Getting to the Core: Inflation Risks Within and Across Asset Classes

Xiang Fang, Yang Liu, and Nikolai Roussanov

HKU, HKU, Wharton and NBER

October 2023

Q-group, Dove Mountain, AZ

Introduction

- Inflation: fundamental source of macro risk
  - One of the most important topics of the time
  - The financial market highly sensitive to inflation news

Introduction

- Inflation: fundamental source of macro risk
  - One of the most important topics of the time
  - The financial market highly sensitive to inflation news
- Challenging to identify macro factors that matter for investors and their compensation, especially inflation

Introduction

- Inflation: fundamental source of macro risk
  - One of the most important topics of the time
  - The financial market highly sensitive to inflation news
- Challenging to identify macro factors that matter for investors and their compensation, especially inflation
- Which assets can protect against inflation, and at what cost?
  - Conventional wisdom: currencies, commodities, and real estate are hedges, stocks are "real" assets
  - Empirically, the price of inflation risk is ambiguous

Introduction

- Inflation: fundamental source of macro risk
  - One of the most important topics of the time
  - The financial market highly sensitive to inflation news
- Challenging to identify macro factors that matter for investors and their compensation, especially inflation
- Which assets can protect against inflation, and at what cost?
  - Conventional wisdom: currencies, commodities, and real estate are hedges, stocks are "real" assets
  - Empirically, the price of inflation risk is ambiguous
- This paper
  - Decomposes inflation into core and non-core components ("crust")
    - in particular, energy
  - Uses data from 8 asset classes and shows that conventional wisdom tells only part of the truth

Main Findings

- Inflation hedging
  - None of the 8 asset classes hedge against core inflation
  - Conventional “real" assets hedge against energy inflation
- Price of inflation risk
  - Core inflation carries a negative risk premium, with magnitude **consistently estimated within and across asset classes**
- New insights on driver of the changing stock-bond correlation
- Two-sector NK model that qualitatively accounts for the facts

Related Literature

- Inflation hedging
  - Fama and Schwert (1977), Fama (1981), Boudoukh and Richardson (1993), Bekaert and Wang (2010), Katz, Lustig, and Nielsen (2017)
- Inflation risk premium
  - Chen, Roll, and Ross (1986), Hollifield and Yaron (2003), Ang, Bekaert, and Wei (2008), Ajello, Benzoni, and Chyruk (2019), Boons, Duarte, de Roon, and Szymanowska (2019), Cooper, Mitrache, and Priestley (2020), Andrews, Colacito, Croce, and Gavazzoni (2021)
- Equilibrium models of inflation, macroeconomy, asset prices
  - Buraschi and Jiltsov (2005), Wachter (2006), Piazzesi and Schneider (2006), Bansal and Shaliastovich (2012), Kung (2015), Kang and Pflueger (2015), Weber (2015), Gomes, Jermann, and Schmid (2016), Eraker, Shaliastovich, and Wang (2016), Bhamra, Dorion, Jeanneret, and Weber (2020), Pflueger and Rinaldi (2021)
- Stock-bond correlation
  - Song (2016), Campbell, Sundarem, and Viceira (2017), Campbell, Pflueger, and Viceira (2019), Cieslak and Pang (2020)
- Commodity prices, inflation, and other asset classes
  - Barro and Misra (2016), Ready, Roussanov, and Ward (2017, 2018), Ready (2017, 2018), Bakshi, Gao, and Rossi (2019)

Empirics

Inflation Summary Statistics

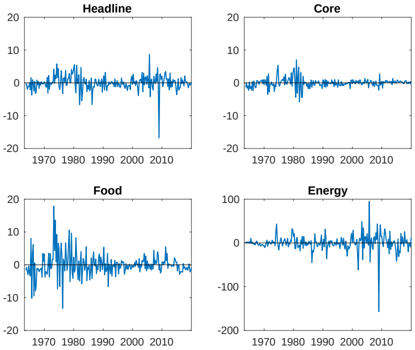
	Headline	Core	Food	Energy
	A. Summary Statistics			
Mean	3.76	3.75	3.75	4.01
Std	3.24	2.66	4.04	19.52
Persist	0.60	0.79	0.43	0.04
	B. Contribution to Headline			
	1.00	0.71	0.20	0.09
	C. Correlation			
Headline	1.00			
Core	0.80	1.00		
Food	0.60	0.44	1.00	
Energy	0.69	0.20	0.17	1.00

Sample: 1963Q3 to 2019Q4

- Similar mean, different volatility and persistence
- Core accounts for the largest portion
- Though a small share, energy inflation volatility makes it important

Inflation Shocks

- VAR, $Y_t = c + AY_{t-1} + u_t$, u_t as shocks
- Y_t includes headline inflation and its components, p/d ratio, risk-free rate, and output gap ▸ VAR details



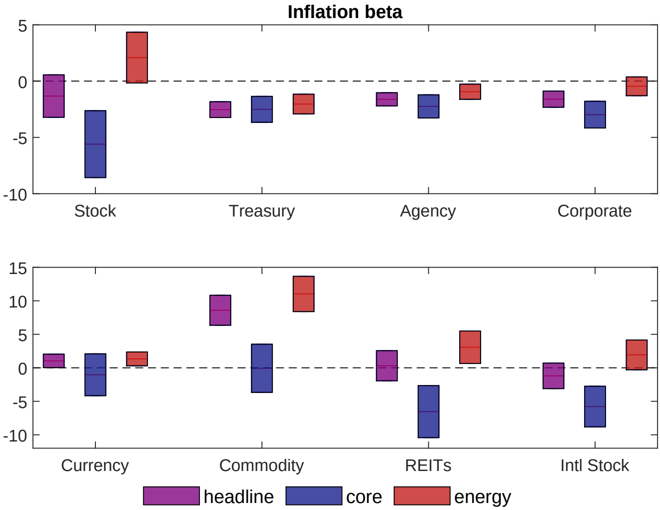
- Alternative: using survey data to extract shocks

