JACOBS LEVY EQUITY MANAGEMENT CENTER
FOR QUANTITATIVE FINANCIAL RESEARCH

Carry

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The Concept of Carry

- Concept of carry almost exclusively applied to currencies
  - Carry = interest rate differential
  - Main findings:
    - Uncovered interest-rate parity (UIP) fails
    - Carry trade earns significant risk-adjusted returns
    - Negative skewness reflecting large sudden crashes
    - Substantial exposure to liquidity and volatility risks
- We generalize the concept of carry to any asset

  Carry = "Return you earn if market conditions stay constant"

Carry and Returns: Key Questions

- Carry = "Return you earn if market conditions stay constant"
- Carry and returns:

$$\text{return} = \underbrace{\text{carry} + \text{E(price appreciation)}}_{\text{expected return}} + \text{unexpected price shock.}$$

  Carry is a characteristic of any asset that is *directly observable*

- Key research questions
  1. Does a generalized pan-asset-class version of UIP/EH hold?
  2. Do expected returns vary over time and across assets?
  3. How can expected returns be estimated ex ante?
  4. What drives expected returns?

What We Do

- Apply the general definition of carry across asset classes
- We test the key research questions in global markets
  - global equities
  - global bonds
  - global slope trades
  - commodities
  - US Treasuries across maturities
  - credit markets
  - options
- Methodology
  - Regression tests
  - Portfolio tests: carry trades
- Study the source of risk: crash, macro, liquidity, and volatility risks

Main Results: Care About Carry

1. Carry predicts returns in each major asset class we study
   - Significant regressions; coefficient $\lesseqgtr 1$ depending on asset class
   - Sharpe ratio of Diversified Carry Factor $= 1.1$
   - Strong rejection of generalized UIP/EH in favor of models of varying risk premia

2. Potential underlying drivers
   - Not crash risk: limited skewness and kurtosis
   - Exposure to liquidity risk
   - Exposure to volatility risk
   - Drawdowns during recessions

3. Carry unifies and extends
   - Unified framework related to known predictors studied separately, one asset class at a time
   - Generates new predictors not studied before

$\Rightarrow$ most finance models have direct implications for carry strategies and hence a useful new set of moments to calibrate models to

Overview of the Rest of Talk

- Understanding carry: what is equity carry, bond carry, etc.?
- Data
- Carry predictability: regression tests and carry trades
- Economic drivers of carry

Defining Carry in Futures Markets

- The (excess) return on a fully-collateralized futures contract equals:

$$r_{t+1} = \frac{S_{t+1} - F_t}{F_t}$$

where S_t is the spot price and F_t the one-month futures price

- Carry is the return you earn if prices stay constant, i.e., $S_{t+1} = S_t$:

$$C_t = \frac{S_t - F_t}{F_t}$$

- We can write the (excess) return as:

$$r_{t+1} = \frac{S_{t+1} - F_t}{F_t} = \underbrace{C_t + \frac{E_t\left(\Delta S_{t+1}\right)}{F_t}}_{E_t(r_{t+1})} + u_{t+1}$$

- We apply this definition in every asset class

Carry in Currencies: Familiar Territory

- The currency carry equals, using $F_t = S_t(1 + r_t^f)/(1 + r_t^{f*})$:

$$\begin{aligned} C_t &:= \frac{S_t - F_t}{F_t} \\ &\propto r_t^{f*} - r_t^f \end{aligned}$$

- The difference between the foreign and domestic interest rate – as usual

Carry in Equities

- The equity carry equals, using $F_t = S_t(1 + r_t^f) - E_t^Q(D_{t+1})$,:

$$C_t \propto \frac{E_t^{\mathbb{Q}}(D_{t+1})}{S_t} - r_t^f,$$

- The difference between the exp. dividend yield and the local r^f
- Consider the Gordon Growth Model for equity prices S_t:

$$S = \frac{D}{E(R) - g}$$

suggesting a link between expected excess returns and carry

$$E(R) - r^f = \frac{D}{S} - r^f + g$$

Carry in Commodities

- Commodity futures prices depend on δ_t the convenience yield, $F_t = S_t(1 + r_t^f - \delta_t)$
- The commodity carry equals:

