Externalities as Arbitrage

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Introduction

- Recently: persistent arbitrages with very short horizons
  - CIP: Du et al. [2018], FF-IOER Bech and Klee [2011]
  - Caused by regulation (Duffie and Krishnamurthy [2016], Bräuning and Puria [2017])
- Questions:
  - If regulation creates arbitrage, does that mean something has gone wrong?
  - What kinds of arbitrage should we observe if regulation is optimal?
  - More generally, how can we determine if macro-prudential policies are optimal?
- My answers:
  - No, optimal regulations should create arbitrage
  - The direction of arbitrage for an asset should depend on the covariance between the asset’s payoff and the externalities being addressed
  - We can study arbitrages and recover the externalities that would rationalize them
• Suppose assets $a$ and $a'$ have identical payoffs, different prices
  • and $a$ is traded by households and intermediaries (e.g. cash asset)
  • while $a'$ is int.-only (e.g. derivative)
  • examples: CIP, bond-cds basis, etc...
• An apparent arbitrage (LoOP violation) exists
• Intermediaries would like to do this arbitrage
  • we infer: a constraint prevents them from doing so
  • suppose constraint is regulatory (e.g. leverage ratio)
Now suppose household wants to buy \( a \) from intermediary

If price of \( a \) higher than \( a' \) \((Q_a > Q_{a'})\), intermediary thinks about hedging

- sell \( a \) to household, buy \( a' \) from another int., profit
- but this will cause constraint to tighten (e.g. use balance sheet)

We infer: regulatory constraint prevents int. from selling \( a \) to household

- keeps risk of \( a \) in intermediary-sector instead of household sector
- macro-prudential perspective: is this a good idea?
Results and Speculation

- Concretely: CIP violations [Du et al., 2018]
  - leverage constraints interact with customer demand to create CIP violations
  - sign of customer demand = carry trade direction
  - carry trade is risky (positive exp. returns, bad returns in stress scenario)
  - therefore, leverage constraints keep risk inside banking sector
  - inconsistent with wanting higher bank wealth in stress scenario/bad times

- Policy:
  - right now, fed checks leverage ratio in stress scenario
  - suggestion: check asset return in stress scenario instead
  - avoids penalizing hedging trades (e.g. long JPY/short USD) that use balance sheet
This Paper

- Outline MB = MC argument
- Show assumption and “externalities as arbitrage” result
- Example based on Fanelli and Straub [2019]
- Conduct revealed preference exercise: if policy creating arbitrages is optimal, what are the externalities? Do they make sense?
  1. Gather data on arbitrages (CIP, FF-IOER) and variance-covariance matrix
  2. Construct “externality-mimicking portfolio” (EMP)
  3. Test expected returns and stress scenario returns of EMP
- Conclusion: recovered externalities do not make sense
  - CIP violations have the wrong sign
Externalities as Arbitrage

- Optimal regulations equates marginal benefits and marginal costs
- Marginal benefits: address externalities by re-allocating consumption
  - between agents, across states and time
- Marginal costs: distorting risk-sharing and intertemporal trade
- Assumption: policy implemented via quantity regulation on financial intermediaries
- Result: risk-sharing distortions manifest as arbitrage
- Implication: externalities as arbitrage under optimal policies
Two types of agents:
- Intermediaries (banks) $i \in \mathcal{I}$, can trade all assets
- Heterogenous households $h \in \mathcal{H}$,
  - can trade some assets, only via intermediaries (as in Gromb and Vayanos [2002])
  - Planner can implement any allocation via regulations on ints.

State $s_0$ at date zero, set $S_1$ in date one
- $S = S_1 \cup \{s_0\}$

Set of goods $J_s$ in state $s \in S$, prices $P_{j,s}$, socially optimal prices $P^*_{j,s}$

Assets $a \in A$, with payoff $Z^*_a,s = Z_a,s(\{P^*_{j,s}\}_{j \in J_s})$
- $Q_a$: price for asset
Wedges