Portfolios

Wide and standard asset classes

- 8 asset classes: stock, Treasury, agency bond, corporate bond, currency, commodity future, REITs, and international stock
- An average portfolio in each asset class
- A cross-section in each asset class, in total 38 portfolios
  portfolios
- An expanded cross-section in each class for within-class study

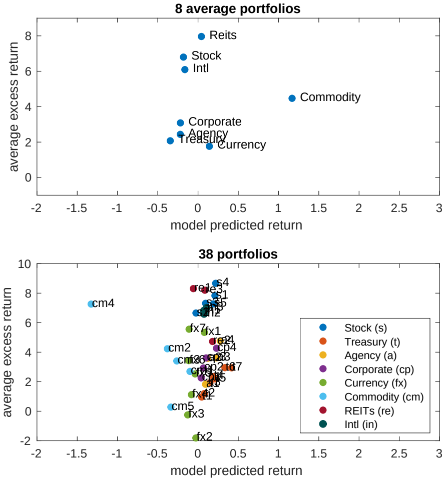
Inflation Betas of 8 Asset Classes



▸ 8-asset betas ▸ 38-asset betas

Expected Returns and Priced Risk: Headline

Model: $E[R] = \lambda' \beta$ estimated with headline inflation risk



Core Inflation Factor Mimicking Portfolios

- Portfolio weights $\omega = (\beta\beta')^{-1}\beta$, where β's are the first-stage estimates (Fama and MacBeth, 1973)

	Stock	Treasury	Agen	Corp	Curr	Comm	REIT	Intl	Aver	All
					A. Core					
mean	**-1.26**	**-0.86**	**-0.68**	**-1.05**	**-1.13**	-1.38	**-1.05**	**-0.97**	**-0.91**	**-0.99**
t-stat	(-3.31)	(-2.84)	(-2.09)	(-3.06)	(-3.92)	(-1.16)	(-3.25)	(-2.09)	(-2.92)	(-3.61)
SR	-0.44	-0.36	-0.27	-0.49	-0.64	-0.17	-0.51	-0.31	-0.40	-0.49
					B. Energy					
mean	2.02	0.64	-8.25	**6.66**	1.34	12.73	3.47	8.08	**5.23**	**5.71**
t-stat	(0.61)	(0.19)	(-1.30)	(2.07)	(0.18)	(1.88)	(0.55)	(1.58)	(2.03)	(2.10)
SR	0.09	0.03	-0.18	0.30	0.03	0.36	0.09	0.24	0.28	0.29
					C. Headline					
mean	**-2.81**	**-0.80**	**-1.39**	**-1.40**	0.79	1.07	0.89	**-2.92**	0.13	-0.11
t-stat	(-3.36)	(-2.24)	(-3.07)	(-2.85)	(0.88)	(1.61)	(1.12)	(-2.34)	(0.42)	(-0.35)
SR	-0.45	-0.30	-0.46	-0.42	0.17	0.29	0.18	-0.34	0.06	-0.05

- Robust to controlling for standard macroeconomic factors

Other macro factors

Conventional Wisdom Revisited: Currencies

	A. Headline			B.Core and energy			
	Mean	Headline β	t-stat	Core β	t-stat	Energy β	t-stat
USD-Carry	5.34	-0.98	(-1.52)	-4.17	(-2.08)	0.00	(-0.04)
Carry-1	-1.81	0.33	(0.57)	-0.52	(-0.28)	0.06	(0.95)
Carry-2	-0.25	1.60	(2.99)	1.72	(1.03)	0.14	(2.55)
Carry-3	1.12	1.02	(1.92)	-0.04	(-0.02)	0.11	(2.02)
Carry-4	2.53	0.45	(0.74)	-2.50	(-1.34)	0.10	(1.60)
Carry-5	3.43	1.44	(2.28)	-1.28	(-0.65)	0.19	(2.94)
Carry-6	5.56	1.38	(1.87)	-3.62	(-1.60)	0.20	(2.72)
Dol-β-1	0.83	-0.37	(-1.24)	-0.04	(-0.04)	-0.04	(-1.39)
Dol-β-2	1.68	-0.82	(-1.90)	-1.46	(-1.04)	-0.05	(-1.20)
Dol-β-3	2.57	-0.30	(-0.56)	-1.77	(-1.01)	0.02	(0.34)
Dol-β-4	3.65	0.57	(0.90)	-3.27	(-1.61)	0.12	(1.99)
Dol-β-5	3.13	-0.79	(-1.02)	-3.85	(-1.52)	0.01	(0.07)
Dol-β-6	4.87	-0.62	(-0.75)	-5.05	(-1.91)	0.04	(0.46)

Conventional Wisdom Revisited: Currencies

- Seven (dollar-)carry portfolios' core betas decline and energy betas increase, largely in line with averege returns
- Dollar carry portfolio (conditioning on AFD)'s core beta is more negative and energy beta is insignificant
- The six dollar beta sorted portfolios (conditional on AFD) have negative core betas
  - The larger the dollar beta, the more negative the core exposure
  - Important to condition on AFD
  - Core betas in line with average returns
- Four value portfolios all have similar exposures to inflation (little spread in betas)