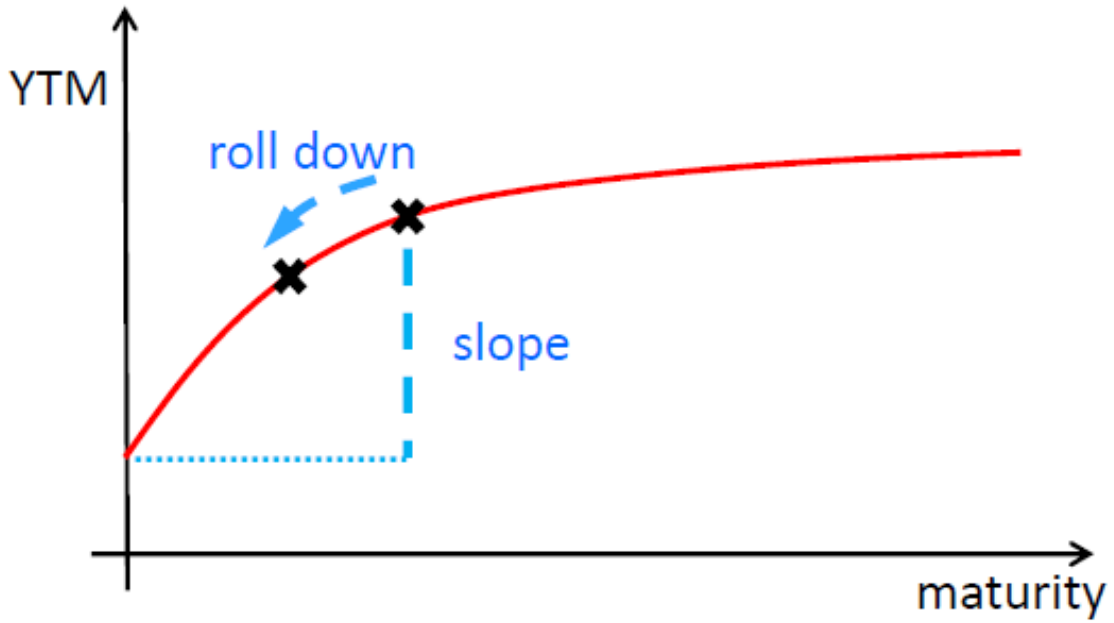
$$C_t \propto \delta - r_t^f,$$

the difference between the convenience yield and the risk-free rate

Carry in Fixed Income

- The carry of a T-year bond with $S_t = P_t^{T-1} = 1/(1+y_t^{T-1})^{T-1}$ and $F_t = (1+r_t^f)P_t^T$ is:

$$\begin{aligned} C_t^T &= \frac{P_t^{T-1}}{(1+r_t^f)P_t^T} - 1 \\ &\simeq \underbrace{y_t^T - r_t^f}_{\text{Slope}} \quad \underbrace{-D^{Modified}\left(y_t^{T-1} - y_t^T\right)}_{\text{Roll down}}, \end{aligned}$$



Carry in Slope Trades

- The carry of a T-year bond with $S_t = P_t^{T-1} = 1/(1+y_t^{T-1})^{T-1}$ and $F_t = (1+r_t^f)P_t^T$ is:

$$\begin{aligned} C_t^T &= \frac{P_t^{T-1}}{(1+r_t^f)P_t^T} - 1 \\ &\simeq \underbrace{y_t^T - r_t^f}_{\text{Slope}} \quad \underbrace{-D^{Modified}\left(y_t^{T-1} - y_t^T\right)}_{\text{Roll down}}, \end{aligned}$$

- We also apply the same concept to the slope of the the term structure across markets:

$$C_t = C_t^{T_1} - C_t^{T_2},$$

where $T_1 > T_2$. Carry determined by two roll-down components and the yield difference between T_1 and T_2

Carry in Treasury and Credit Markets

- We can apply this definition to both Treasuries and corporate bonds
- Carry of longer maturities "mechanically" higher and more volatile due to differences in duration
- We adjust the carry definition to make it duration neutral:

$$C_t^{\text{duration-adjusted},i} = \frac{C_t^i}{D_t^i}$$

- Strategies also work for non-adjusted carry

Carry in Options Markets

- Start from the price of an option, $F_t^j(S_{it}, K, T, \sigma_T)$, $j = \text{Call}, \text{Put}$
- The option carry is defined as before:

$$C_{it}^j(K, T, \sigma_T) = \frac{F_t^j(S_{it}, K, T-1, \sigma_{T-1})}{F_t^j(S_{it}, K, T, \sigma_T)} - 1$$