- Let $P_{j,s}^* + \mu_{j,s}$ be the social value of a good in money units
  - $\mu_{j,s}$ is the multiplier in planner’s problem on market clearing
- When welfare theorems hold: $P_{j,s}^*$ proportional to $P_{j,s}^* + \mu_{j,s}$
- When welfare theorems fail: $P_{j,s}^*$ not proportional to $P_{j,s}^* + \mu_{j,s}$
  - e.g. incomplete markets, prices in constraints, nominal rigidities
- “Wedges” $\tau^r_{j,s}$ measure welfare theorem failure:
  
  $$\pi^r_s \tau^r_{j,s} = -\frac{P_{j,s}^* + \mu_{j,s}}{P_{j,s}^*} + \frac{1}{|J_s|} \sum_{j' \in J_s} \frac{P_{j',s}^* + \mu_{j',s}}{P_{j',s}^*}$$

  - $\pi^r_s$: reference probability measure
  - $\tau^r_{j,s}$: ratio of social cost to price for $j$ in state $s$, vs. avg of all goods in $s$
  - $\tau^r_{j,s} > 0$: price high relative to social cost
• $X_{i,j,s}^h$: $h$’s income effect for $j$ in state $s$ under optimal policies

• Add up “wedges” $\tau_{j,s}^r$ weighted by income effects:

$$\Delta_{s}^{h,i,r} = \sum_{j \in J_s} P_{j,s}^* \tau_{j,s}^r (X_{i,j,s}^h - X_{i,j,s}^i)$$

• I will call $\Delta_{s}^{h,i,r}$ the “externalities”
  • Benefit to planner of moving income from $i$ to $h$ in $s$
  • Sign: positive (negative) when moving income from $i$ to $h$ is good (bad)

• Planner trades off addressing these externalities with risk-sharing distortions
  • tradeoff follows from planner’s FOC, ability to do transfers in $s_0$
  • transfers in $s_0$ ensure planners goal is “macro-pru” not redistribution
MC=MB

- $M_s^{h,r}$: $h$’s SDF under optimal policies, reference measure $\pi_s^r$
  - ratio of marginal utility of income in $s$ vs. $s_0$
- MB (addressing externalities) equals MC (distorting risk-sharing):
  \[
  \sum_{s \in S_1} \pi_s^r \Delta_s^{h,i,r} Z_{a,s}^* = \sum_{s \in S_1} \pi_s^r (M_s^{i,r} - M_s^{h,r}) Z_{a,s}^*
  \]

  \begin{align*}
  \text{Addressing Externalities} & & \text{Distorting Risk-Sharing}
  \end{align*}

- See also Farhi and Werning [2016]
- assumes exogenous constraints do not prevent reallocating asset
Implementation Assumptions

1. Quantity regulations on intermediaries only (i.e. not on households)
   - e.g. capital and LTV requirements as opposed to fees and taxes
2. Intermediary $i^* \in I$ unconstrained for intermediary-only assets $A^l$
   - e.g. derivatives lightly regulated

- Result: these assumptions are without loss of generality
- Implication: arbitrage between assets traded by $h$ and intermediary-only assets
- $A^*$: set of arbitrage-able assets
  - traded by households, replicating portfolio traded by $i$’s only
  - $w_{a'}(a)$: replicating portfolio weights, $Z_{a,s}(\cdot) = \sum_{a' \in A^l} w_{a'}(a) Z_{a',s}(\cdot)$
Proposition 1
The planner can implement the solution to the constrained planning problem using portfolio constraints on intermediaries only, and without constraining the trades of at least one intermediary, $i^* \in I$, in the intermediary-only assets $A^I$.

In this implementation, for any arbitrage-able asset $a \in A^*$ that is tradable by household $h$,

$$-Q_a + \sum_{a' \in A^I} w_{a'}(a)Q_{a'} = \sum_{s \in S_1} \pi^r_s \Delta^{h,i^*,r}_{s} Z^{*}_{a,s}$$

where

- $Q_a$ represents the arbitrage violation
- $\sum_{a' \in A^I} w_{a'}(a)Q_{a'}$ is the expected externality-weighted payoffs