Back

Conventional Wisdom Revisited: Commodities

	A. Headline			B. Core and Energy			
	Mean	Headline β	t-stat	Core β	t-stat	Energy β	t-stat
Agriculture	0.28	4.20	(3.28)	2.06	(0.96)	0.26	(1.66)
Livestock	2.70	1.24	(1.24)	-1.09	(-0.66)	0.15	(1.22)
Prec metals	3.41	3.28	(2.65)	-0.22	(-0.11)	0.43	(2.96)
Ind metals	4.23	4.73	(2.98)	-1.07	(-0.39)	0.66	(3.66)
Energy	7.26	16.51	(7.05)	-0.76	(-0.11)	1.78	(7.54)
Gold	1.98	2.14	(1.97)	1.74	(0.91)	0.24	(1.92)
Silver	3.52	4.95	(2.63)	-0.09	(-0.03)	0.68	(3.06)
Platinum	4.36	3.40	(2.29)	7.51	(1.63)	0.26	(1.69)

- Commodities hedge mostly against energy inflation, including gold

Currencies detail

Core Inflation and Growth

- Fama (1981) proxy effect hypothesis: stock return-inflation relation due to inflation proxying for real variables

	headline	t-stat	R^2	core	t-stat	energy	t-stat	R^2
				1 quarter				
GDP	-0.14	(-1.21)	0.02	-0.21	(-1.88)	0.00	(-0.23)	0.03
Cons	**-0.22**	(-2.42)	0.08	**-0.22**	(-2.32)	-0.01	(-0.86)	0.07
Div	-0.27	(-1.15)	0.02	**-0.67**	(-4.27)	0.04	(0.96)	0.06
				1 year				
GDP	**-0.75**	(-2.34)	0.08	**-0.70**	(-2.24)	-0.05	(-1.05)	0.07
Cons	**-0.66**	(-2.24)	0.09	-0.46	(-1.81)	-0.05	(-1.12)	0.05
Div	-1.26	(-1.12)	0.03	**-2.93**	(-5.78)	0.18	(0.95)	0.11

- Core inflation negatively predicts future GDP, consumption, and dividends, especially at 1-year horizon

Cash Flow and Discount Rate News

- Return news can be decomposed into CF and DR news

$$(E_{t+1} - E_t)r_{t+1} = \underbrace{(E_{t+1} - E_t)\sum_{j=0}^{\infty}\rho^j \Delta d_{t+1+j}}_{N_{CF}} - \underbrace{(E_{t+1} - E_t)\sum_{j=1}^{\infty}\rho^j r_{t+1+j}}_{N_{DR}}$$

	Cash Flow News				Discount Rate News			
	Core β	t-stat	Energy β	t-stat	Core β	t-stat	Energy β	t-stat
Mkt	**-2.14**	(-4.12)	-0.01	(-0.23)	**4.23**	(3.47)	**-0.19**	(-2.05)
Gr	**-4.96**	(-5.58)	-0.11	(-1.60)	**2.57**	(2.57)	**-0.24**	(-3.14)
BM2	**-2.44**	(-2.83)	0.00	(-0.03)	**3.07**	(3.55)	-0.10	(-1.55)
BM3	**-2.28**	(-2.76)	-0.03	(-0.47)	**2.73**	(3.37)	**-0.14**	(-2.26)
BM4	0.71	(0.80)	0.12	(1.80)	**6.27**	(4.33)	-0.12	(-1.07)
Vl	1.27	(1.17)	0.08	(0.92)	**7.17**	(4.35)	-0.14	(-1.09)

- For the stock market portfolio, negative core betas come from both CF and DR news, positive energy betas mainly come from DR news

Cash Flow and Discount Rate News

- Return news can be decomposed into CF and DR news

$$(E_{t+1} - E_t) r_{t+1} = \underbrace{(E_{t+1} - E_t) \sum_{j=0}^{\infty} \rho^j \Delta d_{t+1+j}}_{N_{CF}} - \underbrace{(E_{t+1} - E_t) \sum_{j=1}^{\infty} \rho^j r_{t+1+j}}_{N_{DR}}$$

	Cash Flow News				Discount Rate News			
	Core β	t-stat	Energy β	t-stat	Core β	t-stat	Energy β	t-stat
Mkt	**-2.14**	(-4.12)	-0.01	(-0.23)	**4.23**	(3.47)	**-0.19**	(-2.05)
Gr	**-4.96**	(-5.58)	-0.11	(-1.60)	**2.57**	(2.57)	**-0.24**	(-3.14)
BM2	**-2.44**	(-2.83)	0.00	(-0.03)	**3.07**	(3.55)	-0.10	(-1.55)
BM3	**-2.28**	(-2.76)	-0.03	(-0.47)	**2.73**	(3.37)	**-0.14**	(-2.26)
BM4	0.71	(0.80)	0.12	(1.80)	**6.27**	(4.33)	-0.12	(-1.07)
Vl	1.27	(1.17)	0.08	(0.92)	**7.17**	(4.35)	-0.14	(-1.09)

- For the stock market portfolio, negative core betas come from both CF and DR news, positive energy betas mainly come from DR news
- Growth vs. value portfolios's negative core beta
  - Growth portfolio: mainly comes from CF news
  - Value portfolio: mainly comes from DR news

Inflation, Fed Response, and Asset Returns (1997-2019)

Are inflation betas driven by the Fed response?

