm == automated market maker
# brk == brokerage

# params = {
#     'brokerage': {
#         'sanity_rate': 10,
#         'max_spread': .02,
#     }
# }

params = {
    'sweep': [1], # for selecting parameter sweep from results
    # Automated Market Maker parameters
    'amm.kappa': [kappa],
    'amm.invariant': [amm_initial_invariant],
    'amm.tax_rate': [0],
    # Brokerage
    'brk.sanity_rate': [10], # 1 DAI = 10 I XO
    'brk.reasonable_diff': [.5], # percent
    'brk.rebalance_diff': [False], # percentage difference from last rebalance after which to perform anot
    'brk.max_spread': [.02], # price
    'brk.min_spread': [.005],
    'max_delegators': [20],
    'max_validators': [20],
    'max_service_providers': [20],
    'max_participants': [60], # Sum of above
}

initial_state = {
    'amm.supply': initial_ixo_supply,
    'amm.reserve': amm_initial_reserve,
    'amm.spot_price': amm_initial_spot_price,
    # 'timestamp': '2019-01-01 00:00:00'
}

```

Sigmoidal Participant Base Growth

```

# Number of actors
max_delegators = 20
max_validators = 20
max_service_providers = 20
max_participants = max_delegators + max_validators + max_service_providers

# Sigmoidal growth
default_inflection = time_steps/2
default_slope = 1/5

```

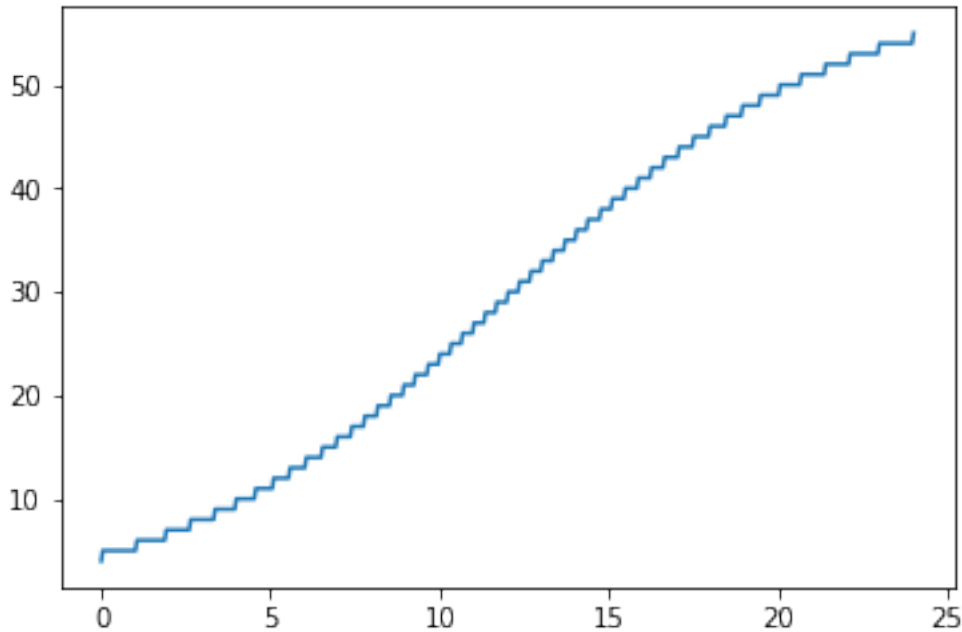
```

def sigmoidal_growth(step, max_value, inflection=default_inflection, slope=default_slope):
    y = np.divide(max_value, (1 + np.power(np.e, -np.multiply(np.subtract(step, inflection), slope))))
    y = np.floor(y)
    y[y < 0] = 0
    return y

x = np.linspace(0, time_steps, 500)
y = sigmoidal_growth(x, max_participants)

plt.plot(x, y)
plt.show()

```



Brokerage framework / liquidity provision

```

# Brokerage framework / liquidity provision (see Uniswap/Kyber)
# https://github.com/runtimeverification/verified-smart-contracts/blob/uniswap/uniswap/x-y-k.pdf
# Newly added... found post setting this up: https://github.com/BlockScience/uniswap

# e.g. reserve == DAI
# e.g. supply == IXX
# e.g. voucher == IXOS

def add_liquidity(network, reserve, supply, voucher, tokens, value):
    reserve_balance = get_pool_balance(network, reserve)
    supply_balance = get_pool_balance(network, supply)
    voucher_balance = get_pool_balance(network, voucher)

    alpha = value/reserve_balance

    dr = alpha*reserve_balance
    ds = alpha*supply_balance
    dv = alpha*voucher_balance

    #new_reserve = (1 + alpha)*reserve_balance
    #new_supply = (1 + alpha)*supply_balance

```

```

    #new_vouchers = (1 + alpha)*voucher_balance

    return (dr, ds, dv)

def remove_liquidity(liquidity_tokens, reserve_balance, supply_balance):
    reserve_balance = 0 # e.g. DAI
    supply_balance = 0 # e.g. IXO
    liquidity_token_balance = 0 # e.g. IXOS

    alpha = liquidity_tokens/liquidity_token_balance

    new_reserve = (1 - alpha)*reserve_balance
    new_supply = (1 - alpha)*supply_balance
    new_liquidity_tokens = (1 - alpha)*liquidity_token_balance

    return False

def get_input_price(dx, reserve_balance, supply_balance):
    x_balance = 0
    y_balance = 0
    rho = 0 # trade fee

    alpha = dx/x_balance
    gamma = 1 - rho

    dy = (alpha*gamma / (1 + alpha*gamma))*y_balance

    new_x = (1 + alpha)*x_balance
    new_y = y_balance - dy

    return False

def get_output_price(dy, reserve_balance, supply_balance):
    x_balance = 0
    y_balance = 0
    rho = 0 # trade fee

    beta = dy/y_balance
    gamma = 1 - rho

    dx = (beta / (1 - beta))*(1 / gamma)*x_balance

    new_x = x_balance + dx
    new_y = (1 - beta)*dy

    return False

# Token trading
def collateral_to_token(value, reserve_balance, supply_balance):
    dv = get_input_price(value, reserve_balance, supply_balance)

    new_reserve = reserve_balance + value
    new_supply = supply_balance - dv

    return False

```

```

def token_to_collateral(tokens, reserve_balance, supply_balance):
    dv = get_input_price(tokens, supply_balance, reserve_balance)

    new_reserve = reserve_balance - dv
    new_supply = supply_balance + value

    return False

def token_to_token():
    # Irrelevant for now
    return False

```

Initialize System and Network

```

# Node generators
def add_new_pool(
    network,
    ticker):

    network.add_node(ticker, _type=Nodes.POOL.name)
    return network

def add_new_brokerage(
    network,
    _params=params,
    pair=('DAI', 'IX0')):

    pair_id = generate_pair_id(Nodes.BROKERAGE, pair)
    network.add_node(pair_id, _type=Nodes.BROKERAGE.name)
    network.add_edge(pair_id, pair[0], _type=Edges.BALANCE.name, balance=0)
    network.add_edge(pair_id, pair[1], _type=Edges.BALANCE.name, balance=0)
    network.add_edge(pair_id, pair[1], _type=Edges.BALANCE.name, balance=0)

    brokerage = {}
    brokerage['target'] = .5 # Target portfolio pair[0]:pair[1]
    brokerage['rate'] = _params['brk.sanity_rate'][0] #TODO
    brokerage['sanity_rate'] = _params['brk.sanity_rate'][0]
    brokerage['reasonable_diff'] = _params['brk.reasonable_diff'][0]
    brokerage['rebalance_diff'] = _params['brk.rebalance_diff'][0]
    brokerage['max_spread'] = _params['brk.max_spread'][0]
    brokerage['min_spread'] = _params['brk.min_spread'][0]
    brokerage['reserve_type'] = pair[0]
    brokerage['supply_type'] = pair[1]
    brokerage['voucher_type'] = pair[1] + 'S' # can be made more robust

    network.nodes[pair_id].update(brokerage)
    return network

def add_new_market_maker(
    network,
    _params=params,
    _initial_state=initial_state,
    pair=('DAI', 'IX0')): # Collateral -> distributed token

    pair_id = generate_pair_id(Nodes.MARKET_MAKER, pair)
    network.add_node(pair_id, _type=Nodes.MARKET_MAKER.name)

```

```

network.add_edge(pair_id, pair[0], _type=Edges.BALANCE.name, balance=0)
network.add_edge(pair_id, pair[1], _type=Edges.BALANCE.name, balance=0)

market_maker = {}
market_maker['pair'] = pair # Reserve/collateral -> supply/token
market_maker['reserve_type'] = pair[0]
market_maker['supply_type'] = pair[1]
market_maker['kappa'] = _params['amm.kappa'][0]
market_maker['invariant'] = _params['amm.invariant'][0]
market_maker['tax_rate'] = _params['amm.tax_rate'][0]
market_maker['spot_price'] = _initial_state['amm.spot_price']

# Initialize pools
reserve_edge = network.edges[(pair_id, pair[0])]
supply_edge = network.edges[(pair_id, pair[1])]
reserve_edge['balance'] = _initial_state['amm.reserve']
supply_edge['balance'] = _initial_state['amm.supply']

network.nodes[pair_id].update(market_maker)
return network

def add_new_bridge(
    network,
    _params=params,
    pair=('IXO', 'cIXO')):

    network.add_edge(pair[0], pair[1], _type=Edges.BRIDGE.name)

def gen_new_participant(
    network,
    _params=params):

    participant = {}
    participant['key'] = 'value'

    return participant

def initialize_network():
    network = nx.Graph()
    color_map = []

    pools = ['IXOS', 'cIXOS']

    for ticker in pools:
        color_map.append('orange')
        add_new_pool(network, ticker)

    brokerage_pairs = [
        ('DAI', 'IXO'),
        ('cDAI', 'cIXO')
    ]

    for pair in brokerage_pairs:
        for ticker in pair:
            color_map.append('green')
            add_new_pool(network, ticker)

```



```

        color_map.append('pink')
        add_new_brokerage(network, params, pair)

market_maker_pairs = [('DAI', 'IXO')]

for pair in market_maker_pairs:
    for ticker in pair:
        color_map.append('blue')
        add_new_pool(network, ticker)
    color_map.append('pink')
    add_new_market_maker(network, params, initial_state, pair)

bridges = [
    ('DAI', 'cDAI'),
    ('IXO', 'cIXO'),
    ('IXOS', 'cIXOS'),
]

for pair in bridges:
    add_new_bridge(network, params, pair)

return (network, color_map)