Equation (1)
• Capital controls example based on Fanelli and Straub [2019]
• Initial state $s_0$, future states $S_1 = \{g, b\}$, probabilities $\pi^D_s$
• Goods $J_s = \{T, NT\}$, common discount factor $\beta$
• Tradables are numeraire, fixed domestic price index
  • exchange rate $e_s = (P_{NT,s})^{1-\alpha}$
• Ricardian and non-participant households, $H = \{r, n\}$
  • foreign ($a_{fc}$) and domestic ($a_{dc}$) risk-free bonds, tradable by $r$ but not $n$
  • Cobb–Douglas preferences over $T$ and $NT$, log utility
• Foreign intermediaries risk-neutral, only consume tradables
  • can trade int.-only f.c. bond $a_I$, currency forward $a_F$ at strike $F$
• Assumption: $n$ endowed with all non-tradables
  • $n$ also endowed with tradables, more in state $g$ than $b$
  • all other endowments same in both states

• $n$ cannot participate in markets, relative to $r$ has high MU in state $b$

• Planner wants to increase $P_{NT,b}$ to help $n$
  • $\mu_{NT,s}$: money-metric multiplier on market clearing constraint in planner’s problem
  • key idea: if market-clearing prices max welfare, $\mu_{NT,s} = 0$ (first welfare theorem)
  • if not, pecuniary externalities don’t cancel (in this case, b/c incomplete markets)
  • measure by “wedges” $\tau^P_{j,s}$, $\pi^p_s \tau^P_{NT,s} = -\frac{1}{2} \frac{\mu_{NT,s}}{P^*_s}$
  • Geanakoplos and Polemarchakis [1986], Farhi and Werning [2016]
Example Externalities and Arbitrage

• How to increase $P_{NT,b}$? transfer wealth foreign ints. $i$ to $r$
  • increase demand for non-tradable
  • Measure benefit ($\Delta_{b}^{r,i,p} > 0$):
    \[
    \Delta_{s}^{r,i,p} = \sum_{j \in J_{s}} P_{j,s}^{*} \pi_{j,s}^{p} \left( X_{l,j,s}^{r} - X_{l,j,s}^{i} \right)
    \]
    change in demand due to income transfer

• Implementation: limit foreign currency borrowing by $r$
  • cost: borrowing limit creates wedge between SDFs $M_{S}^{r}$ and $M_{S}^{i}$
  • arbitrage between fc/dc bonds traded by $r$ and forward/risk-free rates for $i$-only:
    \[
    Q_{a_i} - Q_{a_{fc}} = \pi_{g}^{p} \Delta_{g}^{r,i,p} + \pi_{b}^{p} \Delta_{b}^{r,i,p},
    \]
    risk-free rate arbitrage
    \[
    F \times Q_{a_i} + Q_{a_F} - Q_{a_{dc}} = \pi_{g}^{p} \Delta_{g}^{r,i,p} (P_{NT,g}^{*})^{1-\alpha} + \pi_{b}^{p} \Delta_{b}^{r,i,p} (P_{NT,b}^{*})^{1-\alpha}.
    \]
    CIP violation
• Now imagine a financial economist who observes arbitrages for \( a \in A^* \)
  • preceding example: \( A^* = \{a_{fc}, a_{dc}\} \)
• Can we recover the externalities \( \Delta_s^{h,i,r} \)?
  • Defined with reference to some \( \pi_s^r \)
  • Possibly incomplete markets: more states than \( a \in A^* \)
• Idea: make externality-mimicking portfolio (EMP) whose returns are the (projected) externalities
• Use returns \( R_{a,s} = \frac{Z_{a,s}}{Q_a}, R_{a,s}^l = (1 - \chi_a)R_{a,s} \)

\[
\chi_a = \frac{-Q_a + \sum_{a' \in A^l} w'(a) Q_{a'}}{\sum_{a' \in A^l} w'(a) Q_{a'}}
\]
Example: Inverting the Arbitrages

- Example equations in matrix form:

\[
\begin{bmatrix}
\chi_{a_{fc}} \\
\chi_{a_{dc}}
\end{bmatrix} =
\begin{bmatrix}
\pi_{g} R_{a_{fc},g}^{l} & \pi_{b} R_{a_{fc},b}^{l} \\
\pi_{g} R_{a_{dc},g}^{l} & \pi_{b} R_{a_{dc},b}^{l}
\end{bmatrix}
\cdot
\begin{bmatrix}
\Delta_{g}^{r,i,p} \\
\Delta_{b}^{r,i,p}
\end{bmatrix}
\]

