Inflation risk and the cross-section of stock returns

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Introduction

- How and why inflation is priced in the cross-section of real stock returns.
- How
  - Inflation is priced and its market price of risk is comparable to the aggregate market's.
  - Stocks that have low real returns during periods of increasing inflation earn a risk premium.
- Why
  - The inflation premium cannot be accounted for by factors like Fama-French or industry effects.
  - I argue that inflation is priced because it predicts low real consumption growth.
  - Develop and estimate a model that reproduces the emprical findings.

Why look at the cross-section of stocks?

- Asset pricing
  - New source to estimate the inflation premium.
  - Understand main risks in the cross-section of stocks.
- Macroeconomics
  - Insights about why inflation has real effects.
  - Estimate welfare costs of inflation consistent with asset prices.

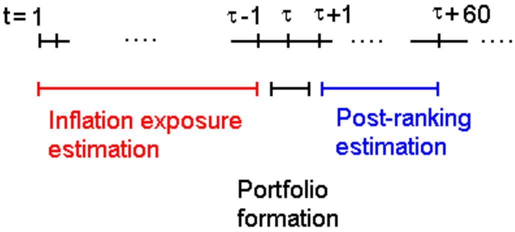
Outline

1. Empirical section
   1.1 Create 10 inflation-sorted portfolios.
   1.2 Estimate inflation premium using Fama-MacBeth.
   1.3 Show that common asset pricing factors cannot account for the inflation premium.
2. Model
   2.1 Set-up and assumptions.
   2.2 Asset pricing, intuition, Fama-MacBeth.
   2.3 GMM estimation and comparison with empirical results.

Data sources

- All stock prices, dividends and market capitalization from CRSP.
- Yield curve from Fama-Bliss discount bond files.
- Consumption is real per-capita consumption of nondurables and services from BEA.
- Inflation is for the corresponding measure of consumption from BEA.
- Fama-French and other factors, Cochrane-Piazzesi factor, from their authors.
- Oil from Global Financial Data.
- Monthly frequency, Jan 1959-Dec 2009 (quarterly and annual also for robustness).

Ex-ante and ex-post inflation exposure



Inflation exposure is measured by a stock's "beta"

- For stock i, its exposure to inflation at time τ is $\hat{\beta}_{i,\tau}$, the coefficient of a weighted-least squares regression of excess returns on inflation innovations.
- Specifically, for observations at times $0 < t_1 < t_2 < ... < t_n < \tau$,

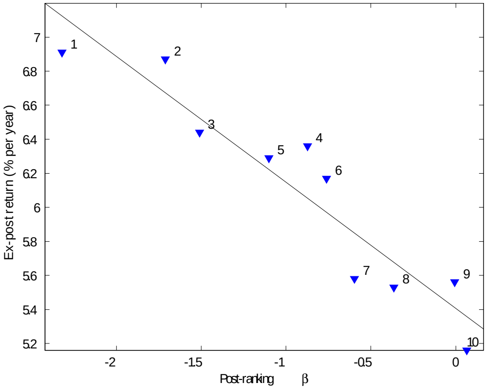
$$\left(\hat{\alpha}_{i,\tau}, \hat{\beta}_{i,\tau}\right) = \arg\min_{\alpha,\beta} \sum_{j=1}^{n} K_h\left(t_j - \tau\right)\left(R_{i,t_j} - R^f_{t_j} - \alpha - \beta \Delta\pi_{t_j}\right)^2$$

with $K_h\left(t_j - \tau\right)$ exponentially decaying and a half-life of five years.

Create portfolios by sorting stocks on exposure to inflation

- Form 10 portfolios with different exposure to inflation but equal exposure to other risk factors.
- First, double sort on 10 groups based on inflation beta and 10 groups based on size and create 100 value-weighted portfolios.
- Then create 10 new value-weighted portfolios from the original 100 by grouping according to size.
- Portfolios are created using past information only.