- 22-minute window around CPI inflation announcement

	Fed Funds Futures			
	core	*t*-stat	headline	*t*-stat
(1)	**2.05**	(3.33)		
(2)			0.50	(1.11)
(3)	**2.18**	(3.15)	-0.20	(-0.41)

	Stock futures					
	core	*t*-stat	headline	*t*-stat	FFF	*t*-stat
(1)	**-1.49**	(-6.33)				
(2)			**-0.73**	(-4.57)		
(3)	**-1.25**	(-5.02)	**-0.44**	(-2.68)		
(4)					-0.11	(-3.93)
(5)	**-1.32**	(-5.37)			-0.08	(-3.08)

- Fed funds rate mainly responds to core inflation
- While the Fed response accounts for some stock return decline, negative core betas remain sizable after FFF control

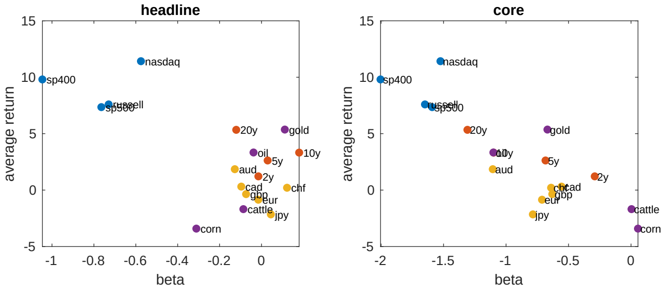
Inflation, Fed Response, and Asset Returns (1997-2022)

Are inflation betas driven by the Fed response?

	Stock futures							
	core	*t*-stat	headline	*t*-stat	ff	*t*-stat	ty	*t*-stat
(1)	**-2.14**	(-8.84)						
(2)			**-1.53**	(-7.40)				
(3)	**-1.61**	(-5.49)	**-0.76**	(-3.13)				
(4)					-0.27	(-11.15)		
(5)	**-1.42**	(-6.03)			-0.22	(-9.29)		
(6)	**-1.29**	(-5.29)			-0.21	(-7.87)	-1.24	(-4.39)

- Even stronger announcement effect in the recent data
- Not fully explained by monetary policy news embedded in Fed Funds futures or 2-year Treasury yields

Avg. Returns and Announcement Betas: Headline vs Core



Time-varying Exposure

- Stock-bond correlation turned negative after 1999 (Song, 2016; Campbell et al, 2017)

Time-varying Exposure

- Stock-bond correlation turned negative after 1999 (Song, 2016; Campbell et al, 2017)

	A. Headline		B. Core and Energy			
	headline	*t*-stat	core	*t*-stat	energy	*t*-stat
			1963-1999			
Stock	**-5.42**	(-4.20)	**-5.19**	(-3.26)	-0.24	(-1.01)
Treasury	**-2.88**	(-5.52)	**-2.77**	(-4.31)	**-0.20**	(-2.03)
			2000-2019			
Stock	**2.96***	(2.22)	-6.30	(-1.18)	**0.35***	(2.63)
Treasury	**-2.23**	(-4.73)	-0.29	(-0.15)	**-0.22**	(-4.65)

Note: * indicates a significant change across the two subsamples.

Time-varying Exposure

- Stock-bond correlation turned negative after 1999 (Song, 2016; Campbell et al, 2017)

	A. Headline		B. Core and Energy			
	headline	*t*-stat	core	*t*-stat	energy	*t*-stat
			1963-1999			
Stock	**-5.42**	(-4.20)	**-5.19**	(-3.26)	-0.24	(-1.01)
Treasury	**-2.88**	(-5.52)	**-2.77**	(-4.31)	**-0.20**	(-2.03)
			2000-2019			
Stock	**2.96***	(2.22)	-6.30	(-1.18)	**0.35***	(2.63)
Treasury	**-2.23**	(-4.73)	-0.29	(-0.15)	**-0.22**	(-4.65)

Note: * indicates a significant change across the two subsamples.

- Inflation and asset returns
  - First subsample: negative for stocks and bonds
  - Second subsample: positive for stock, negative for bonds
    - Driven by energy (switched signs, increased contribution)

Time-varying price of risk

Expected Inflation and Unexpected Inflation

	core exp	t-stat	core shock	t-stat	energy	t-stat
Stock	-0.44	(-0.44)	**-4.14**	(-3.12)	0.40	(1.41)
Trea	-0.38	(-1.06)	**-1.41**	(-2.11)	**-0.21**	(-3.15)
Agency	-0.13	(-0.76)	**-2.11**	(-7.48)	**-0.11**	(-2.64)
Corp	-0.30	(-0.89)	**-2.57**	(-4.45)	-0.04	(-0.44)
Curncy	1.48	(1.66)	-0.92	(-0.37)	**0.26**	(2.27)
Comm	0.42	(0.30)	**-4.68**	(-3.21)	**2.00**	(6.23)
REIT	-1.24	(-0.78)	-3.01	(-1.19)	0.73	(1.72)
Intl	-0.14	(-0.18)	**-4.66**	(-3.63)	0.34	(0.93)

- None of the 8 asset classes' excess returns have significant exposures to expected core inflation, only to core inflation shock
- Risk-free rate largely includes information about expected inflation

Quantitative Model

Households

- Representative agent with Epstein-Zin utility over a bundle of consumption and leisure

$$U_t = \left[(1-\delta)\tilde{C}_t^{1-1/\psi} + \delta E_t[U_{t+1}^{1-\gamma}]^{\frac{1-1/\psi}{1-\gamma}} \right]^{\frac{1}{1-1/\psi}}$$