# Policies
def driving_process(_params, step, sL, s):
    network = s['network']

    participants = get_node_ids_of_type(network, Nodes.PARTICIPANT.name)
    participant_growth = sigmoidal_growth([s['timestep']], _params['max_participants'])[0]
    new_participants = math.ceil(participant_growth - len(participants))

    if new_participants:
        zipOf = zip(range(new_participants), expon.rvs(size=new_participants, loc=0.0, scale=1000))
        new_participants_collateral = dict(zipOf)
    else:
        new_participants_collateral = {}

    return({'new_participants': new_participants,
           'new_participants_collateral': new_participants_collateral})

def bond_process(_params, step, sL, s):
    network = s['network']

    participants = get_node_ids_of_type(network, Nodes.PARTICIPANT.name)
    participants_with_collateral = filter(lambda p: network.edges[(p, 'DAI')].get('balance', 0)>0, participants)

    transactions = []
    for p in participants_with_collateral:
        transactions.append({
            'from': p,
            'type': 'DAI',
            'handler': ('DAI', 'IXO'),
            # Transfer all DAI collateral holdings to DAI:IXO market maker
            'value': network.edges[(p, 'DAI')]['balance'],
        })

```

```

    return({'transactions': transactions})

def provide_liquidity(_params, step, sL, s):
    network = s['network']

    participants = get_node_ids_of_type(network, Nodes.PARTICIPANT.name)
    brokers = get_node_ids_of_type(network, Nodes.BROKERAGE.name)
    participants_with_collateral = filter(lambda p: network.edges[(p, 'IXO')].get('balance', 0)>0, participants)

    transactions = []
    for p in participants_with_collateral:
        transactions.append({
            'from': p,
            'type': generate_pair_id(Nodes.BROKERAGE, ('DAI', 'IXO')),
            'handler': ('DAI', 'IXO'),
            # Transfer all IXO, DAI backed collateral, holdings to brokerage
            'value': network.edges[(p, 'IXO')]['balance'],
        })

    return({'transactions': transactions})

def participants_decisions(params, step, sL, s):
    network = s['network']

    print('TODO')
    return({})

# Mechanisms for updating the state based on driving processes
def update_network(_params, step, sL, s, _input):
    network = s['network']

    new_participants = _input['new_participants'] # Number of
    new_participants_collateral = _input['new_participants_collateral'] # Dict

    for i in range(new_participants):
        index = len([node for node in network.nodes])
        network.add_node(index, _type=Nodes.PARTICIPANT.name)
        participant = gen_new_participant(network)
        network.node[index].update(participant)
        # Deposit seed collateral
        network.add_edge(index, 'DAI', balance=new_participants_collateral[i])

    key = 'network'
    value = network

    return (key, value)

def get_pool_balance(network, pool_node):
    edges = network.edges(pool_node)
    with_balance = filter(lambda edge: network.edges[edge].get('balance', 0) > 0, edges)
    balance = sum([network.edges[edge]['balance'] for edge in with_balance])
    assert(balance >= 0)
    return balance

def update_balances(_params, step, sL, s, _input):
    network = s['network']

```

```

# Process transactions and update balances
# [{'from': 10, 'type': 'DAI', 'handler': ('DAI', 'IXO'), 'value': 0}]
transactions = _input['transactions']

for tx in transactions:
    handler_id = generate_pair_id(Nodes.MARKET_MAKER, tx['handler'])
    handler = network.nodes[handler_id]
    assert(handler['_type'] == Nodes.MARKET_MAKER.name)

    # Collateral -> token; e.g. DAI -> IXO
    participant = tx['from']
    reserve_pool = handler['reserve_type']
    supply_pool = handler['supply_type']
    reserve = get_pool_balance(network, handler['reserve_type'])
    supply = get_pool_balance(network, handler['supply_type'])

    if tx['type'] == reserve_pool: # Mint
        print('Mint %s' % tx['value'])
        V0 = invariant(
            reserve,
            supply,
            handler['kappa'])
        deltaS, realized_price = mint(
            tx['value'],
            reserve,
            supply,
            V0,
            handler['kappa'])

        # Update holdings
        network.edges[(participant, reserve_pool)]['balance'] -= tx['value'] # DAI decrease
        if not network.has_edge(participant, supply_pool):
            network.add_edge(participant, supply_pool, _type=Edges.BALANCE.name, balance=0)
        network.edges[(participant, supply_pool)]['balance'] += deltaS
        network.edges[(handler_id, reserve_pool)]['balance'] += tx['value']

        # Update market maker
        handler['invariant'] = V0
        handler['spot_price'] = spot_price(
            reserve,
            handler['invariant'],
            handler['kappa'])

    elif tx['type'] == supply_pool: # Withdraw
        print('Withdraw %s' % tx['value'])
        print(handler['kappa'])
        V0 = invariant(
            reserve,
            supply,
            handler['kappa'])
        deltaR, realized_price = withdraw(
            tx['value'],
            reserve,
            supply,
            V0,

```

```

        handler['kappa'])

    # Update holdings
    print(participant)
    network.edges[(participant, reserve_pool)]['balance'] += deltaR # DAI increase
    network.edges[(participant, supply_pool)]['balance'] -= tx['value']
    network.edges[(handler_id, reserve_pool)]['balance'] -= deltaR

    # Update market maker
    handler['invariant'] = V0
    handler['spot_price'] = spot_price(
        reserve,
        handler['invariant'],
        handler['kappa'])

    else: raise # We shouldn't get here

key = 'network'
value = network

return (key, value)

def update_brokerage(_params, step, sL, s, _input):
    network = s['network']

    # Process transactions and update balances
    # [{ 'from': 10, 'type': 'DAI', 'handler': ('DAI', 'IXO'), 'value': 0}]
    transactions = _input['transactions']

    for tx in transactions:
        handler_id = generate_pair_id(Nodes.BROKERAGE, tx['handler'])
        handler = network.nodes[handler_id]
        assert(handler['_type'] == Nodes.BROKERAGE.name)

        # Collateral -> token; e.g. DAI -> IXO
        participant = tx['from']
        reserve_pool = handler['reserve_type']
        supply_pool = handler['supply_type']
        voucher_pool = handler['voucher_type']
        reserve = get_pool_balance(network, handler['reserve_type'])
        supply = get_pool_balance(network, handler['supply_type'])

        if tx['type'] == handler_id: # Provide liquidity, get IXOS
            print('Provide liquidity %s' % tx['value'])

            # Calculate a reasonable value for the supplied tokens
            market_maker = network.nodes[generate_pair_id(Nodes.MARKET_MAKER, tx['handler'])]
            V0 = invariant(
                reserve,
                supply,
                market_maker['kappa'])
            deltaR, realized_price = withdraw(
                tx['value'],
                reserve,
                supply,
                market_maker['invariant'],

```

```

        market_maker['kappa'])

dr, ds, dv = add_liquidity(
    network,
    reserve_pool,
    supply_pool,
    voucher_pool,
    tx['value'],
    deltaR)
print((dr, ds, dv))

# Broker balance increases, provider balance decreases, net pool balance remains
network.edges[(handler_id, reserve_pool)]['balance'] += dr
network.edges[(handler_id, supply_pool)]['balance'] += ds

network.edges[(participant, reserve_pool)]['balance'] -= dr
network.edges[(participant, supply_pool)]['balance'] -= ds
if not network.has_edge(participant, voucher_pool):
    network.add_edge(participant, voucher_pool, _type=Edges.BALANCE.name, balance=0)
network.edges[(participant, voucher_pool)]['balance'] += dv

elif tx['type'] == reserve_pool: # Swap reserve (DAI) for tokens (IXO)
    print('TODO')
elif tx['type'] == supply_pool: # Swap tokens for reserve
    print('TODO')
else: raise # We shouldn't get here

key = 'network'
value = network

return (key, value)

```

Configure cadCAD

```

# cadCAD Initial State
#####
network, color_map = initialize_network()
pos = nx.drawing.nx_agraph.graphviz_layout(network, prog='dot') #spring_layout(network, k=0.15, iterations=

plt.figure()
nx.draw(
    network, pos, edge_color='black', width=2, linewidths=1,
    node_size=800, node_color='pink', alpha=0.9,
    labels={node: node for node in network.nodes()})

nx.draw_networkx_edge_labels(
    network, pos,
    edge_labels={(u,v): d['_type'] for u,v,d in network.edges(data=True)},
    font_color='red')

plt.axis('off')
plt.show()

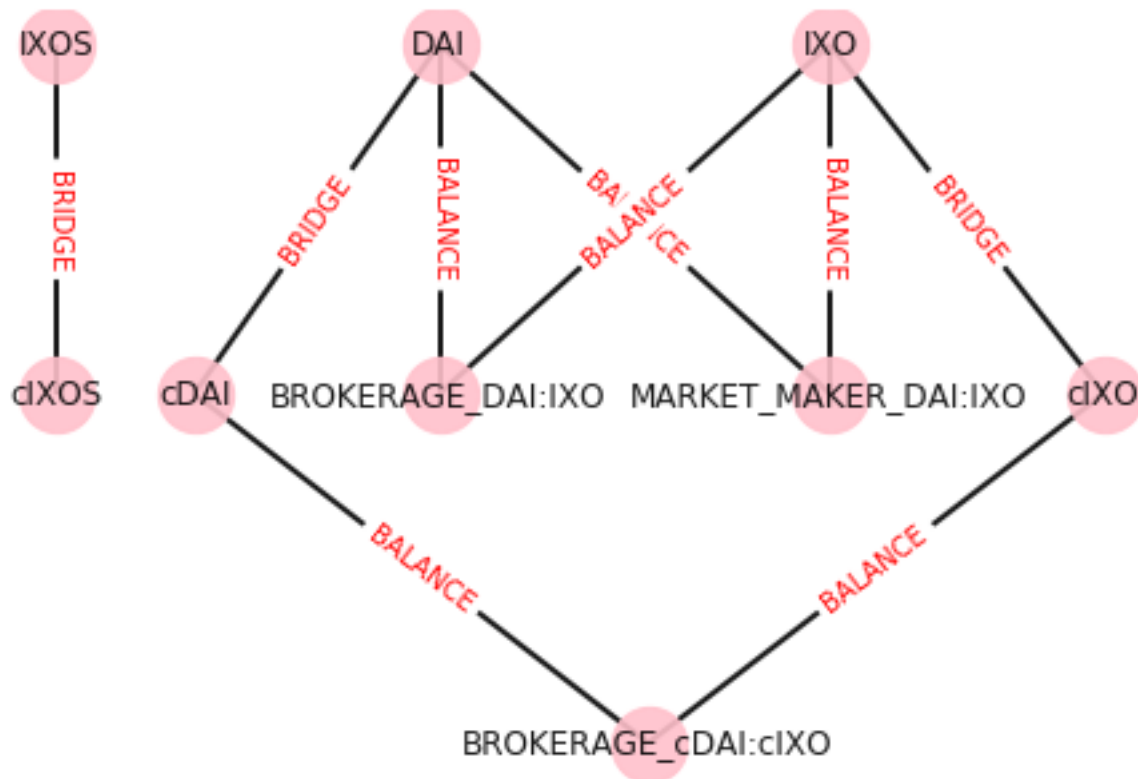
#nx.draw_kamada_kawai(network, node_color=color_map, font_weight='bold', with_labels=True)

initial_state.update({
    'network': network,

```

```
})
```

```
/nix/store/60dnqyh4ks7zjpjxdbhb4rgsv8ma6l1-python3-3.7.2-env/lib/python3.7/site-packages/networkx/drawing
    if cb.is_numlike(alpha):
```