Inflation portfolios have a spread in ex-post returns



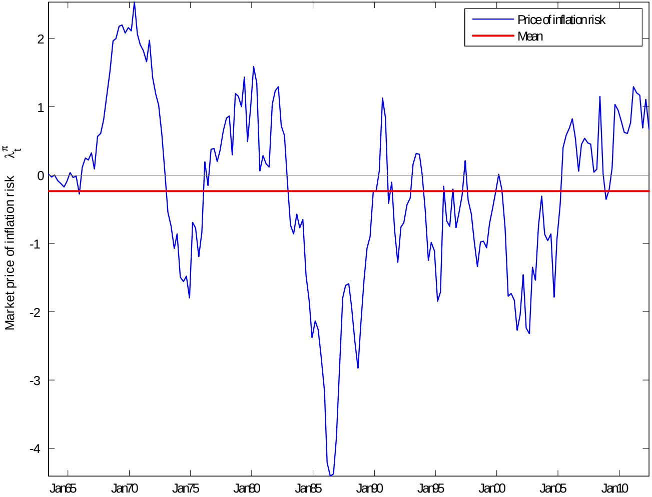
$$\bar{R}_p^e = \underset{(0.132)}{5.41} - \underset{(0.113)}{0.74} \bar{\beta}_p + \varepsilon_t$$

Inflation is priced: Fama-MacBeth estimates

	Results from $R^e_{p,t} = a_t + \lambda_t \beta_{p,t} + \varepsilon_t$		
	10 portfolios	All stocks	5-yr rolling
$\bar{\lambda} = \frac{1}{T}\sum \hat{\lambda}_t$	-0.368**	-0.340**	-0.343**
	(0.024)	(0.019)	(0.031)
$\bar{\lambda}/\sigma_\pi$	-0.323	-0.298	-0.300

Notes: (**) Significant at the 1% level.

Time-variation in inflation compensation



Portfolios have similar exposure to other risks

	Market	Size	Book-to-Market	Momentum
Portfolios				
$p=$ 1	0.992	0.990	0.568	-0.086
2	0.997	0.979	0.525	-0.101
3	1.00	0.985	0.599	-0.088
4	0.999	0.983	0.581	-0.093
5	0.987	0.964	0.557	-0.085
6	1.00	0.981	0.609	-0.055
7	1.01	0.985	0.568	-0.105
8	1.03	0.995	0.562	-0.116
9	1.03	0.992	0.580	-0.098
$p=10$	1.01	0.985	0.557	-0.098
Spread	-0.018	0.005	0.011	0.012

Portfolios are diversified in their industry composition

Portfolios	Concentration	Correlation	Persistence
$p = 1$	0.142	0.316	0.377
2	0.143	0.315	0.377
3	0.130	0.315	0.378
4	0.118	0.312	0.356
5	0.131	0.313	0.371
6	0.130	0.316	0.375
7	0.119	0.311	0.361
8	0.114	0.313	0.367
9	0.130	0.307	0.340
$p = 10$	0.127	0.319	0.354
Spread	0.015	-0.003	0.023

Other pricing factors do not work

	$R^e_{p,t} = a_p + b_p X_t + e_{p,t}$					
Factors X_t						
Market	Yes	Yes	Yes	Yes	×	Yes
HML / SMB / Mom	×	Yes	×	×	×	Yes
Oil	×	×	Yes	×	×	Yes
CP factor	×	×	×	Yes	×	Yes
Industry	×	×	×	×	Yes	Yes
Mean $\|a_p\|$	2.08	2.80	1.88	3.11	2.31	1.77
p-value all $a_p = 0$	0.005	0.00	0.027	0.00	0.043	0.00
R^2	58.3%	60.9%	58.6%	57.2%	62.3%	61.8%

Summary of empirical results

- Inflation risk is priced in the cross section of stocks
- Stocks more exposed to π have higher mean returnson average.
- Linear relationship between inflation β and mean returns.
- The price of risk for inflation is -0.3, with substantial time variation.
- Spread not explained by standard pricing factors.