- Consumption leisure aggregation

$$\tilde{C}_t = \left[\frac{1}{1+o} C_t^{\frac{\xi_l - 1}{\xi_l}} + \frac{o}{1+o} \left(N_{t-1}(\bar{L} - L_t) \right)^{\frac{\xi_l - 1}{\xi_l}} \right]^{\frac{\xi_l}{\xi_l - 1}}$$

- Consumption aggregator of core good and energy good

$$C_t^{\frac{\phi-1}{\phi}} = \alpha_c C_{c,t}^{\frac{\phi-1}{\phi}} + (1-\alpha_c) \left(e^{\eta_t} C_{e,t} \right)^{\frac{\phi-1}{\phi}}$$

Firms: Production Technology

- Final good (core) firms

$$Y_t = \left[\int_i X_{i,t}^{\frac{v-1}{v}} di \right]^{\frac{v}{v-1}}$$

This leads to the demand for intermediate variety i

$$X_{i,t} = Y_t \left(\frac{P_{c,t}(i)}{P_{c,t}} \right)^{-v}$$

Firms: Production Technology

- Final good (core) firms

$$Y_t = \left[\int_i X_{i,t}^{\frac{v-1}{v}} di \right]^{\frac{v}{v-1}}$$

This leads to the demand for intermediate variety i

$$X_{i,t} = Y_t \left(\frac{P_{c,t}(i)}{P_{c,t}} \right)^{-v}$$

- Each variety is produced with labor and capital

$$X_{i,t} = K_{i,t}^{\alpha} (Z_t L_{i,t})^{1-\alpha}, Z_t = A_t N_{t-1}$$

where

$$\log A_t = (1 - \rho_a)\mu_a + \rho_a \log A_{t-1} + \sigma_a \exp(h_{t-1})\varepsilon_{a,t}$$

$$\log N_t - \log N_{t-1} \equiv \Delta n_t = (1-\rho_n)\mu_n + \rho_n \Delta n_{t-1} + \varphi_n \sigma_a \exp(h_{t-1})\varepsilon_{a,t}$$

Firms: Investment and Price Setting

- Each firm makes capital investment decisions subject to adjustment cost $\Phi_k\left(\frac{I_{i,t}}{K_{i,t}}\right)K_{i,t}$
- Each firm faces price adjustment cost $\Phi_p(P_{i,t}, P_{i,t-1})$ (Rotemberg)
- Firm's optimization problem

$$V_{i,t} = \max_{P_{i,t}, I_{i,t}, K_{i,t+1}, L_{i,t}} \frac{P_{i,t}X_{i,t}}{P_t} - W_t L_{i,t} - I_{i,t} - \Phi_{p,t} + E_t\left[M_{t+1}V_{i,t+1}\right]$$

$$s.t.: K_{i,t+1} = (1-\delta_k)K_{i,t} + \Phi_{k,t}K_{i,t}$$

$$X_{i,t} = Y_t\left(\frac{P_{c,t}(i)}{P_{c,t}}\right)^{-v}$$

$$X_{i,t} = K_{i,t}^{\alpha}(Z_t L_{i,t})^{1-\alpha}$$

Energy Good, Monetary Policy, and Volatility

- Energy goods are endowed, exogenously
  - Capture the inelastic feature of energy supply
- Energy demand shock (procyclical)

$$\eta_t = \rho_\eta \eta_{t-1} + \sigma_\eta \varepsilon_t + \delta_a \varepsilon_{a,t}$$

- Monetary policy follows a Taylor rule

$$y_t^{(1)} - y_{ss}^{(1)} = \rho_r \left(y_{t-1}^{(1)} - y_{ss}^{(1)} \right) + \rho_r \left[\rho_\pi \log \left(\frac{\Pi_t}{\Pi_{ss}} \right) + \rho_y \log \left(\frac{\hat{Y}_t}{\hat{Y}_{ss}} \right) \right] + \sigma_m \varepsilon_{m,t}$$

  - Consistent with evidence: Fed response to core inflation
- Stochastic volatility

$$h_t = \rho_h h_{t-1} - \sigma_h \varepsilon_{a,t}$$

Asset Prices

- Stock: claim to an aggregate dividend

$$D_{\text{agg},t} = D_{\text{core},t} + \psi_e P_{e,t} C_{e,t}$$

  where ψ_e is the share of capitalization for energy good

- Bond

$$P_t^{(n)} = E_t M_{t+1}^{\$} P_{t+1}^{(n-1)}$$

- Currency exchange rate

$$\Delta s_t = \log M_t^{*\$} - \log M_t^{\$}$$

  where $\log M_t^{*\$}$ has the same volatility as $\log M_t^{\$}$ and their correlation matches the exchange rate vol

- Commodity future

$$E_t M_{t+1}^{\$} F_t^{\$} = E_t M_{t+1}^{\$} P_{e,t+1}^{\$}, R_{t+1}^{\text{comm}} = \frac{P_{e,t+1}^{\$}}{F_t^{\$}}$$

Calibration

- The core sector mostly follow Kung (2015) and Croce (2014)
- The energy demand and supply shocks calibrated to the dynamics of energy consumption growth and energy inflation
- Energy share $1 - \alpha_c = 0.1$ matches the share of energy in CPI
- The elasticity of substitution between core and energy $\phi = 5$, implying a weak pass-through from energy to the core sector