```
runs = 1 # Monte Carlo runs
```

```
#####
# Settings of general simulation parameters, unrelated to the system itself
# `T` is a range with the number of discrete units of time the simulation will run for;
# `N` is the number of times the simulation will be run (Monte Carlo runs)
# In this example, we'll run the simulation once (N=1) and its duration will be of 10 timesteps
```

```
simulation_parameters = config_sim({
    'T': range(time_steps),
    'N': runs,
    'M': params
})
```

```
simulation_parameters
```

```
[{'N': 1,
  'T': range(0, 24),
  'M': {'sweep': 1,
        'amm.kappa': 1,
        'amm.invariant': 10.0,
        'amm.tax_rate': 0,
        'brk.sanity_rate': 10,
        'brk.reasonable_diff': 0.5,
        'brk.rebalance_diff': False,
        'brk.max_spread': 0.02,
```

```

'brk.min_spread': 0.005,
'max_delegators': 20,
'max_validators': 20,
'max_service_providers': 20,
'max_participants': 60}}]

```

Perform Simulation

```

# ts_format = '%Y-%m-%d %H:%M:%S'
# t_delta = timedelta(days=30, minutes=0, seconds=0)
# def time_model(_g, step, sL, s, _input):
#     y = 'time'
#     x = ep_time_step(s, dt_str=s['time'], fromat_str=ts_format, _timedelta=t_delta)
#     return (y, x)

# exogenous_states = {
#     'time': time_model
# }
# env_processes = {}

partial_state_update_blocks = [
    { # Generate new participants
      'policies': {
        'generate': driving_process,
      },
      'variables': {
        'network': update_network,
      }
    },
    {
      'policies': {
        'bond': bond_process,
      },
      'variables': {
        'network': update_balances,
      }
    },
    { # Participants provide liquidity via brokerage
      'policies': {
        'provide': provide_liquidity,
      },
      'variables': {
        'network': update_brokerage,
      }
    },
    { # Brokerage rebalance
      'policies': {
        'rebalance': brokerage_rebalance,
      },
      'variables': {
        'network': update_brokerage,
      }
    },
    # TODO: sync bridges
    { # Accounting
      'policies': {
        'participants_act': participants_decisions,

```

```

#         },
#         'variables': {
#             'network': update_holdings,
#             'amm.supply': update_supply,
#             'amm.reserve': update_reserve,
#             'amm.spot_price': update_price,
#         }
#     }
# }
]

append_configs(
    initial_state=initial_state, #dict containing variable names and initial values
    partial_state_update_blocks=partial_state_update_blocks, #dict containing state update functions
    sim_configs=simulation_parameters, #dict containing simulation parameters
    #     raw_exogenous_states=exogenous_states,
    #     env_processes=env_processes
)

sys.setrecursionlimit(10000)
from cadCAD import configs

exec_mode = ExecutionMode()
exec_context = ExecutionContext(context=exec_mode.multi_proc)
run = Executor(exec_context=exec_context, configs=configs)

i = 0
verbose = False
results = {}
for raw_result, tensor_field in run.execute():
    result = pd.DataFrame(raw_result)
    if verbose:
        print()
        print(f"Tensor Field: {type(tensor_field)}")
        print(tabulate(tensor_field, headers='keys', tablefmt='psql'))
        print(f"Output: {type(result)}")
        print(tabulate(result, headers='keys', tablefmt='psql'))
        print()
    results[i] = {}
    results[i]['result'] = result
    results[i]['simulation_parameters'] = simulation_parameters[i]
    i += 1

[{'N': 1, 'T': range(0, 24), 'M': {'sweep': 1, 'amm.kappa': 1, 'amm.invariant': 10.0, 'amm.tax_rate': 0, '

```



by BlockScience