A consumption-based model prices inflation risk

- Consumption and inflation exogenous, Epstein-Zin representative agent prices assets.
- Crucial ingredients
  - Inflation predicts real consumption growth.
  - Inflation is persistent.
  - Non-separable utility.
- Main result: linear relationship between inflation β and mean returns as in the data, right market price of risk.

Representative agent's problem

$$V_t\left(W_t\right) = \max_{\{C_t\}} \left((1-\delta)\, C_t^{1-1/\psi} + \delta E_t \left[V_{t+1}(W_{t+1})^{1-\gamma} \right]^{\frac{1-1/\psi}{1-\gamma}} \right)^{\frac{1}{1-1/\psi}}$$

$$\begin{aligned}
\text{(bc):} \qquad & W_{t+1} &=& \left(1+R_{c,t+1}\right)\left(W_t - C_t\right) \\
\text{(consumption):} \qquad & \Delta c_{t+1} &=& \mu_c + \rho_c\left(\pi_t - \mu_\pi\right) + \sigma_c \eta_{t+1} \\
\text{(inflation):} \qquad & \pi_{t+1} &=& \mu_\pi + \rho_\pi\left(\pi_t - \mu_\pi\right) + \sigma_\pi \varepsilon_{t+1}
\end{aligned}$$

Inflation predicts consumption growth

	Regression of $\Delta c_{t\to t+12}$ on lags of inflation and consumption growth		
π_{t-1}	-1.15*	-0.440	-0.452
	(0.507)	(0.389)	(0.430)
π_{t-2}	$\times$	-0.616*	-0.610*
		(0.250)	(0.249)
π_{t-3}	$\times$	-0.695*	-0.701*
		(0.298)	(0.290)
Δc_{t-1}	$\times$	$\times$	-0.044
			(0.186)
R^2	6.12%	9.71%	9.73%

Notes: (*) Significant at the 5% level. NW standard errors with 24 lags.

Inflation is persistent

	Regression of π_t on its lags	
π_{t-1}	0.629^{**} (0.031)	0.519^{**} (0.040)
π_{t-2}	$\times$	0.091^{**} (0.046)
π_{t-3}	$\times$	0.107^{**} (0.040)
R^2	39.6%	41.6%

Notes: (**) Significant at the 1% level.

Model gives an inflation-consumption CAPM

- The (log) stochastic discount factor is

$$sdf_{t+1} = \theta \log \delta - \frac{\theta}{\psi} \Delta c_{t+1} + (\theta - 1) \, r_{c,t+1}$$

- If $r^e_{i,t+1}$ are expected excess returns,

$$\begin{aligned} E_t \left[r^e_{i,t+1} \right] &= -Cov_t \left(sdf_{t+1}, r_{i,t+1} \right) \\ &\approx \gamma Cov_t \left(\Delta c_{t+1}, r_{i,t+1} \right) + \\ &\quad + \frac{(\gamma - 1/\psi)(\rho_c - 1/\psi)}{(1 - \rho_\pi)(1 - 1/\psi)} Cov_t \left(\pi_{t+1}, r_{i,t+1} \right) \end{aligned}$$

Mean returns are decreasing in inflation betas

- Dividends are leveraged consumption (Abel 1999):

$$\Delta d_{i,t+1} = \mu_{i,d} + l_i \rho_c \left(\pi_t - \mu_\pi\right) + \varphi_i \omega_{i,t+1}$$

- What are we after? Relationship between returns and inflation betas

$$E\left[r_i^e\right] = \gamma \sigma_c^2 + \frac{\left(\gamma - 1/\psi\right)\left(\rho_c - 1/\psi\right)}{\left(1 - \rho_\pi\right)\left(1 - 1/\psi\right)} \beta_i$$

where

$$\beta_i = \frac{Cov\left(r_{i,t}^e, \Delta \pi_t\right)}{Var\left(\Delta \pi_t\right)} = \frac{l_i \rho_c - 1/\psi}{1 - \rho_\pi}$$

- Same linear relation as observed empirically.