- Using linear approximations, we get:

$$C_{it}^j(K, T, \sigma_T) \simeq \frac{-\theta_t^j(S_{it}, K, T, \sigma_T) + \nu_t^j(S_{it}, K, T, \sigma_T)(\sigma_{T-1} - \sigma_T)}{F_t^j(S_{it}, K, T, \sigma_T)}$$

$\Rightarrow$ Carry depends on the option's

- theta $\theta_t^j = -\frac{\partial F}{\partial \tau}$ and
- volatility "roll-down" $\sigma_{T-1} - \sigma_T$ scaled by vega $\nu_t^j = \frac{\partial F}{\partial \sigma}$

Data Overview: Global Markets

- Equity index data from 13 countries

  US, Canada, UK, France, Germany, Spain, Italy, Netherlands, Norway, Switzerland, Japan, Hong Kong, Australia

- Currency data for 20 countries

  Australia, Austria, Belgium, Canada, Denmark, France, Germany, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, UK, Euro, US

- Data on 24 commodities

  Aluminium, Copper, Nickel, Zinc, Lead, Gold, Silver, Crude Oil, Gasoil, WTI Crude, Unleaded Gasoline, Heating Oil, Natural Gas, Cotton, Coffee, Cocoa, Sugar, Soybeans, Kansas Wheat, Corn, Wheat, Lean Hogs, Feeder Cattle, Live Cattle

- Fixed income data for 10 countries

  Australia, Canada, Germany, UK, Japan, New Zealand, Norway, Sweden, Switzerland, US

  $\Rightarrow$ For all asset classes, we have more than 20 years of data

Data Overview: Global Markets, Continued

- Treasuries:
  - 6 portfolios of US Treasuries sorted by maturity starting in 1971
  - Maturities: 1-12, 13-24, 25-36, 37-48, 49-60, and 61-120 months
- Credit portfolios:
  - 8 portfolios of corporate bonds from Barclays that vary by credit quality (AAA, AA, A, and BAA) and maturity (int. and long)
  - Sample starts in 1973
- Index options
  - Dow Jones Industrial Average, NASDAQ 100 Index, CBOE Mini-NDX Index, AMEX Major Market Index, S&P500 Index, S&P100 Index, S&P Midcap 400 Index, S&P Smallcap 600 Index, Russell 2000 Index, PSE Wilshire Smallcap Index
  - Consider two delta groups, $|\Delta| \in$[0.2-0.4] or $|\Delta| \in$ [0.4-0.6], and maturities between 1 and 2 months starting in 1996
  - Implement the carry strategies separately for call and put options

Data Sources

- Bloomberg: Futures and spot prices for
  - Global equities
  - Global fixed income (Jonathan Wright for earlier sample)
  - Commodities
- Datastream:
  - Currency forward and spot exchange rates
  - Duration, yields, and returns for credit portfolios
- OptionMetrics:
  - Index options and implied volatilities by maturity and moneyness
- CRSP:
  - Maturity and returns for Treasuries portfolios
- Gürkaynak, Sack, and Wright:
  - Yields for Treasuries portfolios
- ECRI:
  - Business cycle data following the NBER methodology

Carry Predictability: Portfolio Tests

- Our carry trade portfolio weights

$$w_t^i = z_t \left(\text{rank}(C_t^i) - \frac{N_t + 1}{2} \right),$$

  - Linear in the rank of the carry
  - Invests a dollar long and short each period