Moments

	Data		Model	
A. Standard Moments				
$E[\Delta y]$	2.20		1.78	
$\sigma(\Delta y)$	2.22		2.67	
$\sigma(\Delta c)$	1.42		1.37	
$\sigma(\Delta i)$	2.80		3.02	
$AC(\Delta c_e)$	-0.17		-0.12	
$\sigma(\Delta c_e)$	4.00		4.18	
$E[r_f]$	1.62		1.45	
$E[y^{(1)}]$	5.03		4.98	
B.Asset Returns				
	Mean	S.D.	Mean	S.D.
Stock	6.80	16.79	6.87	18.58
Bond	1.93	5.86	1.13	2.62
Currency	1.76	7.05	0.25	7.28
Commodity	4.47	21.90	1.88	9.72

- Macro moments and asset returns match the data

Moments

	Data			Model		
C. Inflation						
	core	energy	headline	core	energy	headline
Mean	3.75	3.75	3.76	3.60	3.59	3.60
S.D.	2.66	19.52	3.24	3.29	19.48	3.92
Autocorr	0.79	0.04	0.60	0.94	0.01	0.65
D. Exposures to Inflation Risks						
	core	energy	headline	core	energy	headline
Stock	-5.60	0.21	-1.33	-5.70	0.34	1.07
Bond	-2.21	-0.13	-1.85	-1.27	-0.08	-0.87
Currency	-1.04	0.13	1.04	-0.89	0.02	-0.05
Commodity	-0.07	1.10	8.59	-0.10	1.00	6.84
E Prices of Inflation Risks						
	core	energy	headline	core	energy	headline
λ	-1.03	3.86	0.14	-1.07	1.80	0.39

- Inflation moments, inflation betas, and price of inflation risks match the data

Economic Mechanism

- Stocks have negative core beta
  - Positive TFP shock raises growth (r_s) and lowers core inflation
  - Naturally, the price of core inflation is negative
- Stocks have positive energy beta
  - Energy demand shock is procyclical
  - A positive energy demand raises energy price and raises the demand for consumption good
- Bonds have negative core and energy betas
  - Bond prices decrease when inflation is high
- Extensive robustness checks on parameter values

Stock-Bond Correlation

	Data		Model						
	Pre-99	Post-99	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Stock-bond corr	0.28	-0.57	0.43	0.31	0.26	0.08	-0.18	-0.25	0.47
Stock core β	-5.19	-6.30	-6.48	-6.44	-4.13	-2.35	0.55	2.36	-6.20
Bond core β	-2.77	-0.29	-1.32	-1.44	-1.31	1.23	1.46	2.03	-1.41
Stock energy β	-0.24	0.35	0.16	0.14	0.32	0.31	0.31	0.28	-0.09
Bond energy β	-0.20	-0.22	-0.15	-0.17	-0.05	-0.05	-0.17	-0.10	-0.02
Core vol	2.85	0.64	3.40	4.23	3.33	1.69	2.76	1.46	3.21
Energy vol	12.67	28.16	11.93	25.84	30.14	30.00	30.19	29.97	17.51
energy volatility				Y	Y	Y	Y	Y	
procyclical energy					Y	Y	Y	Y	
aggresive MP						Y		Y	
low transitory							Y	Y	
Supply dominant									Y

- (1) matches the Pre-99 sample
- High energy vol (2) and more procyclical energy demand (3) decreases the stock-bond correlation
- More aggressive monetary policy (4) and smaller transitory shocks (5) decrease the stock-bond correlation
- When energy supply shock is dominant (7), stocks have negative energy beta

Conclusion

- Shed new light on the nature of inflation risk: core and energy
  - Conventional inflation "hedges" only protect against energy inflation, not the core inflation
  - Core inflation carries a negative risk premium, consistently estimated within and across asset classes
- New insights into the changing stock-bond correlation
- A two-sector quantitative NK model to replicate these facts

VAR Estimates and Inflation Expectation

- VAR estimates (t-stats in the parentheses)

	core	energy
core	0.46 (7.41)	1.74 (2.15)
food	0.08 (2.96)	0.28 (0.77)
energy	0.01 (1.22)	-0.02 (-0.29)
rf	1.81 (3.02)	0.02 (0.00)
pd	-1.23 (-3.19)	6.13 (1.22)
output	0.06 (1.32)	0.30 (0.49)
R^2	0.70	0.04

VAR Estimates and Inflation Expectation

- VAR estimates (t-stats in the parenthese)

	core	energy
core	0.46 (7.41)	1.74 (2.15)
food	0.08 (2.96)	0.28 (0.77)
energy	0.01 (1.22)	-0.02 (-0.29)
rf	1.81 (3.02)	0.02 (0.00)
pd	-1.23 (-3.19)	6.13 (1.22)
output	0.06 (1.32)	0.30 (0.49)
R^2	0.70	0.04

- Expected inflation AY_t and change of expected inflation Au_t
- Core shock u_t and shock to expected core Au_t correlation 0.90
- Energy inflation largely unpredictable

Back

Portfolio Details

- Stocks: 5 industry portfolios
- Treasuries: 7 maturity-sorted portfolios
- Agency bonds: 4 maturity-sorted portfolios
- Corporate bonds: 4 maturity-sorted portfolios
- Currencies: dollar carry and 6 carry portfolios
- Commodities: livestock, precious metal, industrial metal, energy, and agriculture
- REITs: equity, mortgage, hybrid
- International stocks: MSCI North America, Europe, Far East