```

Execution Mode: multi_proc: [<cadCAD.configuration.Configuration object at 0x7fc639d81208>]
Configurations: [<cadCAD.configuration.Configuration object at 0x7fc639d81208>]
Mint 1225.226539905078
Mint 2542.1096942481186
Mint 1280.7479612084023
Mint 224.05046463652295

```


Provide liquidity 12251.942429542542
(1001.1451514065266, 10011.451509378921, 0.0)
Provide liquidity 25420.582567691803
(3319.1557924151425, 33191.391765989465, 0.0)
Provide liquidity 12807.383246183395
(4599.908448457718, 45998.26957774306, 0.0)
Provide liquidity 2240.5021352767944
(4824.035248756409, 48239.18898063541, 0.0)
Mint 305.71883001643016
Provide liquidity 2240.49092016362
(-81.66374063491821, -816.6167951538285, -0.0)
Provide liquidity 3057.1064670085907
(-81.66374066472054, -816.6171288596807, -0.0)
Mint 81.66374066472054
Mint 808.6361995839795
Mint 440.65955838354796
Provide liquidity 3057.1077153174488
(-134.94064688682556, -1349.373512857976, -0.0)
Provide liquidity 4690.335624228638
(-106.5541542172432, -1065.5162377144472, -0.0)
Provide liquidity 8086.1140015125275
(233.0327252149582, 2330.2719115873333, 0.0)
Provide liquidity 4406.47825551033
(98.09207832813263, 980.8963456068954, 0.0)
Mint 106.5541542172432
Mint 1047.4743525763406
Provide liquidity 4406.481228175425
(-606.8129626214504, -6067.9787074593205, -0.0)
Provide liquidity 6821.36075590976
(-972.13070166111, -9721.094731929277, -0.0)
Provide liquidity 5755.842089925194
(-1078.6857763528824, -10786.622210360481, -0.0)
Provide liquidity 3425.5819099034347
(-1544.7515355944633, -15447.196024366393, -0.0)
Provide liquidity 10474.42815876007
(-937.9377661645414, -9379.188370461914, -0.0)
Mint 972.13070166111
Mint 845.6530511379242
Mint 1446.6594572663307
Mint 937.9377661645414
Mint 43.08158668377226
Mint 110.1941084696616
Provide liquidity 10474.459935634746
(937.251595079899, 9372.52370943168, 0.0)
Provide liquidity 26263.558863273913
(3453.412645727396, 34533.99322660786, 0.0)
Provide liquidity 24998.8587638248
(5953.3121092021465, 59532.109739898355, 0.0)
Provide liquidity 33339.20093150608
(9287.334062814713, 92870.60220827749, 0.0)
Provide liquidity 29232.95078610942
(12210.904745519161, 122103.41190883586, 0.0)
Provide liquidity 430.81589341163635
(12254.553258538246, 122538.08618337872, 0.0)
Provide liquidity 1101.941389799118
(12365.495400220156, 123647.41355930535, 0.0)

Mint 1647.3603659266782
 Provide liquidity 1101.9362262030663
 (-1537.1590552926061, -15370.644730772929, -0.0)
 Provide liquidity 16472.454403162003
 (-1114.9793963432312, -11149.170041586298, -0.0)
 Mint 422.1796589493749
 Mint 1114.9793963432312
 Mint 101.56643092147672
 Mint 271.70883708123307
 Provide liquidity 20694.133426706372
 (1797.8072233796122, 17977.204328257303, 0.0)
 Provide liquidity 38770.79721143379
 (5403.370550900698, 54030.61149648306, 0.0)
 Provide liquidity 1015.6133825778961
 (5504.978144139051, 55045.56254171406, 0.0)
 Provide liquidity 2716.9535117149353
 (5776.835646003485, 57763.89989266324, 0.0)
 Mint 941.7741051608135
 Mint 438.2279753220894
 Mint 767.931352964383
 Provide liquidity 2716.929098449069
 (-496.2160698771477, -4961.77115241293, -0.0)
 Provide liquidity 9416.90064239502
 (-322.37981271743774, -3223.5530420826176, -0.0)
 Provide liquidity 4381.909316062927
 (-825.920407295227, -8258.57617762253, -0.0)
 Provide liquidity 7678.681208848953
 (-496.21606990695, -4961.783457206864, -0.0)
 Mint 322.37981271743774
 Mint 825.920407295227
 Mint 496.21606990695
 Mint 75.06320031881246
 Mint 1485.6781501175901
 Provide liquidity 7678.700250861999
 (-717.7503538131714, -7177.016861047565, -0.0)
 Provide liquidity 15863.981583504508
 (-616.9109918177128, -6168.713743047072, -0.0)
 Provide liquidity 20899.010561253283
 (-113.37021264433861, -1133.6293210316906, -0.0)
 Provide liquidity 17602.237896131654
 (-443.0722826719284, -4430.438289368613, -0.0)
 Provide liquidity 750.5752515792847
 (-2128.3653317689896, -21282.28649909969, -0.0)
 Provide liquidity 14855.663825035095
 (-717.7503538131714, -7177.0426047984765, -0.0)
 Mint 616.9109918177128
 Mint 113.37021264433861
 Mint 443.0722826719284
 Mint 2128.3653317689896
 Mint 717.7503538131714
 Mint 1061.1493817682074
 Mint 2565.2711352565707
 Mint 587.4701776679382
 Provide liquidity 14855.717111909564
 (898.1714617609977, 8981.318221287505, 0.0)
 Provide liquidity 28201.279165491247

(3130.961948573589, 31308.097148830402, 0.0)
 Provide liquidity 23166.248825508927
 (5447.700739830732, 54473.59086839356, 0.0)
 Provide liquidity 26463.037344824912
 (8094.214277148247, 80936.12944491282, 0.0)
 Provide liquidity 43314.82486684795
 (12426.121006906033, 124250.33532709497, 0.0)
 Provide liquidity 29209.716316098373
 (15347.732741206884, 153460.5741119311, 0.0)
 Provide liquidity 10610.802043676376
 (16409.81585869193, 164077.85108864057, 0.0)
 Provide liquidity 25651.175054073334
 (18976.312517255545, 189738.6356414847, 0.0)
 Provide liquidity 5874.425258159637
 (19565.338517725468, 195625.62842939157, 0.0)
 Mint 690.3942864419116
 Mint 127.39233478884843
 Mint 1559.118858274446
 Provide liquidity 5874.398890622058
 (-971.5893194675446, -9714.486320966238, -0.0)
 Provide liquidity 6902.861212015152
 (-1840.316711336374, -18400.59160836099, -0.0)
 Provide liquidity 1273.728152513504
 (-2403.3159240186214, -24029.79582336379, -0.0)
 Provide liquidity 15588.809559822083
 (-971.5893194973469, -9714.533465347818, -0.0)
 Mint 1840.316711336374
 Mint 2403.3159240186214
 Mint 971.5893194973469
 Mint 48.98784692856011
 Mint 3057.17463545605
 Mint 495.1036197633353
 Provide liquidity 15588.885211588296
 (1063.9663404524326, 10638.451506329022, 0.0)
 Provide liquidity 43703.71344716905
 (4939.742732942104, 49391.5382936339, 0.0)
 Provide liquidity 49333.10843971206
 (9873.641800433397, 98722.49164027841, 0.0)
 Provide liquidity 35017.90765687042
 (13376.083744853733, 133738.67531834167, 0.0)
 Provide liquidity 489.8138597011566
 (13425.730460315945, 134232.71230575434, 0.0)
 Provide liquidity 30567.721756219864
 (16483.755308806896, 164807.31899925892, 0.0)
 Provide liquidity 4950.460013389587
 (16979.96414500475, 169765.9055059624, 0.0)
 Mint 1174.2424410322876
 Mint 351.3244167027391
 Mint 917.4940295427012
 Provide liquidity 4950.433705259275
 (-422.34879148006445, -4222.638348789828, -0.0)
 Provide liquidity 11739.91918849945
 (-165.6093240082264, -1655.763603981845, -0.0)
 Provide liquidity 3512.515216588974
 (-988.5190205872059, -9883.222614028498, -0.0)
 Provide liquidity 9173.05271077156

(-422.34879148006445, -4222.64725314422, -0.0)
 Mint 165.6093240082264
 Mint 988.5190205872059
 Mint 422.34879148006445
 Mint 159.82901802093784
 Mint 143.13544914650714
 Provide liquidity 9173.072054049102
 (774.3478115797042, 7741.9977572854505, 0.0)
 Provide liquidity 15051.443891819827
 (2136.6456283330917, 21362.288963005383, 0.0)
 Provide liquidity 23278.953666904017
 (4464.994512856007, 44640.90105304995, 0.0)
 Provide liquidity 17618.365162003473
 (6227.216803282499, 62258.83073645577, 0.0)
 Provide liquidity 1597.9822101593018
 (6387.184513151647, 63857.603406777984, 0.0)
 Provide liquidity 1431.0798296928406
 (6530.518539905547, 65290.57197929172, 0.0)
 Mint 1228.5270559105215
 Mint 2891.179742186061
 Mint 1274.2603452529152
 Provide liquidity 1431.0742967636515
 (-1131.1198721826077, -11308.659514649815, -0.0)
 Provide liquidity 12282.181962966919
 (-1176.8784266412258, -11766.208776558748, -0.0)
 Provide liquidity 28904.706076860428
 (485.7577973604202, 4856.514937482505, 0.0)
 Provide liquidity 12739.661875963211
 (-645.3620748221874, -6452.192786732019, -0.0)
 Mint 1176.8784266412258
 Mint 645.3620748221874
 Mint 1012.6988161913988
 Mint 198.62121045415861
 Mint 1136.3800885609196
 Provide liquidity 12739.733811413465
 (137.8708782196045, 1378.4162606516413, 0.0)
 Provide liquidity 35814.433087910526
 (2583.714457988739, 25831.644917384223, 0.0)
 Provide liquidity 24048.191139377923
 (3990.5483468770985, 39896.4746576187, 0.0)
 Provide liquidity 25644.009737530054
 (6555.539655208588, 65539.8102224664, 0.0)
 Provide liquidity 10124.720853090286
 (7568.362935870886, 75664.66616203844, 0.0)
 Provide liquidity 1985.7774548530579
 (7767.231614053249, 77652.46212640556, 0.0)
 Provide liquidity 11361.325370073318
 (8903.905137002468, 89016.20362475199, 0.0)
 Mint 17.389828423698642
 Mint 382.271900120528
 Mint 613.6444531194436
 Provide liquidity 11361.317550761823
 (522.7888387143612, 5226.517247071708, 0.0)
 Provide liquidity 9982.788170526303
 (907.6881523430347, 9074.477214263336, 0.0)
 Provide liquidity 173.85179591178894

(834.2223316729068, 8339.975823344794, 0.0)
 Provide liquidity 3821.697404384613
 (1216.4969034194946, 12161.69059247107, 0.0)
 Provide liquidity 6134.816310882568
 (1830.146421521902, 18296.49708884748, 0.0)
 Mint 669.2130804599664
 Mint 31.663685824300423
 Provide liquidity 6134.8003036901155
 (581.9848682582378, 5818.251321569812, 0.0)
 Provide liquidity 908.310956262967
 (641.1772294640541, 6409.9938510832435, 0.0)
 Provide liquidity 6690.270627975464
 (1310.3898358643055, 13100.257769037025, 0.0)
 Provide liquidity 316.5499014854431
 (1342.0577149689198, 13416.803767618501, 0.0)
 Mint 1051.5385579019278
 Mint 1190.9254353270517
 Mint 2623.4399104290164
 Provide liquidity 316.54898212030366
 (-2591.7756899297237, -25910.465655941694, -0.0)
 Provide liquidity 10512.172086000443
 (-3609.8261361420155, -36088.47315415938, -0.0)
 Provide liquidity 11905.677374362946
 (-3470.434568852186, -34694.93544781669, -0.0)
 Provide liquidity 26226.675404548645
 (-2037.913015514612, -20373.60426159253, -0.0)
 Mint 553.8626743853092
 Mint 3609.8261361420155
 Mint 3470.434568852186
 Mint 2037.913015514612
 Mint 257.62777703850304
 Mint 825.6127286539509
 Provide liquidity 31764.109623547076
 (2351.5194941163063, 23509.95348078123, 0.0)
 Provide liquidity 82689.02304968436
 (9796.686671316624, 97943.88077779024, 0.0)
 Provide liquidity 81296.08165204986
 (17928.215412259102, 179232.69112832687, 0.0)
 Provide liquidity 66974.55001445164
 (24628.06769299507, 246202.7387177772, 0.0)
 Provide liquidity 2575.689602136612
 (24887.898490309715, 248791.90794286347, 0.0)
 Provide liquidity 8254.253012180328
 (25716.569653570652, 257075.3898067019, 0.0)
 Mint 1386.370648539608
 Provide liquidity 8254.156142765845
 (-560.6559672355652, -5604.567779620469, -0.0)
 Provide liquidity 13858.685165405273
 (-560.6559672653675, -5604.583453524584, -0.0)
 Mint 560.6559672653675
 Mint 844.1672317476811
 Mint 556.8378805624092
 Provide liquidity 13858.723922386314
 (829.5231545865536, 8292.33080418261, 0.0)
 Provide liquidity 25067.81290637302
 (2780.3504273593426, 27793.666724950184, 0.0)

```

Provide liquidity 8438.661396026611
(3624.5178862810135, 36231.90125049656, 0.0)
Provide liquidity 5566.416150331497
(4181.406032294035, 41798.56667726978, 0.0)
Mint 1570.7135897205374
Provide liquidity 5566.393118203705
(-1013.862037062645, -10134.835490025534, -0.0)
Provide liquidity 15701.149210214615
(-1013.8620370626448, -10134.886740389189, -0.0)
Mint 1013.8620370626448
Mint 2555.8696512643282
Mint 16.48373767365873
Provide liquidity 15701.22860822924
(1554.209733515978, 15536.452391737119, 0.0)
Provide liquidity 35970.79266041788
(5136.112504005432, 51342.07250596135, 0.0)
Provide liquidity 25549.08571100235
(7691.988965809345, 76889.97606710778, 0.0)
Provide liquidity 164.77749395370483
(7708.669745057821, 77055.73674506226, 0.0)

```

Model Data Analysis

```

# Choose which experiment parameter configuration to use, integer starting from zero
import os

```

```

def select_experiment(results, i):
    df = pd.DataFrame(results[i - 1]['result'])
    directory = './experiment_%s/' % i
    if not os.path.exists(directory):
        os.makedirs(directory)
    return df[df.substep==len(partial_state_update_blocks)].copy()

```

```

def save_experiment(fig, experiment, name):
    pickle.dump(fig, open('experiment_%s/%s.pickle' % (experiment, name), 'wb'))
    fig.savefig('experiment_%s/%s.png' % (experiment, name))

```

```

rdf = select_experiment(results, 1)
network_output = rdf['network'][24]

```

```

pos = nx.drawing.nx_agraph.graphviz_layout(network_output, prog='neato') #spring_layout(network, k=0.15, it

```

```

node_sizes = [50 if network_output.nodes[node]['_type'] == Nodes.PARTICIPANT.name else 800 for node in net

```

```

plt.figure()
nx.draw(
    network_output, pos, edge_color='black', width=2, linewidths=1,
    node_size=node_sizes, node_color='pink', alpha=0.9,
    labels={node: node for node in network.nodes()})

```

```

nx.draw_networkx_edge_labels(
    network_output, pos,
    edge_labels={(u,v): d['_type'] for u,v,d in network.edges(data=True)},
    font_color='red')