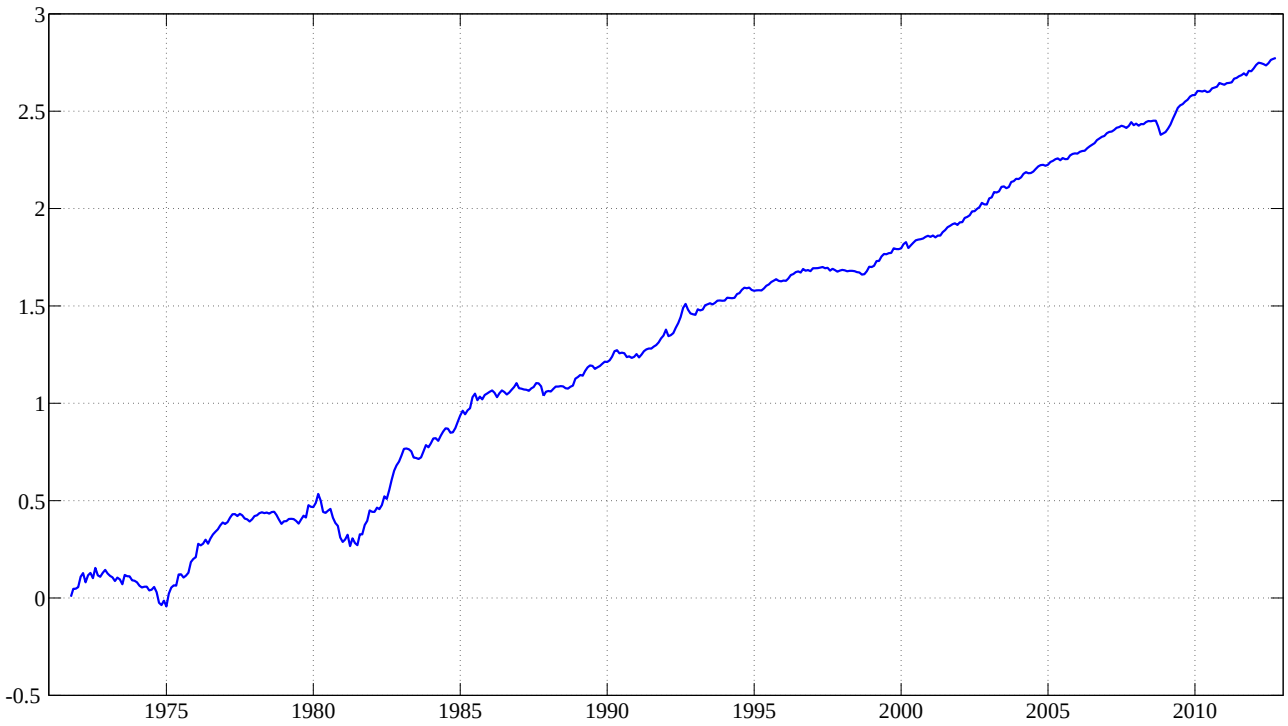
- We consider two versions of the carry strategy:
  - "Current carry": uses the current, 1-month carry
  - "Carry1-12": uses the 12-month moving average of the current carry to remove seasonal effects

Global Carry Trade Returns

Asset class	Strategy	Mean	Stdev	Skewness	Kurtosis	Sharpe ratio
Global equities	Carry	9.14	10.42	0.22	4.74	0.88
	EW	5.00	15.72	-0.63	3.91	0.32
Fixed income 10Y global	Carry	3.85	7.45	-0.43	6.66	0.52
	EW	5.04	6.85	-0.11	3.70	0.74
Fixed income 10Y−2Y global	Carry	3.77	5.72	-0.22	5.49	0.66
	EW	4.04	5.73	-0.05	3.67	0.71
US Treasuries	Carry	0.46	0.67	0.47	10.46	0.68
	EW	0.69	1.22	0.58	12.38	0.57
Commodities	Carry	11.22	18.78	-0.40	4.55	0.60
	EW	1.05	13.45	-0.71	6.32	0.08
Currencies	Carry	5.29	7.80	-0.68	4.46	0.68
	EW	2.88	8.10	-0.16	3.44	0.36
Credit	Carry	0.24	0.52	1.32	18.19	0.47
	EW	0.37	1.09	-0.03	7.09	0.34
Options calls	Carry	64	172	-2.82	14.49	0.37
	EW	-73	313	1.15	3.88	-0.23
Options puts	Carry	179	99	-1.75	10.12	1.80
	EW	-299	296	1.94	7.11	-1.01
All asset classes (global carry factor)	Carry	6.75	6.12	-0.02	5.24	1.10
	EW	3.46	7.34	-0.38	7.94	0.47

Global Carry Factor: Cumulative Returns

- Strong performance of the global carry factor:



Regression Tests: Does the Market Take Back Part of the Carry?

- We start from:

$$r_{t+1} = \frac{S_{t+1} - F_t}{F_t} = \underbrace{C_t + \frac{E_t\left(\Delta S_{t+1}\right)}{F_t}}_{E_t(r_{t+1})} + u_{t+1},$$

- To link expected returns to carry, we consider panel regressions of the form:

$$r^i_{t+1} = a^i + b_t + cC^i_t + \varepsilon_{i,t+1}$$

- We consider three cases:
  - Time fixed effects
  - Security fixed effects
  - Both time and security fixed effects

$\Rightarrow$ Results even stronger if we use the rank of the carry instead

Regression Tests: Does the Market Take Back Part of the Carry?