Back

Inflation Exposure: 8 Average Portfolios

	A. Headline			B. Core and Energy			
	Mean	Headline β	t-stat	Core β	t-stat	Energy β	t-stat
Trea	2.07	-2.53	(-7.06)	-2.51	(-4.27)	-0.20	(-4.57)
Agen	2.44	-1.62	(-5.42)	-2.25	(-4.28)	-0.09	(-2.75)
Corp	3.08	-1.60	(-4.38)	-2.98	(-4.91)	-0.05	(-1.08)
Stock	6.80	-1.33	(-1.38)	-5.60	(-3.69)	0.21	(1.81)
Intl	6.09	-1.20	(-1.23)	-5.78	(-3.74)	0.19	(1.70)
REIT	7.96	0.31	(0.27)	-6.54	(-3.30)	0.31	(2.48)
Curr	1.76	1.04	(2.02)	-1.04	(-0.65)	0.13	(2.54)
Comm	4.47	8.59	(7.53)	-0.07	(-0.04)	1.10	(8.21)

- Fixed-income exposed negatively to both core and energy
- Stocks and REITs have significant negative core beta and positive energy beta
- Currencies and commodities only hedge energy inflation

Back

Inflation Exposure: Equities

		A. Headline			B. Core and energy		
	Mean	headline β	t-stat	core β	t-stat	energy β	t-stat
				U.S Stocks			
Cons	7.83	-2.62	(-2.61)	-6.34	(-3.97)	0.06	(0.48)
Manu	6.65	0.32	(0.35)	-4.20	(-3.02)	0.36	(3.39)
HiTech	7.31	-1.17	(-1.00)	-6.07	(-3.29)	0.26	(1.86)
Health	8.67	-2.73	(-2.70)	-6.30	(-3.91)	0.04	(0.34)
Others	7.27	-2.38	(-2.08)	-7.40	(-4.09)	0.17	(1.22)
				REITs			
Equity	8.31	0.72	(0.61)	-6.48	(-3.20)	0.35	(2.77)
Mort	4.73	-2.25	(-1.63)	-8.61	(-3.56)	0.04	(0.25)
Hyb	8.20	-1.05	(-0.79)	-6.14	(-2.60)	0.12	(0.79)
				International Stocks			
NorthAme	6.82	-0.92	(-0.96)	-5.47	(-3.57)	0.23	(2.02)
Europe	6.60	-0.93	(-0.85)	-6.09	(-3.48)	0.20	(1.56)
FarEast	7.01	-1.33	(-0.99)	-5.05	(-2.32)	0.15	(0.93)

Back

Inflation Exposure: Fixed Income

	A. Headline			B. Core and energy			
	Mean	Headline β	t-stat	core β	t-stat	energy β	t-stat
			Treasury Bonds				
1-year	0.96	-0.56	(-5.60)	-0.84	(-5.20)	-0.03	(-2.20)
3-year	1.19	-0.97	(-5.70)	-1.44	(-5.26)	-0.05	(-2.24)
5-year	1.93	-1.85	(-5.90)	-2.21	(-4.34)	-0.13	(-3.28)
7-year	2.35	-2.33	(-6.31)	-2.46	(-4.08)	-0.18	(-3.89)
10-year	2.19	-2.68	(-6.07)	-3.10	(-4.30)	-0.19	(-3.40)
20-year	2.95	-4.16	(-7.05)	-3.79	(-3.92)	-0.35	(-4.82)
30-year	2.94	-5.18	(-7.60)	-3.72	(-3.33)	-0.51	(-6.00)
			Agency Bonds				
1-5 year	1.83	-1.17	(-4.99)	-1.90	(-4.66)	-0.05	(-2.03)
5-10 year	3.58	-1.48	(-3.89)	-0.26	(-0.21)	-0.14	(-3.70)
10-15 year	3.62	-2.84	(-5.69)	-3.71	(-4.25)	-0.18	(-3.10)
>15 year	4.76	-3.42	(-5.72)	-3.63	(-3.44)	-0.26	(-3.66)
			Corporate Bonds				
1-3 year	2.26	-0.48	(-2.44)	-1.56	(-4.69)	0.02	(0.70)
3-5 year	2.93	-0.84	(-2.78)	-2.14	(-4.17)	0.00	(0.06)
5-10 year	3.61	-1.25	(-2.93)	-2.98	(-4.05)	-0.01	(-0.26)
>15 year	4.27	-2.85	(-4.98)	-4.47	(-4.66)	-0.13	(-1.91)

▸ Back

Price of Risk Estimates

	A. 8 Average Portfolios		B. 38 Portfolios	
headline	0.14		-0.08	
t-stat	(0.47)		(-0.32)	
core		-1.03		-1.07
t-stat		(-2.94)		(-3.72)
energy		3.86		3.81
t-stat		(1.35)		(1.36)
R^2	0.44	0.98	0.41	0.82

- Only core inflation carries a significant price of risk
- The price of risk estimate is consistent using both sets of portfolios

Back

Inflation Risk Within and Across Asset Classes

	Stock	Trea	Agen	Corp	Curr	Comm	REIT	Intl	Aver	All
core	-1.26	-0.89	-0.68	-1.09	-0.99	-0.80	-1.06	-0.97	-1.03	-1.07
t-stat	(-2.51)	(-2.43)	(-1.57)	(-2.75)	(-1.96)	(-0.75)	(-2.70)	(-1.69)	(-2.94)	(-3.72)
energy	2.02	0.56	-8.25	7.65	2.37	4.18	3.27	8.08	3.86	3.81
t-stat	(0.50)	(0.14)	(-1.06)	(2.01)	(0.26)	(1.41)	(0.41)	(1.31)	(1.35)	(1.36)
R^2	0.26	0.93	0.96	0.75	0.63	0.89	0.23	0.49	0.98	0.82

- Magnitude of the price of core inflation risk consistently estimated both within and across asset classes

Back

Expanded Set of Test Portfolios

- Stocks: 17 industry + 6 size-B/M + 6 size-inv + 6 size-prof portfolios
- Treasuries: 7 fixed-term + 12 maturity sorted (<6M, 6-12M, 12-18M, ..., 54-60M, 60-120M, >120M)
- Agency bonds: 6 maturity sorted (1-3y, 3-5y, 5-7y, 7-10y, 10-15y, >15y)
- Corporate bonds: 8 double sorted (Aaa-Aa, A-Baa) $\times$ (1-3y, 3-5y, 5-10y, >15y)
- Currencies: dollar carry, 6 carry, 4 value, 6 dollar beta portfolios
- Commodity futures
- REITs: equity, mortgage, hybrid plus 8 sectors

Other Macroeconomic Factors

- Does core inflation proxy for known macroeconomic factors? No!