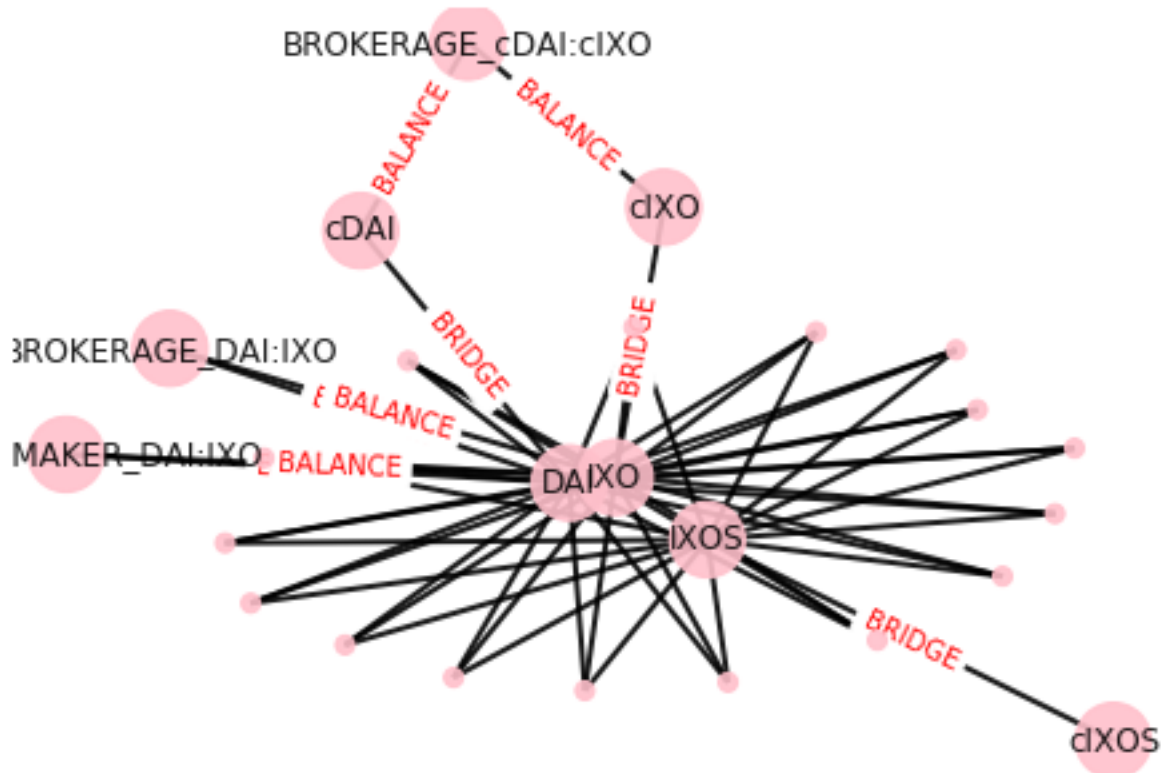
```

```

plt.axis('off')

```

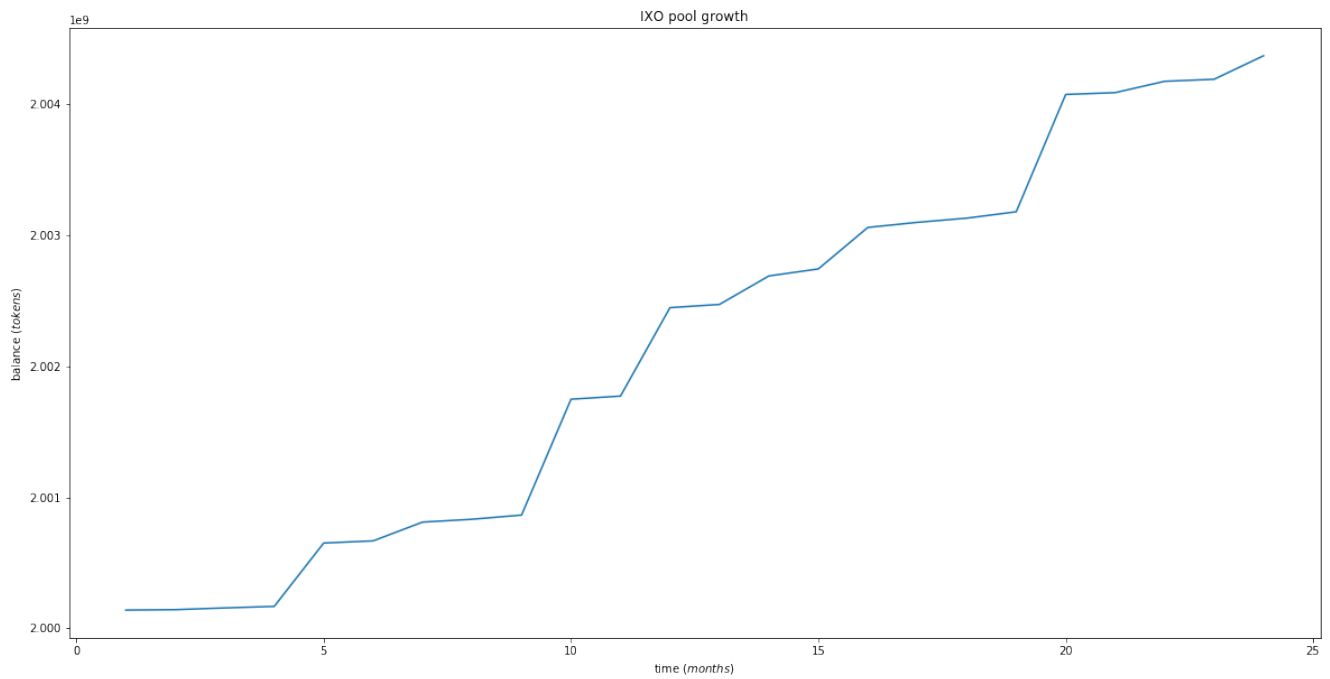
```
plt.show()
```



```
for experiment in params['sweep']:
    rdf = select_experiment(results, experiment)
    rdf['IXO_pool_growth'] = rdf['network'].apply(lambda g: get_pool_balance(g, 'IXO'))

    fig = plt.figure(1,figsize=(20,10))
    #data = make2D('IXO_pool_growth', rdf)
    plt.plot(rdf.timestep, rdf['IXO_pool_growth'])
    plt.title('IXO pool growth')
    plt.xlabel('time ($months$)')
    plt.ylabel('balance ($tokens$)')

    save_experiment(fig, experiment, 'IXO_pool_growth')
```



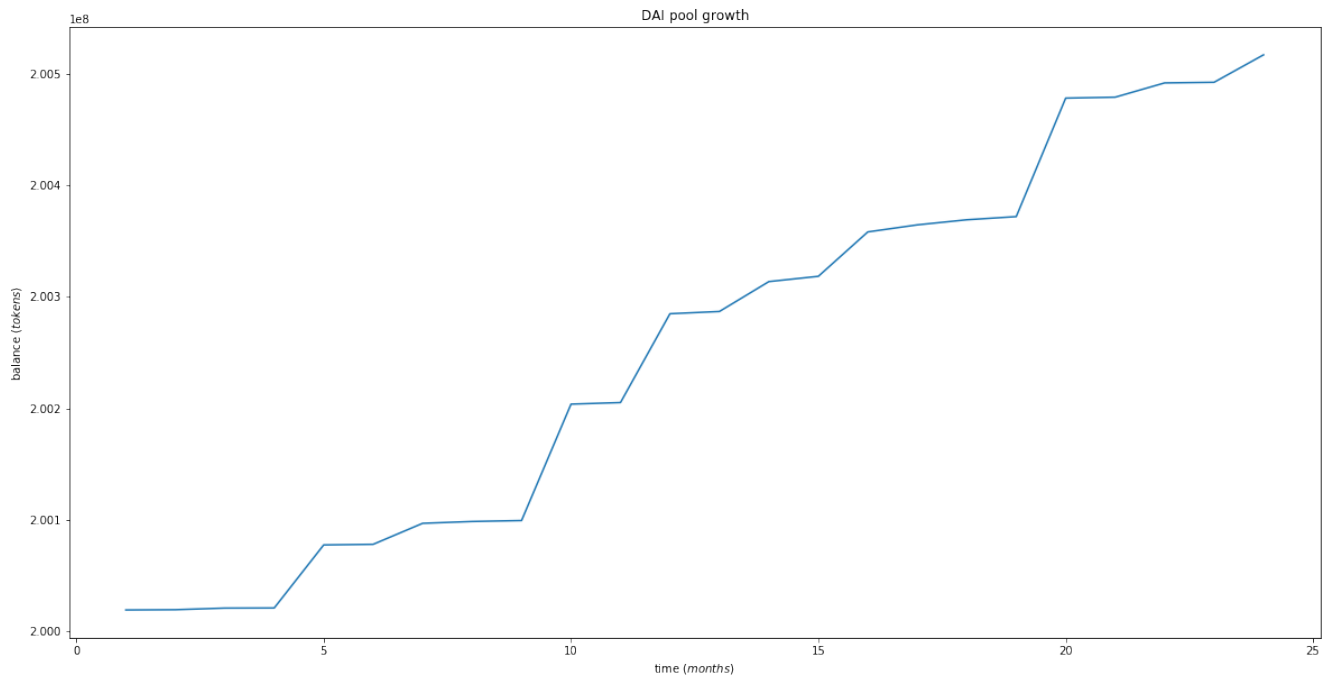
```

for experiment in params['sweep']:
    rdf = select_experiment(results, experiment)
    rdf['DAI_pool_growth'] = rdf['network'].apply(lambda g: get_pool_balance(g, 'DAI'))

    fig = plt.figure(1,figsize=(20,10))
    #data = make2D('IXO_pool_growth', rdf)
    plt.plot(rdf.timestep, rdf['DAI_pool_growth'])
    plt.title('DAI pool growth')
    plt.xlabel('time ($months$)')
    plt.ylabel('balance ($tokens$)')