- We want:

\[
\begin{bmatrix}
\Delta_{g}^{r,i,p} \\
\Delta_{b}^{r,i,p}
\end{bmatrix} =
\begin{bmatrix}
R_{a_{fc},g}^{l} & R_{a_{dc},g}^{l} \\
R_{a_{fc},b}^{l} & R_{a_{dc},b}^{l}
\end{bmatrix}
\cdot
\begin{bmatrix}
\theta_{a_{fc}}^{*} \\
\theta_{a_{dc}}^{*}
\end{bmatrix}
\]

- We solve:

\[
\begin{bmatrix}
\theta_{a_{fc}}^{*} \\
\theta_{a_{dc}}^{*}
\end{bmatrix} =
\left(\begin{bmatrix}
R_{a_{fc},g}^{l} & R_{a_{dc},g}^{l} \\
R_{a_{fc},b}^{l} & R_{a_{dc},b}^{l}
\end{bmatrix}\right)^{-1}
\cdot
\begin{bmatrix}
\pi_{g} R_{a_{fc},g}^{l} & \pi_{b} R_{a_{fc},b}^{l} \\
\pi_{g} R_{a_{dc},g}^{l} & \pi_{b} R_{a_{dc},b}^{l}
\end{bmatrix}
\cdot
\begin{bmatrix}
\chi_{a_{fc}} \\
\chi_{a_{dc}}
\end{bmatrix}
\]

inverse second moment matrix of \(R_{a,s}^{l}\)
Recovering Externalities

- This inversion is the projection of $\Delta_{s,i,r}$ on to the return space
  - $R_{a,s}^l$ and $R_{a,s}$ are the same return spaces
  - Like projecting an SDF on to payoff space (Hansen and Richard [1987])
  - uses standard “L2” projection
  - projection works without $A^*$ being a complete market
- Assume positive-price assets, one risk-free asset in $A^*$
  - e.g. price of 1 yen in one month, in USD today
- Expected return vector $\mu_{A^*,r}$ and cov. matrix $\Sigma_{A^*,r}$
  - for risky returns $R_{a,s}$, $\mu_{A^*,l,r}$ and $\Sigma_{A^*,l,r}$ for $R_{a,s}^l$
- Arbitrage vector $\chi_{A^*}$, risk-free arbitrage $\chi_f$, $R_f = (1 - \chi_f)R_f^l$
Definition 1

The externality-mimicking portfolio is a portfolio of the replicating portfolios of $A^*$, with weights on the risky replicating portfolios equal to

$$\theta^{A^*, r} = \left(\Sigma^{A^*, I, r}\right)^{-1} \left(\chi^{A^*} - \chi_f \frac{\mu^{A^*, I, r}}{R_f^l}\right),$$

and a weight on the risk-free replicating portfolio equal to

$$\theta^{A^*, r}_f = -\left(\theta^{A^*, r}\right) T \frac{\mu^{A^*, I, r}}{R_f^l} + \frac{1}{(R_f^l)^2} \chi_f.$$

• defined as “portfolio of replicating portfolios” for $a \in A^*$
The EMP has the following properties:

1. The externalities are the return on the externality mimicking portfolio plus a zero-mean residual:

   \[ \Delta_{s,i,r}^{h,i,r} = \sum_{a \in A^*} R_{a,s}^l \theta_{a}^{A^*}, r + \epsilon_{s}^{A^*}, r, \]

   \[ \sum_{s \in S_1} \pi_{s}^{r} R_{a,s}^l \epsilon_{s}^{A^*}, r = 0 \quad \forall a \in A^*. \]