Estimate a richer model

- Add stochastic volatility and inflation lags in consumption:

$$
\begin{aligned}
\Delta c_{t+1} &= \mu_c + \textstyle\sum_{s=0}^{2} \rho_{c,s} \left(\pi_{t-s} - \mu_\pi\right) + \sigma_{c,t}\eta_{t+1} \\
\sigma^2_{c,t+1} &= \sigma^2_c + \nu_c \left(\sigma^2_{c,t} - \sigma^2_c\right) + \sigma_{cw} w_{t+1} \\
\pi_{t+1} &= \mu_\pi + \textstyle\sum_{s=0}^{2} \rho_{\pi,s} \left(\pi_{t-s} - \mu_\pi\right) + \sigma_{\pi,t}\varepsilon_{t+1} + \varphi_{\pi c}\sigma_{c,t}\eta_{t+1} \\
\sigma^2_{\pi,t+1} &= \sigma^2_\pi + \textstyle\sum_{s=0}^{2} \nu_{\pi,s} \left(\sigma^2_{\pi,t-s} - \sigma^2_\pi\right) + \sigma_{\pi w} u_{t+1} \\
\Delta d_{i,t+1} &= \mu_{i,d} + l_i \textstyle\sum_{s=0}^{2} \rho_{c,s} \left(\pi_{t-s} - \mu_\pi\right) + \varphi_i \sigma_{c,t}\omega_{t+1}
\end{aligned}
$$

GMM estimation

- 53 Parameters:

$$\Theta = \left\{ \underbrace{\mu_c, \mu_\pi, \sigma_c, \sigma_\pi, \rho_{c,s}, \rho_{\pi,s}, \varphi_{\pi,c}}_{\text{cons and inflation (11)}}, \quad \underbrace{\nu_{\pi,s}, \nu_{c,s}, \sigma_{\pi w}, \sigma_{cw}}_{\text{vol (6)}}, \right.$$

$$\left. \underbrace{\mu_{i,d}, l_i, \varphi_i}_{\text{stocks (33)}}, \quad \underbrace{\delta, \psi, \gamma}_{\text{pref (3)}} \right\}$$

GMM estimation

- 59 Moment conditions:

$$\mathbb{M} = \Big\{ \underbrace{E\left[\Delta c_t\right], Var(\Delta c_t), E\left[\pi_t\right], Cov(\Delta c_t, \pi_{t-s}), Cov(\pi_t, \pi_{t-s}),}_{\text{cons and inflation (11)}}$$

$$\underbrace{E\left[R^e_{m,t}\right], Var\left(R^e_{m,t}\right), \bar{\beta}_{m,t}, E\left[\Delta d_{m,t}\right], E[pd_t], Var(pd_t)}_{\text{aggregate market (6)}}$$

$$\underbrace{E\left[y^n_t\right], Var\left(y^n_t\right)}_{\text{bonds (12)}}, \underbrace{E\left[R^e_{p,t}\right], Var\left(R^e_{p,t}\right), \bar{\beta}_{p,t},}_{\text{inf portfolios (30)}} \Big\}$$

GMM estimates

Preference parameters		
Discount factor	δ	0.989 (0.04)
Elasticity of intertemporal substitution	ψ	1.44 (0.18)
Risk aversion coefficient	γ	8.46 (0.93)

Notes: GMM asymptotic standard errors in parenthesis.

GMM estimates: consumption and inflation

Regression of Δc_t on lags of π_t			
	Data	Model	B.S. (2010)
π_{t-1}	0.02	-0.14	-0.30
π_{t-2}	-0.11	-0.08	-0.08
π_{t-3}	-0.07	-0.05	-0.01

Regression of π_t on its lags			
	Data	Model	B.S. (2010)
π_{t-1}	0.52	0.62	0.65
π_{t-2}	0.09	0.12	0.63
π_{t-3}	0.11	0.10	0.52

GMM estimates: Fama-MacBeth

	Results from $R^e_{p,t} = a_t + \lambda_t \beta_{p,t} + \varepsilon_t$			
	10 portfolios	All stocks	Flat kernel	Model
$\bar{\lambda}$	-0.368**	-0.340**	-0.343**	-0.377**
	(0.024)	(0.019)	(0.031)	(0.033)
$\bar{\lambda}/\sigma_\pi$	-0.323	-0.298	-0.300	-0.285

Notes: (**) Significant at the 1% level.