    save_experiment(fig, experiment, 'IXO_pool_growth')

```



Augumented bonding curve Mathematics

Hatch Sale Equations

- Initial Raise d_0 Dai
- Initial Reserve is $R_0 = (1 - \theta)d_0$
- Hatch sale Price p_0 (dai per token) determines the initial supply: $S_0 = d_0/p_0$
- Power Function Invariant shape: $V(R, S) = \frac{S^\kappa}{R}$
- Price function (DAI per Token): $P(R) = \frac{\kappa R^{(\kappa-1)/\kappa}}{V_0^{1/\kappa}}$
- Supply function (tokens): $S(R) = \sqrt[\kappa]{V_0 R}$
- Reserve function (xDAI): $\$R(S) = \frac{S^\kappa}{V_0} \cdot \frac{1}{p_0(1-\theta)} R_0^{\kappa-1}$
- The invariant coef: $V_0 = V(R_0, S_0) = \frac{S_0^\kappa}{R_0} = \left(\frac{1}{p_0(1-\theta)}\right)^\kappa R_0^{\kappa-1}$
- The post hatch price: $p_1 = P(R_0) = \frac{\kappa R_0^{(\kappa-1)/\kappa}}{V_0^{1/\kappa}} = \kappa R_0^{(\kappa-1)/\kappa} \cdot (1-\theta)p_0 \cdot R_0^{-(\kappa-1)/\kappa} = \kappa(1-\theta)p_0$
- The Return factor: $\frac{p_1}{p_0} = \kappa(1-\theta)$

Invariant Preserving Deposit-to-Mint

- Deposit ΔR xdai
- Conservation equation: $V(R + \Delta R, S + \Delta S) = \frac{(S + \Delta S)^\kappa}{R + \Delta R} = V_0$
- Derived Mint equation: $\Delta S = \text{mint}(\Delta R; (R, S)) = \sqrt[\kappa]{V_0(R + \Delta R)} - S$
- Realized Price is: $\bar{P}(\Delta R) = \frac{\Delta R}{\Delta S} = \frac{\Delta R}{\sqrt[\kappa]{V_0(R + \Delta R)} - \sqrt[\kappa]{V_0(R)}} \rightarrow \left(\frac{\partial S(R)}{\partial R}\right)^{-1}$ as $\Delta R \rightarrow 0$
- The limiting price is the spot price: $\lim_{\Delta R \rightarrow 0} \bar{P}(\Delta R) = \left(\frac{\partial S(R)}{\partial R}\right)^{-1} = \left(\frac{V_0^{1/\kappa} \cdot R^{1/\kappa-1}}{\kappa}\right)^{-1} = \frac{\kappa R^{1-1/\kappa}}{V_0^{1/\kappa}} = \frac{\kappa R^{(\kappa-1)/\kappa}}{V_0^{1/\kappa}} = P(R)$

Invariant Preserving Burn-to-Withdraw

- Burn ΔS tokens
- Conservation equation: $V(R - \Delta R, S - \Delta S) = \frac{(S - \Delta S)^\kappa}{R - \Delta R} = V_0$
- Derived Withdraw equation: $\Delta R = \text{withdraw}(\Delta S; (R, S)) = R - \frac{(S - \Delta S)^\kappa}{V_0}$
- Realized Price is: $\bar{P}(\Delta S) = \frac{\Delta R}{\Delta S} = \frac{R - \frac{(S - \Delta S)^\kappa}{V_0}}{\Delta S} = \frac{R}{\Delta S} - \frac{(S - \Delta S)^\kappa}{V_0 \Delta S} \rightarrow \frac{\partial R(S)}{\partial S}$ as $\Delta S \rightarrow 0$
- The limiting price is the spot price: $\lim_{\Delta S \rightarrow 0} \bar{P}(\Delta S) = \frac{\partial R(S)}{\partial S} = \frac{\kappa S^{\kappa-1}}{V_0} = \frac{\kappa \cdot (\sqrt[\kappa]{V_0 R})^{\kappa-1}}{V_0} = \frac{\kappa R^{(\kappa-1)/\kappa}}{V_0^{1/\kappa}} = P(R)$
- Given friction coef ϕ
 - sent to burning agent address: $\Delta R_{agent} = (1 - \phi)\Delta R$
 - sent to the funding pool address: $\Delta R_{pool} = \phi\Delta R$
 - due to the friction the true realized price for the agent is $(1 - \phi) \cdot \bar{P}(\Delta S)$
 - due to the friction the true return factor post withdraw is: $\kappa(1 - \theta)(1 - \phi)$

Bonding curve parameter analysis

```
V0 = invariant(R0,S0,kappa)
```

```
reserve = np.arange(0,100,.01)
```

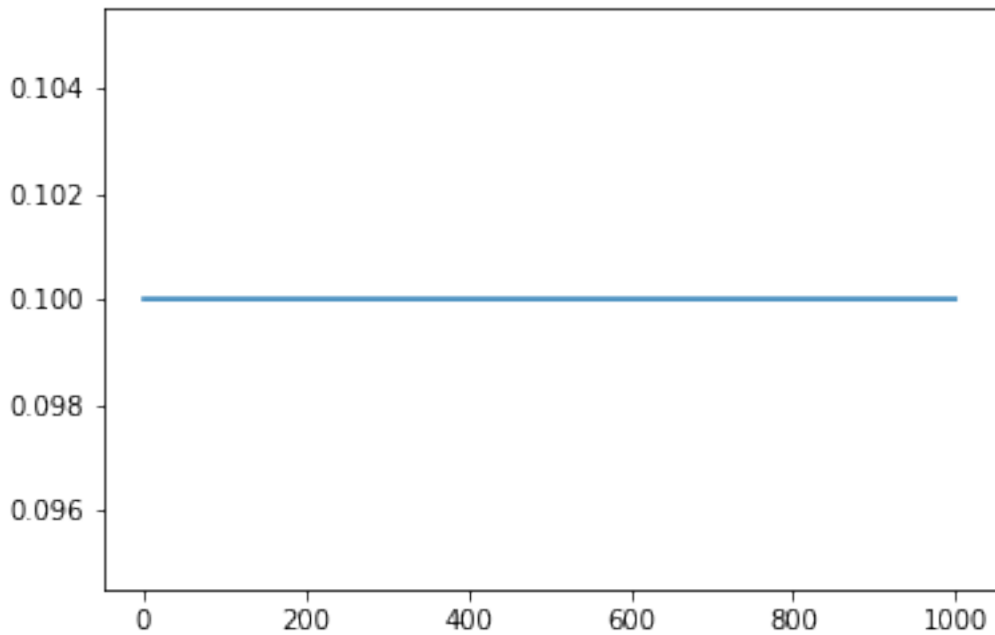
```
supp = np.array([supply(r, V0, kappa) for r in reserve])
```

```
price = np.array([spot_price(r, V0, kappa) for r in reserve])
```

```
fig, axs = plt.subplots()
```

```
axs.plot(supp, price)
```

```
[<matplotlib.lines.Line2D at 0x7fc644ed5f28>]
```



```

V0 = invariant(R0,S0,kappa)

reserve = np.arange(0,100,.01)
supp = np.array([supply(r, V0, kappa) for r in reserve])
price = np.array([spot_price(r, V0, kappa) for r in reserve])

fig, ax1 = plt.subplots()

color = 'tab:red'
ax1.set_xlabel('Reserve (Millions of xDAI)')
ax1.set_ylabel('Supply (Millions of Tokens)', color=color)
ax1.plot(reserve, supp, '--', color=color)
ax1.tick_params(axis='y', labelcolor=color)

ax2 = ax1.twinx() # instantiate a second axes that shares the same x-axis

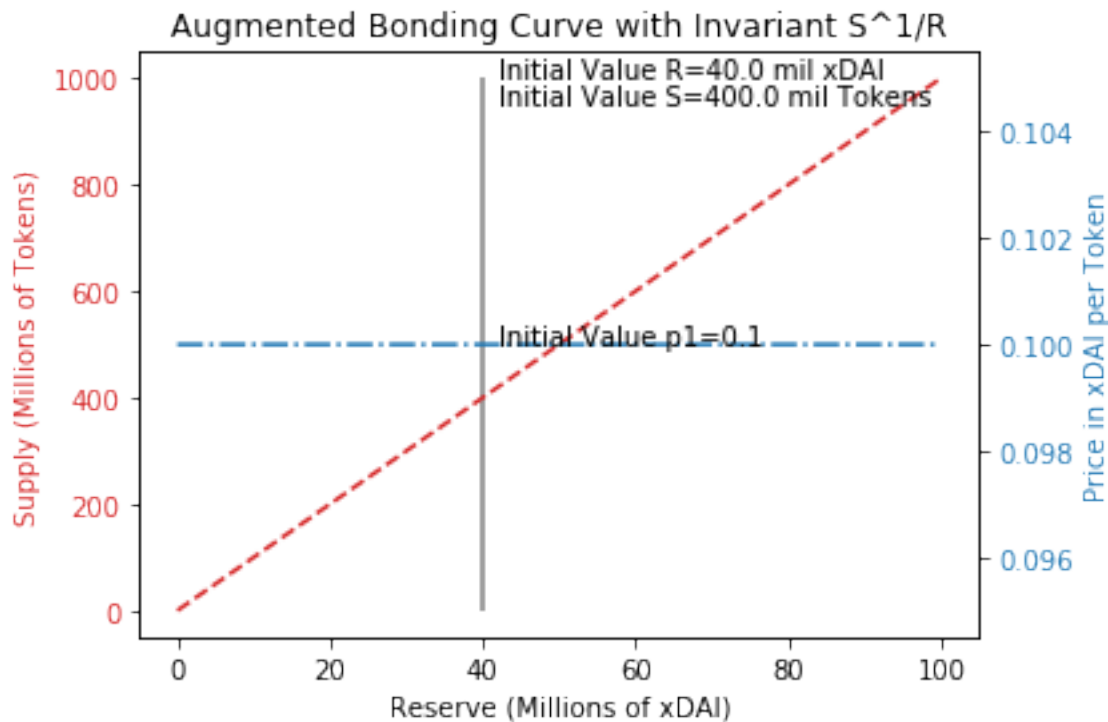
color = 'tab:blue'
ax2.set_ylabel('Price in xDAI per Token', color=color) # we already handled the x-label with ax1
ax2.plot(reserve, price, '-.', color=color)
ax2.tick_params(axis='y', labelcolor=color)

ax1.vlines(R0,0,supp[-1], alpha=.5)
ax1.text(R0+.02*reserve[-1], supp[-1], "Initial Value R="+str(int(100*R0)/100)+" mil xDAI")
ax1.text(R0+.02*reserve[-1], .95*supp[-1], "Initial Value S="+str(S0)+" mil Tokens")
#ax1.hlines(S0,0,R0)

ax2.text(R0+.02*reserve[-1], price[3], "Initial Value p1="+str(int(100*spot_price(R0,V0,kappa))/100))

plt.title('Augmented Bonding Curve with Invariant  $S^{\kappa}+R$ ')
fig.tight_layout() # otherwise the right y-label is slightly clipped
plt.show()

```



```
fig, ax1 = plt.subplots()

cp = 100
color = 'tab:red'
ax1.set_xlabel('Supply (Millions of Tokens)')
ax1.set_ylabel('Reserve (Millions of xDAI)', color=color)
ax1.plot(supp[cp:], reserve[cp:], '--', color=color)
ax1.tick_params(axis='y', labelcolor=color)