2. The variance of the externalities under the reference measure,

   \[ \sum_{s \in S_1} \pi_{s}^{r} (\Delta_{s,i,r}^{h,i,r} - \frac{\chi_{f}}{R_{f}^l})^2, \]

   is weakly greater than the variance of the externality-mimicking portfolio’s return,

   \[ (\theta_{A^*}, r)^T \sum_{A^*}^{l}, r \theta_{A^*}, r. \]
3. Let $m^{l,r}_s$ be any SDF that prices the replicating portfolios under the measure $\pi^r_s$. Then $m^r_s = m^{l,r}_s + \sum_{a \in A^*} R_{a,s} A^*_a$ is the solution to the problem:

$$\min_{m \in \mathbb{R}^{|S_1|}} \sum_{s \in S_1} \pi^r_s (m_s - m^{l,r}_s)^2$$
subject to

$$\sum_{s \in S_1} \pi^r_s m_s R_{a,s} = 1 \quad \forall a \in A^*.$$ 

4. The Sharpe ratio due to arbitrage,

$$\hat{S}^{A^*,l,r}(\theta) = \frac{\theta^T \cdot (\chi^{A^*} - \chi_f \frac{\mu^{A^*,l,r}}{R_f})}{\left(\theta^T \Sigma^{A^*,l,r} \theta\right)^{\frac{1}{2}}}$$

is maximal for the EMP among portfolios of replicating portfolios of assets in $A^*$. 

HJ Bounds and the EMP
Interpretation

- Portfolio (generally) has negative returns when $\Delta_s^{h,i,r}$ is negative
  - Planner wants to transfer wealth to ints from households
  - -10%: for planner, $1$ loss for $h$ is $\sim$ $1.1$ gain for $i$
  - because this fixes externalities

- Analogy: Revealed Preference

- Which reference measure to use?
  - Two obvious choices: physical $\pi^p_s$ and risk-neutral $\pi^q_s$
  - $\pi^p_s \Delta_s^{h,i,p} = \pi^q_s \Delta_s^{h,i,q}$
Constructing the externality-mimicking portfolio requires three ingredients:

1. A set of arbitrage-able assets $A^*$,
2. Prices for both the arbitrage-able assets in $A^*$ and their replicating portfolios, and
3. Expected returns and a variance-covariance matrix for the assets in $A^*$.

- using risk-neutral measure convenient b/c expected returns $=$ risk free rate
  - but will still need expected returns later
- can get risk-neutral cov. matrix from options (at least for currencies)
- constructing the EMP is easy; the next step is to use it
Expected Return Test

- What should the covariance be between $\Delta_s^{h,i,q}$ and $\frac{\pi_s^q}{\pi_s^p}$ be?
  - bad times: $\Delta_s^{h,i,q}$ negative, SDF high?
  - Covariance should be negative

- Observe:

$$\text{Cov}_p\left(\frac{\pi_s^i}{\pi_s^p}, \Delta_s^{h,i,i}\right) = \left(\frac{\tilde{\chi}_f}{R_f} - \sum_{s \in S_1} \pi_s^p \Delta_s^{h,i,i}\right)$$

$$= - (\theta^{A^*,i})^T (\mu^{A^*,I,p} - R_f) + \text{Cov}_p\left(\frac{\pi_s^i}{\pi_s^p}, \epsilon_s^{A^*,i}\right).$$

- Simple test: check excess returns on tracking portfolio
  - Should be positive, subject to “unspanned externalities”
What should $\Delta_{s}^{h,i,q}$ be in the Fed’s stress test scenario?

- Stress test scenario is when Fed wants intermediaries to have more wealth
- Intermediaries must trade with households to make this happen
- Therefore, $\Delta_{s}^{h,i,q}$ negative in the stress scenario

Stress tests conducted annually

- Stress test scenarios from Fed website
- Consider one and four quarter returns
- But pretend they happen in one month
Empirical Strategy

- Use $/Euro, $/AUD, and $/Yen in Portfolio
  - IOER and OIS rates are risk-free rates
  - $\Sigma^q$ is covariance matrix using intermediary risk-neutral measure
  - Use 1-month atm-option-implied variance-covariance

- Look at arbitrages at daily frequency
  - Use a one-month horizon
  - Look only at dates $> 1m$ before FOMC meeting

- Expected returns: assume log exchange rates are random walks
### Table 1: Summary Statistics for Arbitrage