	Global Equities				Commodities			
Slope current carry	1.48	1.21	1.53	1.25	0.05	0.05	-0.01	-0.01
t-stat	3.49	4.27	3.45	4.29	0.56	0.59	-0.06	-0.12
Slope carry 1-12	2.42	1.46	2.89	1.76	0.34	0.41	0.21	0.26
t-stat	3.48	2.82	3.49	2.83	2.87	3.35	1.58	1.94
Contract FE	No	No	Yes	Yes	No	No	Yes	Yes
Time FE	No	Yes	No	Yes	No	Yes	No	Yes
	Fixed Income				**Currencies**			
Slope current carry	1.54	1.64	1.58	1.85	1.24	0.69	1.54	0.90
t-stat	2.64	3.78	2.25	3.63	3.56	2.70	3.03	2.60
Slope carry 1-12	1.52	1.05	1.56	1.03	1.14	0.53	1.48	0.61
t-stat	2.43	2.36	2.04	1.93	3.27	1.71	2.75	1.21
Contract FE	No	No	Yes	Yes	No	No	Yes	Yes
Time FE	No	Yes	No	Yes	No	Yes	No	Yes

Risk Exposures

Common carry structure across markets

- Correlations across carry trade

What are the risk exposures that could help explain the return premium?

- Value and momentum?
- Liquidity or volatility risk?
- Prolonged drawdowns during bad times

Carry Correlations

Correlations of carry trade returns across asset classes

	EQ	FI 10Y	FI 10Y−2Y	Treasuries	COMM	FX	Credit	Calls	Puts
EQ	1.00	0.17	0.13	0.07	-0.02	0.05	0.06	0.11	-0.09
FI 10Y		1.00	0.66	0.09	0.05	0.15	-0.02	-0.07	0.06
FI 10Y−2Y			1.00	0.11	0.08	0.14	-0.08	0.00	0.09
Treasuries				1.00	0.12	-0.05	0.12	0.08	-0.06
COMM					1.00	0.02	0.04	-0.15	0.08
FX						1.00	0.21	-0.14	0.11
Credit							1.00	-0.04	0.09
Calls								1.00	0.15
Puts									1.00

Carry vs. Value and Momentum

Carry different from value and momentum

- Momentum: One-year past returns
- Value: Current price relative to fundamental value (or 5-year past returns)
- Carry: Forward-looking return, assuming market conditions stay constant

Risk-adjustment Performance and Exposures

	Equities global		FI Level		FI Slope		Treasuries		Commodities	
α	0.79	0.77	0.35	0.33	0.34	0.29	0.03	0.02	0.93	0.64
	(4.51)	(4.51)	(3.06)	(3.08)	(4.00)	(3.63)	(3.38)	(2.74)	(3.43)	(2.57)
Passive long	-0.06	-0.06	-0.07	-0.18	-0.07	-0.23	0.16	0.12	0.01	-0.02
	(-1.10)	(-1.16)	(-0.94)	(-2.10)	(-0.91)	(-3.03)	(2.57)	(3.51)	(0.12)	(-0.31)
Value		0.17		0.07		0.07		0.00		-0.21
		(1.84)		(0.51)		(0.64)		(-0.67)		(-2.96)
Momentum		0.06		0.56		0.43		0.00		0.29
		(0.74)		(4.26)		(4.37)		(0.04)		(3.81)
TSMOM		-0.04		0.03		0.04		0.00		-0.04
		(-1.69)		(1.82)		(3.12)		(0.80)		(-0.45)
R^2	0.01	0.03	0.00	0.16	0.00	0.20	0.08	0.07	0.00	0.20
IR	0.91	0.90	0.57	0.61	0.71	0.70	0.54	0.64	0.60	0.47