	Cons	Cons/Dur	IP	Pay	Unem	HHL	Unf Cons	Cap
core	-1.06	-1.04	-1.07	-1.07	-1.06	-1.04	-1.07	-1.08
t-stat	(-3.69)	(-3.67)	(-3.51)	(-3.27)	(-3.39)	(-3.48)	(-3.70)	(-3.72)
energy	3.90	4.38	4.08	3.68	3.84	3.97	3.98	3.94
t-stat	(1.29)	(1.36)	(1.38)	(1.33)	(1.36)	(1.29)	(1.44)	(1.38)
macro	0.10	0.17	-0.34	-0.08	0.11	0.46	0.00	-0.31
t-stat	(0.18)	(0.32)	(-0.24)	(-0.16)	(0.26)	(0.62)	(0.26)	(-0.59)
macro2		-2.62				-0.01		
t-stat		(-0.67)				(-0.58)		
R^2	0.82	0.82	0.82	0.82	0.82	0.81	0.82	0.80

Back

Conventional Wisdom Revisited: Currencies

	A. Headline			B.Core and energy			
	Mean	Headline β	t-stat	Core β	t-stat	Energy β	t-stat
Dollar carry	5.34	-0.98	(-1.52)	-4.17	(-2.08)	0.00	(-0.04)
Carry-1	-1.81	0.33	(0.57)	-0.52	(-0.28)	0.06	(0.95)
Carry-2	-0.25	1.60	(2.99)	1.72	(1.03)	0.14	(2.55)
Carry-3	1.12	1.02	(1.92)	-0.04	(-0.02)	0.11	(2.02)
Carry-4	2.53	0.45	(0.74)	-2.50	(-1.34)	0.10	(1.60)
Carry-5	3.43	1.44	(2.28)	-1.28	(-0.65)	0.19	(2.94)
Carry-6	5.56	1.38	(1.87)	-3.62	(-1.60)	0.20	(2.72)
Value-1	-0.01	1.65	(2.32)	-2.12	(-0.96)	0.21	(2.94)
Value-2	1.16	1.48	(2.15)	-2.53	(-1.19)	0.20	(2.85)
Value-3	2.52	1.54	(2.23)	-1.74	(-0.82)	0.20	(2.84)
Value-4	4.14	1.43	(2.22)	-2.73	(-1.38)	0.21	(3.24)
Dol-β-1	0.83	-0.37	(-1.24)	-0.04	(-0.04)	-0.04	(-1.39)
Dol-β-2	1.68	-0.82	(-1.90)	-1.46	(-1.04)	-0.05	(-1.20)
Dol-β-3	2.57	-0.30	(-0.56)	-1.77	(-1.01)	0.02	(0.34)
Dol-β-4	3.65	0.57	(0.90)	-3.27	(-1.61)	0.12	(1.99)
Dol-β-5	3.13	-0.79	(-1.02)	-3.85	(-1.52)	0.01	(0.07)
Dol-β-6	4.87	-0.62	(-0.75)	-5.05	(-1.91)	0.04	(0.46)

Back

Time-varying Price of Risk

How does the price of inflation risk covary with other macroeconomic variables? (Adrian et al, 2015)

- Conditioning variable F_t: term spread $10y - 3m$
- Suppose the SDF follows

$$\frac{M_{t+1} - E_t M_{t+1}}{E_t M_{t+1}} = -\lambda_t u_{t+1}, \text{where } \lambda_t = \Sigma_u^{-\frac{1}{2}} (\lambda_0 + \lambda_1 F_t)$$

- Then $E_t R^i_{t+1} = \beta_i' (\lambda_0 + \lambda_1 F_t)$
- Result with 38 portfolios

	Estimate	t-stat
λ_0	-0.94	(-1.70)
λ_1	-0.52	(-1.58)

Back

Price Stickiness and Core Inflation

- Flexible and sticky inflation
  - Sticky inflation: a basket of items that change price slowly
  - Flexible inflation: the rest
  - Core inflation and sticky inflation correlation about 0.8

	sticky	*t*-stat	flexible	*t*-stat
A. Asset Return Exposures				
Stock	-4.68	(-2.99)	0.25	(0.61)
Trea	-1.12	(-1.86)	-0.93	(-5.93)
Agen	-0.94	(-1.93)	-0.51	(-4.20)
Corp	-1.61	(-2.70)	-0.39	(-2.56)
Curr	-1.14	(-0.69)	0.41	(2.16)
Comm	-1.53	(-0.87)	3.88	(8.51)
REIT	-4.35	(-2.38)	0.61	(1.38)
Intl	-4.95	(-3.27)	0.23	(0.58)
B. Price of Risks				
8 portfolios	-1.50	(-2.61)	0.45	(0.47)
38 portfolios	-1.45	(-3.49)	-0.21	(-0.24)

- Sticky inflation resembles core Back