<table>
<thead>
<tr>
<th></th>
<th>Pounds</th>
<th>Euros</th>
<th>Yen</th>
<th>AUD</th>
<th>OIS-IOER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arbitrage Mean (bps/year)</td>
<td>6.7</td>
<td>22.4</td>
<td>28.3</td>
<td>-15.4</td>
<td>-12.5</td>
</tr>
<tr>
<td>Arbitrage SD (bps/year)</td>
<td>28.2</td>
<td>37.7</td>
<td>37.2</td>
<td>18.5</td>
<td>2.8</td>
</tr>
<tr>
<td>OI Vol. (bps/year)</td>
<td>859</td>
<td>950</td>
<td>977</td>
<td>1073</td>
<td>-</td>
</tr>
<tr>
<td>OI Corr. with Pound/USD</td>
<td>1.00</td>
<td>0.56</td>
<td>0.22</td>
<td>0.47</td>
<td>-</td>
</tr>
<tr>
<td>OI Corr. with Euro/USD</td>
<td>0.56</td>
<td>1.00</td>
<td>0.31</td>
<td>0.51</td>
<td>-</td>
</tr>
<tr>
<td>OI Corr. with Yen/USD</td>
<td>0.22</td>
<td>0.31</td>
<td>1.00</td>
<td>0.26</td>
<td>-</td>
</tr>
<tr>
<td>Empirical Corr. with SPDR</td>
<td>0.23</td>
<td>0.10</td>
<td>-0.34</td>
<td>0.37</td>
<td>-</td>
</tr>
<tr>
<td>Empirical Corr. with HKM</td>
<td>0.26</td>
<td>0.17</td>
<td>-0.31</td>
<td>0.31</td>
<td>-</td>
</tr>
<tr>
<td>N</td>
<td>444</td>
<td>444</td>
<td>444</td>
<td>444</td>
<td>444</td>
</tr>
</tbody>
</table>
Time Series of Excess Arbitrage

![Graph of Time Series of Excess Arbitrage]

- **Excess Arb. (bps)**
- **Date**: 1-Jan-11, 1-Jan-12, 1-Jan-13, 1-Jan-14, 1-Jan-15, 1-Jan-16, 1-Jan-17, 1-Jan-18
- **Currencies**: JPY, EUR, AUD

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Hébert

Externalities as Arbitrage
Externality Mimicking Portfolio Weights

![Graph showing portfolio weights over time for JPY, EUR, and AUD from 1st January 2011 to 1st January 2018.]
Test #1: Expected Return

Note: top-coded at +/- 200% (esp. YE 2017)
# Table 2: Risk-Neutral EMP Expected Returns

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean (bps)</th>
<th>Standard Deviation (bps)</th>
<th>Test</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Sample</td>
<td>444</td>
<td>-222</td>
<td>25.9</td>
<td>≥ 0</td>
<td>0.0000</td>
</tr>
<tr>
<td>Quarter-Ends</td>
<td>155</td>
<td>-431</td>
<td>69.7</td>
<td>≥ 0</td>
<td>0.0000</td>
</tr>
<tr>
<td>Year-Ends</td>
<td>46</td>
<td>-1005</td>
<td>209.2</td>
<td>≥ 0</td>
<td>0.0000</td>
</tr>
<tr>
<td>QE - NQE</td>
<td></td>
<td>-321</td>
<td></td>
<td>= 0</td>
<td>0.0000</td>
</tr>
<tr>
<td>YE - NYE QE</td>
<td></td>
<td>-816</td>
<td></td>
<td>= 0</td>
<td>0.0000</td>
</tr>
</tbody>
</table>
## Stress Test Scenarios