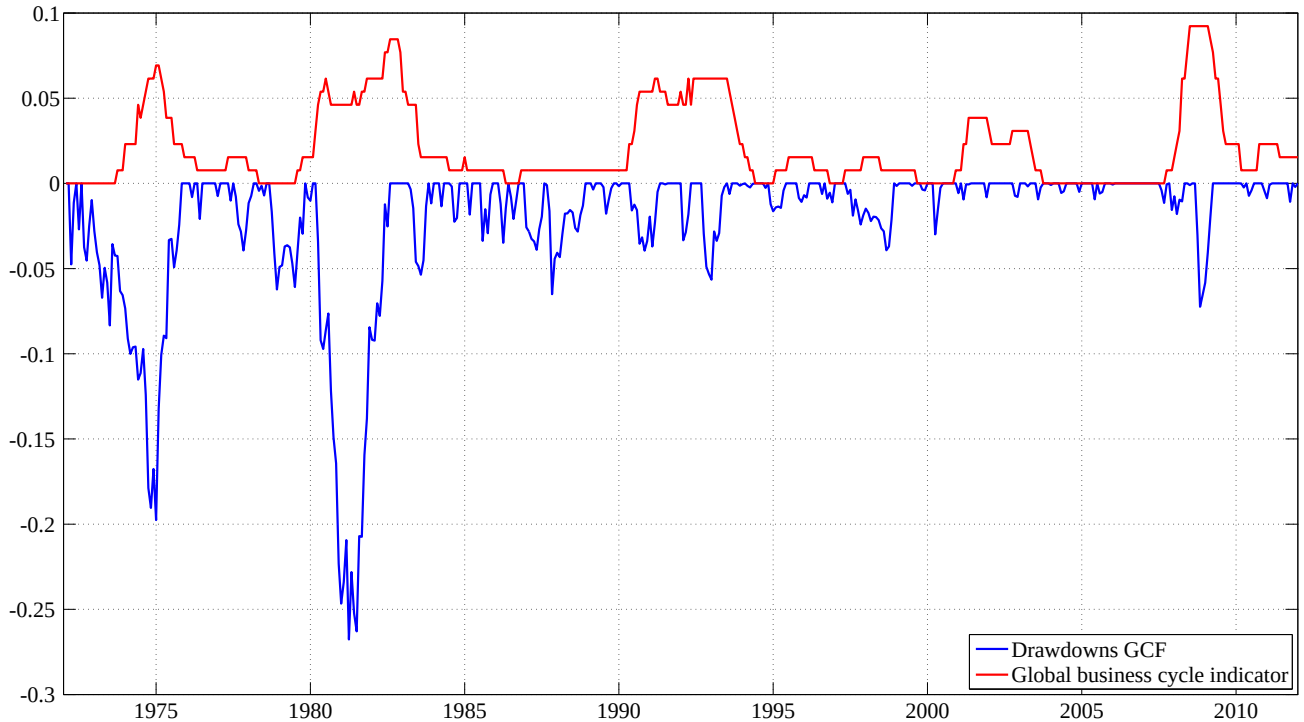
	FX		Credits		Calls		Puts		*GCF*	
α	0.40	0.30	0.02	0.02	3.21	6.93	13.02	12.55	0.53	0.44
	(3.31)	(2.31)	(2.85)	(1.70)	(1.07)	(2.15)	(4.74)	(4.55)	(6.52)	(5.51)
Passive long	0.17	0.22	0.02	0.14	-0.34	-0.35	-0.08	-0.09	0.10	0.14
	(2.47)	(3.46)	(0.50)	(2.31)	(-5.90)	(-6.07)	(-1.85)	(-2.10)	(1.34)	(1.78)
Value		0.11		0.01		-5.96		2.82		0.08
		(1.08)		(0.81)		(-2.14)		(0.98)		(1.00)
Momentum		0.03		0.00		-4.32		2.14		0.10
		(0.31)		(-0.21)		(-2.54)		(1.01)		(1.45)
TSMOM		0.01		0.00		-0.92		-0.77		-0.01
		(0.25)		(-1.42)		(-1.00)		(-1.07)		(-0.22)
R^2	0.03	0.05	0.00	0.07	0.39	0.43	0.05	0.07	0.02	0.04
IR	0.63	0.47	0.45	0.39	0.29	0.64	1.61	1.56	1.05	1.24

Exposures to Global Liquidity and Volatility Shocks

Asset class	Exposure liquidity shocks	T-stat.	Exposure volatility changes	T-stat.
Equities	0.22	1.65	-0.12	-0.49
FI 10Y	0.28	1.44	-0.54	-2.25
FI 10Y−2Y	0.32	1.65	-0.31	-1.19
Treasuries	-0.21	-0.80	0.54	2.92
Commodities	0.26	2.36	-0.42	-2.74
Currencies	0.88	3.62	-1.03	-6.46
Credit	1.24	3.78	-0.58	-2.05
Options calls	-0.03	-0.33	-0.10	-0.84
Options puts	0.57	2.48	-0.62	-2.00