Model in different inflation regimes

	Panel A: Regression of π_t on its lag		
	Full Sample	Pre-1980	Post-1980
π_{t-1}	0.629^{**} (0.031)	0.679^{**} (0.047)	0.547^{**} (0.044)
$\sigma(\pi_t)$	1.14	1.14	1.07
	Panel B: Inflation premium $\bar{\lambda}$		
	Full Sample	Pre-1980	Post-1980
Data	-0.368	-0.371	-0.317
Model	-0.377	-0.401	-0.324

Conclusion

- Inflation is an important systematic risk-factor priced in the cross-section of stock returns.
- Stocks that hedge inflation have lower unconditional returns, but conditional returns are time-varying.
- A consumption equilibrium model with high inflation predicting low consumption growth can generate the observed inflation market price of risk.

GMM moments

	Data	Model	B.S. (2010)
$\mathbb{E}[\pi_t]$	4.47	4.52	3.30
$\sigma(\pi_t)$	1.14	1.34	1.82
$\mathbb{E}[\Delta c_t]$	3.14	3.14	1.92
$\sigma(\Delta c_t)$	2.14	2.25	1.35
$corr(\pi_t, \Delta c_t)$	-0.26	-0.26	-0.34

GMM moments

	Data	Model	B.S. (2010)
$\mathbb{E}[R_t^{m,e}]$	6.65	7.25	5.01
$\sigma(R_t^{m,e})$	15.5	16.8	15.2
$\mathbb{E}[P_t/D_t]$	26.97	25.42	21.71
$\sigma(P_t/D_t)$	7.32	8.32	12.17
$\mathbb{E}[R_t^f]$	1.18	1.26	1.19
$\sigma(R_t^f)$	0.97	0.45	0.12

Fama-MacBeth estimates controlling for market in the TS

	Results from $R^e_{p,t} = a_t + \lambda_t \beta_{p,t} + \varepsilon_t$		
	10 portfolios	All stocks	Controlling for market
$\bar{\lambda} = \frac{1}{T} \sum \hat{\lambda}_t$	-0.368** (0.024)	-0.340** (0.019)	-0.392** (0.035)

Notes: (**) Significant at the 1% level.

Fama-MacBeth estimates controlling for lags in the TS

	Results from $R^e_{p,t} = a_t + \lambda_t \beta_{p,t} + \varepsilon_t$		
	10 portfolios	All stocks	Controlling for lags
$\bar{\lambda} = \frac{1}{T} \sum \hat{\lambda}_t$	-0.368**	-0.340**	-0.402**
	(0.024)	(0.019)	(0.048)

Notes: $(^{**})$ Significant at the 1% level.

Fama-MacBeth estimates controlling for market in the cross-section

	$R^e_{p,t} = a_t + \lambda_t \beta_{p,t} + \lambda^{mkt}_t \beta^{mkt}_{p,t} + \varepsilon_t$
$\bar{\lambda} = \frac{1}{T} \sum \hat{\lambda}_t$	-0.371** (0.017)

Fama-MacBeth estimates using quarterly and annual data

	Results from $R^e_{p,t} = a_t + \lambda_t \beta_{p,t} + \varepsilon_t$		
	Monthly	Quarterly	Annual
$\bar{\lambda} = \frac{1}{T} \sum \hat{\lambda}_t$	-0.368**	-0.381*	-0.243
	(0.024)	(0.192)	(0.232)

Notes: (*,**) Significant at the 5%, 1% level.