### Table 3: Stress Test “Severely Adverse” Scenarios

<table>
<thead>
<tr>
<th>Stress Test Date</th>
<th>Euro One-Quarter Return</th>
<th>Euro Four-Quarter Return</th>
<th>Stocks One-Quarter Return</th>
<th>Stocks Four-Quarter Return</th>
<th>Yen One-Quarter Return</th>
<th>Yen Four-Quarter Return</th>
<th>AUD* One-Quarter Return</th>
<th>AUD* Four-Quarter Return</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/30/12</td>
<td>-7.7</td>
<td>-15.4</td>
<td>-19.3</td>
<td>-51.5</td>
<td>2.8</td>
<td>-1.0</td>
<td>-8.8</td>
<td>-24.5</td>
</tr>
<tr>
<td>9/30/13</td>
<td>-14.3</td>
<td>-21.4</td>
<td>-26.5</td>
<td>-49.5</td>
<td>3.1</td>
<td>-1.1</td>
<td>-17.2</td>
<td>-28.7</td>
</tr>
<tr>
<td>9/30/14</td>
<td>-12.0</td>
<td>-13.4</td>
<td>-16.3</td>
<td>-57.1</td>
<td>7.6</td>
<td>6.5</td>
<td>-5.1</td>
<td>-17.2</td>
</tr>
<tr>
<td>12/31/15</td>
<td>-7.7</td>
<td>-13.9</td>
<td>-20.2</td>
<td>-50.7</td>
<td>2.7</td>
<td>5.1</td>
<td>-7.7</td>
<td>-18.3</td>
</tr>
<tr>
<td>12/31/16</td>
<td>-9.1</td>
<td>-11.9</td>
<td>-34.0</td>
<td>-49.7</td>
<td>3.3</td>
<td>7.5</td>
<td>-17.0</td>
<td>-24.1</td>
</tr>
<tr>
<td>12/31/17</td>
<td>-6.6</td>
<td>-10.9</td>
<td>-51.3</td>
<td>-62.8</td>
<td>11.7</td>
<td>4.6</td>
<td>-23.7</td>
<td>-32.9</td>
</tr>
</tbody>
</table>

*Imputed
## Table 4: Risk-Neutral Returns in Stress Scenario

<table>
<thead>
<tr>
<th>Stress Test Date</th>
<th>N</th>
<th>Mean (1Q,%)</th>
<th>S.D. (1Q,%)</th>
<th>P-value (1Q)</th>
<th>Mean (4Q,%)</th>
<th>S.D. (4Q,%)</th>
<th>P-value (4Q)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/30/12</td>
<td>63</td>
<td>-0.8</td>
<td>0.3</td>
<td>0.9923</td>
<td>-1.8</td>
<td>1.0</td>
<td>0.9593</td>
</tr>
<tr>
<td>9/30/13</td>
<td>59</td>
<td>-0.9</td>
<td>0.4</td>
<td>0.9838</td>
<td>-2.1</td>
<td>0.7</td>
<td>0.9987</td>
</tr>
<tr>
<td>9/30/14</td>
<td>62</td>
<td>4.8</td>
<td>0.6</td>
<td>0.0000</td>
<td>9.9</td>
<td>1.0</td>
<td>0.0000</td>
</tr>
<tr>
<td>12/31/15</td>
<td>60</td>
<td>1.9</td>
<td>0.4</td>
<td>0.0000</td>
<td>4.5</td>
<td>0.8</td>
<td>0.0000</td>
</tr>
<tr>
<td>12/31/16</td>
<td>61</td>
<td>2.8</td>
<td>0.8</td>
<td>0.0000</td>
<td>7.0</td>
<td>1.2</td>
<td>0.0000</td>
</tr>
<tr>
<td>12/31/17</td>
<td>45</td>
<td>31.4</td>
<td>5.0</td>
<td>0.0000</td>
<td>28.6</td>
<td>4.3</td>
<td>0.0000</td>
</tr>
</tbody>
</table>
Robustness

- Use physical-measure and stress-test returns
  - similar results
- Add in equity-related arbitrage (SPDR vs SPY options)
  - expected return test similar, stress tests look better sometimes
- Use “dollar” and “carry” factors instead of specific currencies vs. USD
  - as in Lustig et al. [2011]
  - results similar
  - EMP is short dollar (makes sense), short carry (does not make sense)
Conclusion

- Under optimal policy, externalities appear as arbitrage
- Allows for revealed-preference exercise
- The EMP recovers externalities from observed arbitrage
- The externalities I recover do not fit with basic intuition
  - data: arb <0 for AUD, >0 for JPY—should be reverse
- Speculation: the problem is leverage constraints
  - leverage constraints don’t account for signs
  - customer demand for carry trade (Du et al. [2018])
  - i.e. customers want to take macro risk
  - but leverage ratios keep this risk inside banking system
References


Darrell Duffie and Arvind Krishnamurthy. Passthrough efficiency in the fed’s new monetary policy setting. 2016.


John Geanakoplos and Heraklis M Polemarchakis. Existence, regularity, and constrained suboptimality of competitive allocations when the asset market is incomplete.