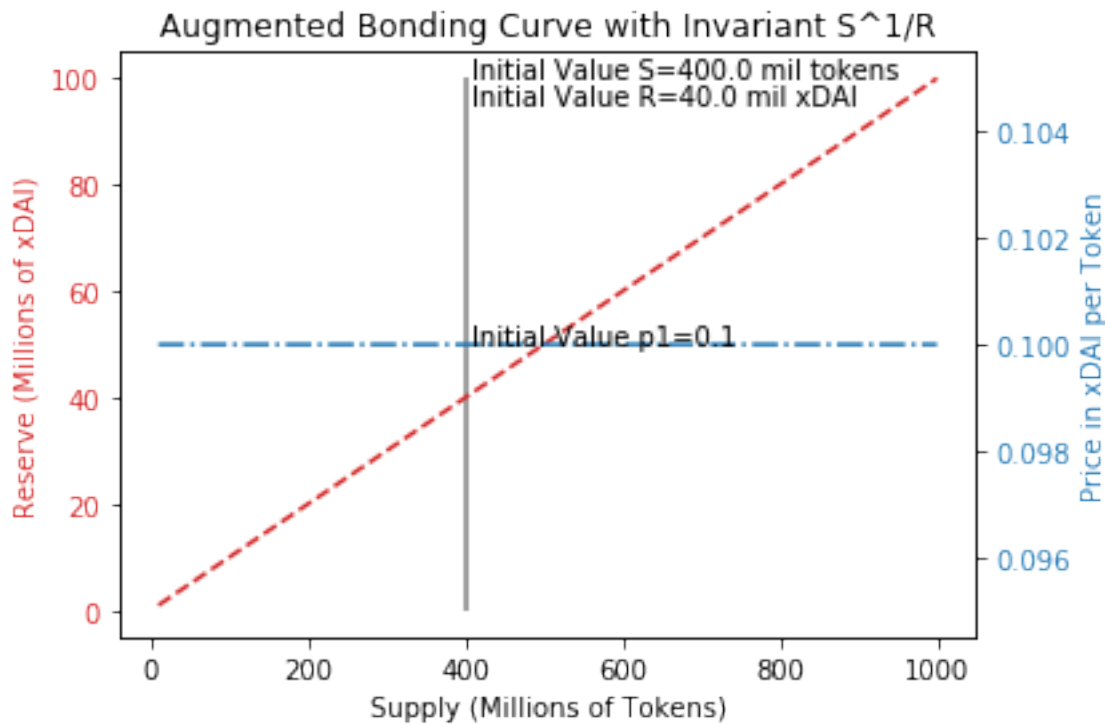
ax2 = ax1.twinx() # instantiate a second axes that shares the same x-axis

color = 'tab:blue'
ax2.set_ylabel('Price in xDAI per Token', color=color) # we already handled the x-label with ax1
ax2.plot(supp[cp:], price[cp:], '-.', color=color)
ax2.tick_params(axis='y', labelcolor=color)

ax1.vlines(S0,0,reserve[-1], alpha=.5)
ax1.text(S0*1.02, reserve[-1], "Initial Value S="+str(int(100*S0)/100)+" mil tokens")
ax1.text(S0*1.02, .95*reserve[-1], "Initial Value R="+str(R0)+" mil xDAI")
#ax1.hlines(S0,0,R0)

ax2.text(S0*1.02, price[3], "Initial Value p1="+str(int(100*spot_price(R0,V0,kappa))/100))

plt.title('Augmented Bonding Curve with Invariant S1/R')
fig.tight_layout() # otherwise the right y-label is slightly clipped
plt.show()
```



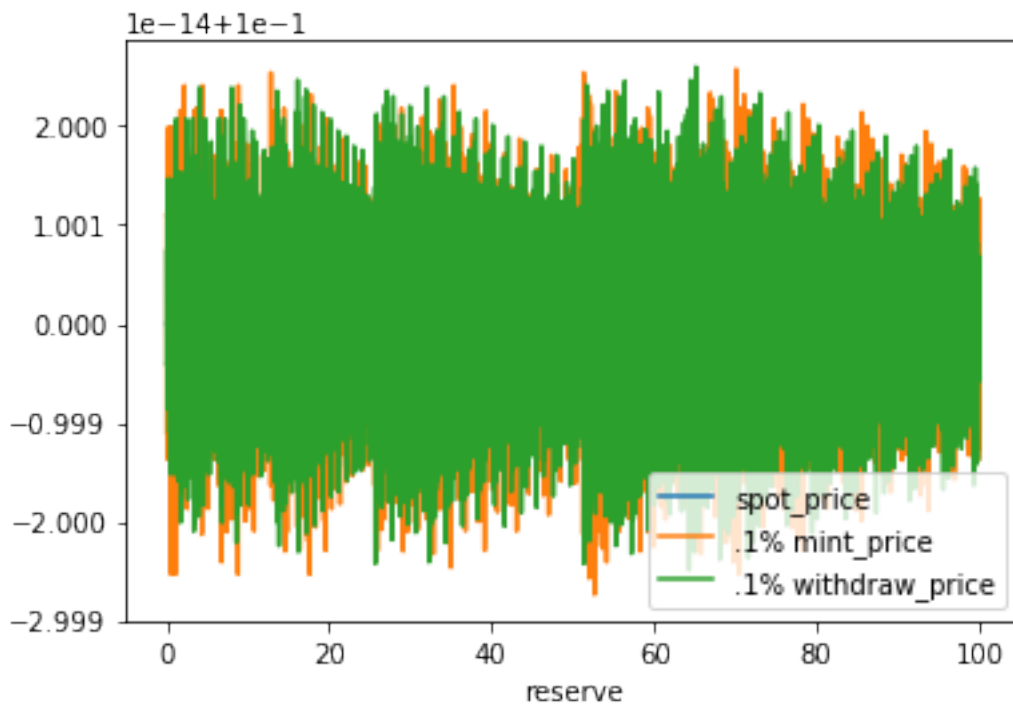
```
#given V0 and kappa
#sweep the reserve
reserve = None
reserve = np.arange(.01,100,.01)
price = np.array([spot_price(r,V0,kappa) for r in reserve])

#realized price for withdrawing burning .1% of tokens
withdraw_price=[withdraw(supply(r,V0,kappa)/1000, r,supply(r,V0,kappa), V0, kappa)[1] for r in reserve]

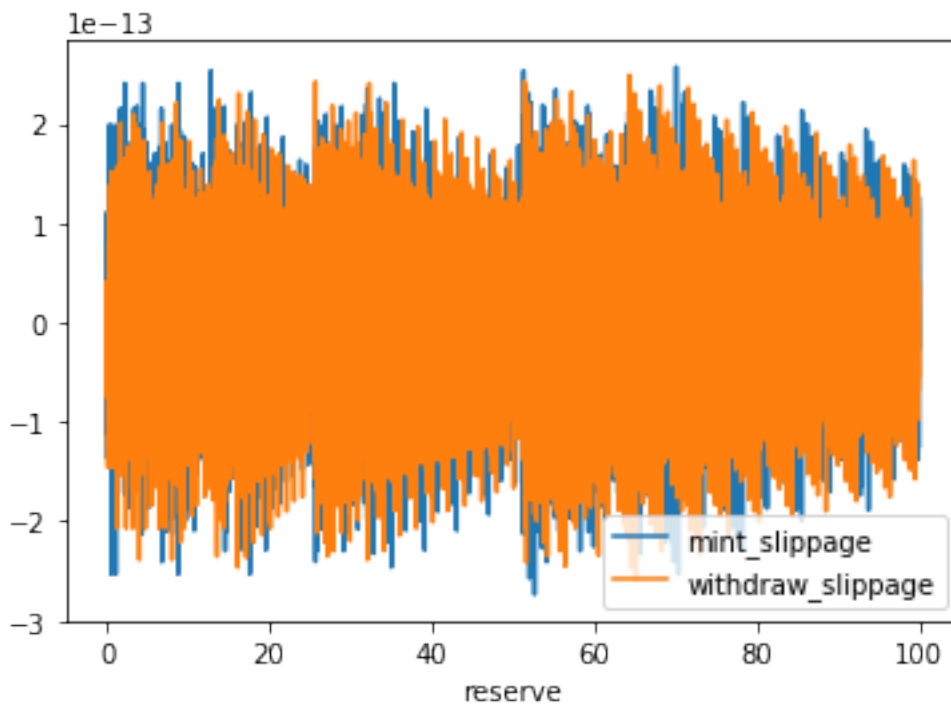
#realized price for depositing .1% more Xdai into the reserve
mint_price=[mint(r/1000, r, supply(r,V0,kappa), V0, kappa)[1] for r in reserve]

pdf = pd.DataFrame({'reserve':reserve, 'spot_price':price, '.1% mint_price':mint_price, '.1% withdraw_price':withdraw_price})
pdf.plot(x='reserve')
```

<matplotlib.axes._subplots.AxesSubplot at 0x7fc638120320>



```
pdf['mint_slippage'] = (pdf['.1% mint_price']-pdf['spot_price'])/pdf['spot_price']
pdf['withdraw_slippage'] = (pdf['spot_price']-pdf['.1% withdraw_price'])/pdf['spot_price']
pdf.plot(x='reserve', y = ['mint_slippage', 'withdraw_slippage'])#, logy=True)
<matplotlib.axes._subplots.AxesSubplot at 0x7fc622438710>
```



```
#given V0 and kappa
R = 20
S = supply(R,V0,kappa)
p = spot_price(R,V0,kappa)
```

```

#sweep the transaction fraction
TXF = np.logspace(-6, 0, num=1000)

#realized price for withdrawing burning .1% of tokens
withdraw_price2=[withdraw(S*txf, R,S, V0, kappa)[1] for txf in TXF]

#realized price for depositing .1% more Xdai into the reserve
mint_price2=[mint(R*txf, R,S, V0, kappa)[1] for txf in TXF]