Carry Drawdowns and Recession Risk

Carry drawdowns: $D_t = \sum_{s=1}^{t} r_s - \max_{u \in \{1,\ldots,t\}} \sum_{s=1}^{u} r_s$



Three major carry drawdowns:

- 1972.8 - 1975.9 (DD = -19.6%)
- 1980.3 - 1982.6 (DD = -26.8%)
- 2008.8 - 2009.2 (DD = -7.2%)

Carry Drawdowns: Returns per Asset Class

		Carry expansions		Carry drawdowns	
Asset class	Strategy	Mean	Stdev	Mean	Stdev
Equities	Carry	15.03	9.71	-6.15	10.95
	EW	8.31	13.73	-3.62	19.87
FI global, 10Y	Carry	10.84	6.19	-13.90	7.93
	EW	3.75	6.53	8.33	7.55
FI global, 10Y−2Y	Carry	8.10	5.10	-7.25	5.98
	EW	2.94	5.45	6.85	6.34
Treasuries	Carry	0.97	0.64	-0.57	0.65
	EW	0.98	1.14	0.10	1.34
Commodities	Carry	21.49	17.33	-13.23	20.24
	EW	4.54	11.73	-7.24	16.68
Currencies	Carry	10.06	7.29	-6.81	8.00
	EW	5.17	7.68	-2.95	8.89
Credit	Carry	0.60	0.52	-0.50	0.45
	EW	0.84	1.03	-0.61	1.15
Options calls	Carry	152	138	-161	225
	EW	195	272	-237	389
Options puts	Carry	258	77	-22	124
	EW	364	238	132	409

Static and Dynamic Components of Carry Returns

Decompose expected return into static and dynamic components:

$$
\begin{aligned}
E\left(r_{t+1}^{\text{carry trade}}\right) &= E\left(\sum_i w_t^i r_{t+1}^i\right) \\
&= \sum_i E\left(w_t^i\right) E\left(r_{t+1}^i\right) \\
&\quad + \sum_i E\left[\left(w_t^i - E\left(w_t^i\right)\right)\left(r_{t+1}^i - E\left(r_{t+1}^i\right)\right)\right]
\end{aligned}
$$

Static and Dynamic Components of Carry Returns

Individual securities	Static	Dynamic	% Dynamic
Equities global	-0.1%	9.3%	101%
Fixed income - 10Y global	0.6%	3.3%	86%
Fixed income - 10Y−2Y global	0.1%	3.7%	99%
US Treasuries	0.3%	0.2%	42%
Commodities	4.1%	7.1%	64%
Currencies	2.2%	3.1%	58%
Credit	0.2%	0.1%	30%
Options calls	-7.2%	70.8%	111%
Options puts	-0.4%	179.3%	100%

Regions and groups	Static	Dynamic	% Dynamic
Equities global	-0.6%	6.6%	111%
Fixed income - 10Y global	0.5%	3.3%	87%
Fixed income - 10Y−2Y global	0.2%	3.9%	96%
Commodities	-0.4%	15.4%	103%
Currencies	2.3%	2.4%	51%

Carry in the Time Series: Timing Strategies

Timing carry by going long/short based on carry (relative to zero)

Individual securities	mean	stdev	skewness	kurtosis	Sharpe ratio
Equities	7.40	18.55	0.39	4.49	0.40
FI global, 10Y	7.09	10.93	-0.16	4.05	0.65
FI global, 10Y−2Y	6.90	9.62	-0.15	4.29	0.72
Treasuries	1.36	2.28	-0.48	14.51	0.60
Commodities	8.28	20.78	0.13	5.56	0.40
Currencies	7.86	10.08	-0.72	5.63	0.78
Credit	1.27	2.00	-0.24	8.00	0.64
Options calls	146.45	626.92	-1.15	3.88	0.23
Options puts	597.76	592.72	-1.94	7.11	1.01

Conclusion

- Carry is an important characteristic which is directly observable
- Carry predicts returns in every asset class
  - Broad rejection of UIP/EH
  - E(R) varies over time and across assets as captured by carry
  - Strong performance of our Global Carry Factor
- Carry captures varying E(R) driven by
  - Recession risk in carry drawdowns
  - Liquidity risk
  - Volatility risk
  - Limited arbitrage and other effects – future research