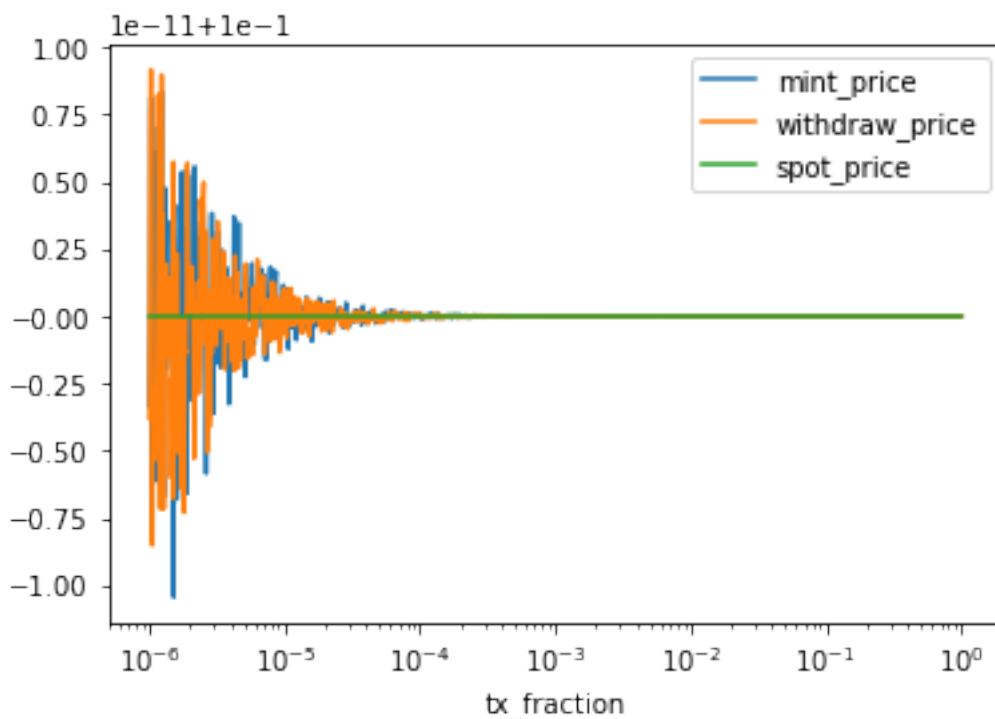
print(S)

200.0

pdf2 = pd.DataFrame({'tx_fraction':TXF, 'spot_price':p*np.ones(len(TXF)), 'mint_price':mint_price2,'withdraw_price':withdraw_price2})
pdf2.plot(x='tx_fraction',y=['mint_price','withdraw_price','spot_price'], logx=True)

<matplotlib.axes._subplots.AxesSubplot at 0x7fc6226cf9b0>

```



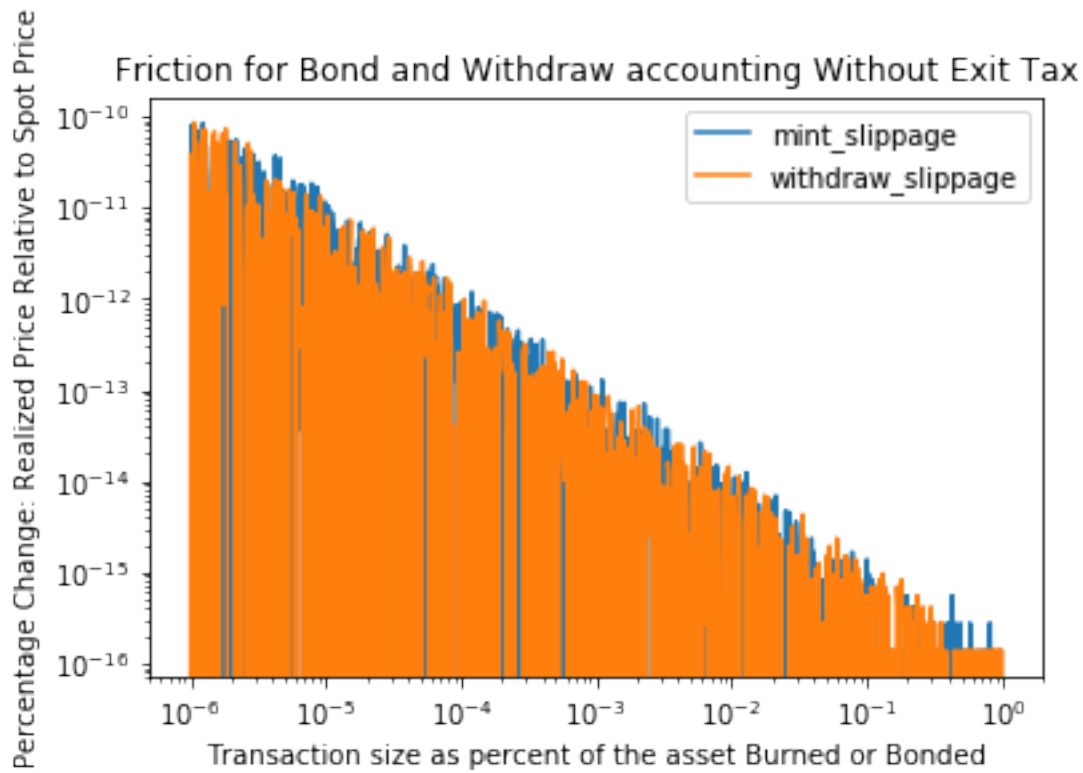
```

pdf2['mint_slippage'] = (pdf2['mint_price']-pdf2['spot_price'])/pdf2['spot_price']
pdf2['withdraw_slippage'] = (pdf2['spot_price']-pdf2['withdraw_price'])/pdf2['spot_price']

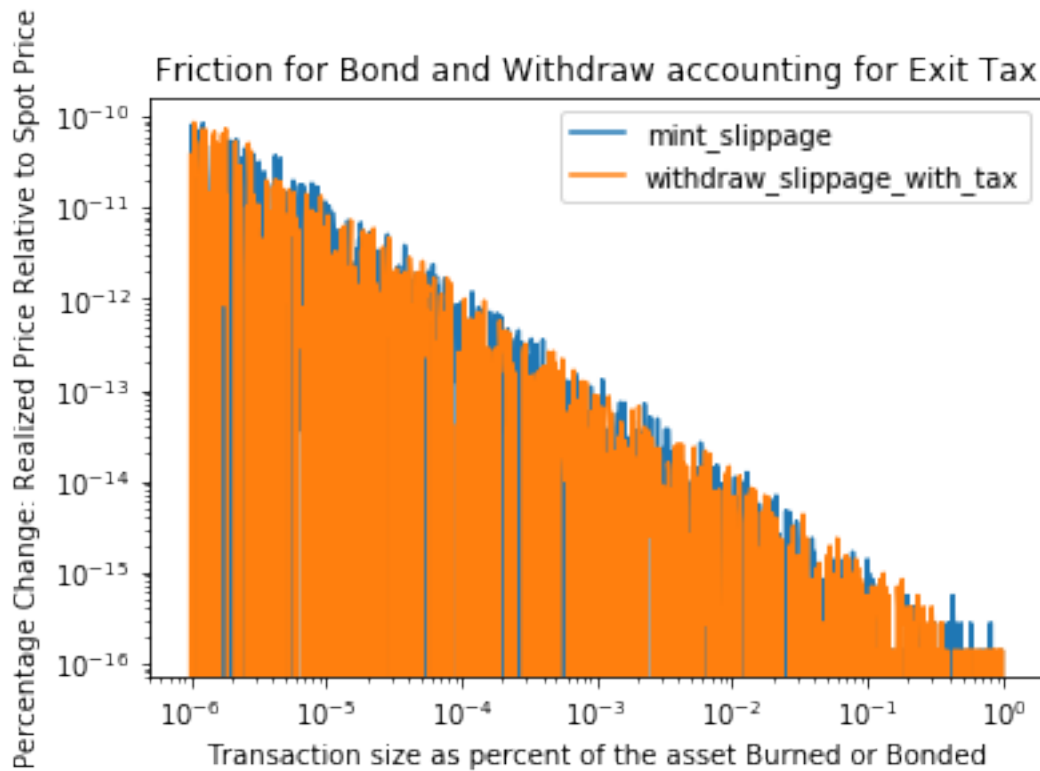
pdf2.plot(x='tx_fraction', y = ['mint_slippage', 'withdraw_slippage'], logx=True, logy=True)
plt.title("Friction for Bond and Withdraw accounting Without Exit Tax")
plt.ylabel("Percentage Change: Realized Price Relative to Spot Price")
plt.xlabel("Transaction size as percent of the asset Burned or Bonded")

Text(0.5, 0, 'Transaction size as percent of the asset Burned or Bonded')

```



```
pdf2['withdraw_slippage_with_tax'] = pdf2['withdraw_slippage']+tax
pdf2.plot(x='tx_fraction', y = ['mint_slippage', 'withdraw_slippage_with_tax'], logx=True, logy=True)
plt.title("Friction for Bond and Withdraw accounting for Exit Tax")
plt.ylabel("Percentage Change: Realized Price Relative to Spot Price")
plt.xlabel("Transaction size as percent of the asset Burned or Bonded")
Text(0.5, 0, 'Transaction size as percent of the asset Burned or Bonded')
```



```
Kappa_List = [1,2,4,6,8]
for kappa in Kappa_List:

    V0 = invariant(R0,S0,kappa)

    reserve = np.arange(0,100,.01)
    supp = np.array([supply(r, V0, kappa) for r in reserve])
    price = np.array([spot_price(r, V0, kappa) for r in reserve])

    fig, ax1 = plt.subplots()

    color = 'tab:red'
    ax1.set_xlabel('Reserve (Millions of xDAI)')
    ax1.set_ylabel('Supply (Millions of Tokens)', color=color)
    ax1.plot(reserve, supp, '--', color=color)
    ax1.tick_params(axis='y', labelcolor=color)

    ax2 = ax1.twinx() # instantiate a second axes that shares the same x-axis

    color = 'tab:blue'
    ax2.set_ylabel('Price in xDAI per Token', color=color) # we already handled the x-label with ax1
    ax2.plot(reserve, price, '-', color=color)
    ax2.tick_params(axis='y', labelcolor=color)

    ax1.vlines(R0,0,supp[-1], alpha=.5)
    ax1.text(R0+.02*reserve[-1], supp[-1], "Initial Value R="+str(int(100*R0)/100)+" mil xDAI")
    ax1.text(R0+.02*reserve[-1], .95*supp[-1], "Initial Value S="+str(int(100*S0)/100)+" mil Tokens")
    #ax1.hlines(S0,0,R0)

    ax2.text(R0+.02*reserve[-1], price[3], "Initial Value p1="+str(int(1000*spot_price(R0,V0,kappa))/1000))
```



```
plt.title('Augmented Bonding Curve with Invariant  $S^{1/R}$ ')
fig.tight_layout() # otherwise the right y-label is slightly clipped
plt.show()
```

