Causal Inference for Asset Pricing

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A Framework for Estimation of Demand in Asset Pricing

- Flexible demand: rich patterns of **substitution** across assets
- Built on a clear, realistic, portable assumption
- Transparent estimation through IV/DiD of the elasticity matrix
- Answers macrostructure questions:
  - price impact, QE, operation twist
  - spillovers across maturities and ratings

This paper: what we do

Central assumption: Homogeneous Substitution Conditional on Observables (HSCO)

- Holds in many existing models of demand: logit, mean-variance, ...
- Captures finance features: factor structure, ...

Estimation

- Natural decomposition of the elasticity in finance context:

$$\text{Elasticity} = \underbrace{\text{relative elasticity}}_{\text{“arbitrage”}} + \underbrace{\text{substitution}}_{\text{“factor management”}}$$

- Cross-section: estimate a *relative* elasticity
  - *Missing coefficient* problem: impossible to estimate substitution
- Time series: estimate the *substitution* matrix

Applications

- Both are necessary to estimate counterfactuals (even the cross-section)
- Example: non-standard monetary policy on the corporate bond market

Related literature

- **Asset pricing using causal inference methods**
  - Shleifer (1986); Harris, Gurel (1986); Chang, Hong, Liskovich (2014); Pavlova, Sikorskaya (2023); Greenwood, Sammon (2024); Gompers, Metrick (2001); Coval, Stafford (2007); Lou (2012); Ben-David, Li, Rossi, Song (2022); Hartzmark, Solomon (2022); Krishnamurthy, Vissing-Jorgensen (2011); Haddad, Moreira, Muir (2021, 2025); Selgrad (2024); Du, Tepper, Verdelhan (2018); Greenwood, Vissing-Jorgensen (2018); Haddad, Muir (2021); Chen, Chen, He, Liu, Xie (2023); ...
- **Structural approach and demand systems**
  - Koijen, Yogo (2019, 2024); Koijen, Richmond, Yogo (2024); Haddad, Huebner, Loualiche (2024); van der Beck (2024); Lu, Wu (2023); Gabaix, Koijen (2024); Bretscher, Schmid, Sen, Sharma (2024); Jansen, Li, Schmid (2024); Fang (2023); Fang, Xiao (2024); Graves (2025); ...
  - Li, Lin (2024); Chaudhary, Fu, Li (2023); Aghaee (2024); An, Huber (2025); Peng, Wang (2023); Fuchs, Fukuda, Neuhann (2024); ...
- **What we don't do:**
  - Strategic responses (Haddad, Huebner, Loualiche, 2024)
  - Dynamics (Greenwood, Hanson, Liao, 2018; Huebner, 2024; Gabaix, Koijen, 2024; He, Kondor, Li)
  - State-contingent shocks (Haddad, Moreira, Muir, 2025)
- **Spillovers/substitution outside asset pricing:**
  - Berry, Levinsohn, Pakes (1995), Berg, Reisinger, Streitz (2021); Chodorow-Reich, Nenov, Simsek

Background

How do portfolio decisions respond to prices: the elasticity matrix

$$\underbrace{\mathcal{E}}_{N\times N} = \frac{\partial D}{\partial P} = \left[\frac{\partial D_i}{\partial P_j}\right]_{ij}$$

Elasticity matrix: sensitivity of demand to prices

- Example of foundations: **mean-variance utility** $D = \frac{1}{\gamma}\Sigma^{-1}(M-P)$, $\mathcal{E} = -\frac{1}{\gamma}\Sigma^{-1}$
- Could be log, levels, shares, changes or not, ...
- Crucial for macrostructure questions: e.g. price impact $\mathcal{E}_{agg}^{-1}$, how do shifts in demand affect prices?

$\Rightarrow$ **Answer to such questions about different parts of $\mathcal{E}$**

Learning from Standard Finance Models

APT-style model: factor model with i.i.d. residuals, $\alpha_i \perp \beta_i$:

$$R_{it} = \alpha_i + \beta_i F_t + \epsilon_{it}$$

Optimal portfolio (Campbell Viceira 2001, Koijen Yogo 2019):

- *Force 1:* factor management, if expected return only depends on exposures β
  - mutual fund theorem: only buy portfolios replicating the factors (β sorted)
  - choose exposure to the factors based on the expected returns of those factors
- *Force 2:* "arbitrage": if expected returns deviate from factor pricing
  - buy more of cheap (= high alpha) assets, less of expensive ones

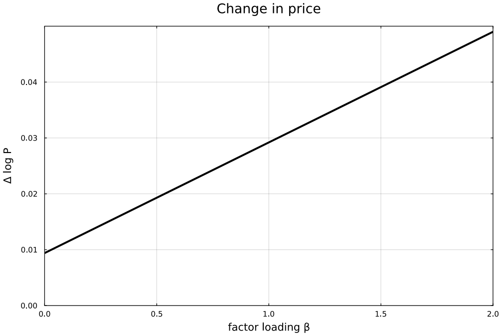
$$\omega_i = \frac{1}{\gamma}\left[\frac{1}{\sigma_\epsilon^2}\alpha_i + \beta_i' \Upsilon E[F_t]\right]$$

Elasticity: changing prices = changing expected returns

$$\mathcal{E} = \underbrace{-\frac{1}{\gamma\sigma_\epsilon^2}\mathbf{I}}_{\text{diagonal}} + \underbrace{\boldsymbol{\beta}\Psi\boldsymbol{\beta}'}_{\text{substitution matrix}}$$

Why is Everything Needed?

There was a shock to the supply of various assets and you see the price of high-beta assets increase more than those of low-beta assets. What was the supply shock?



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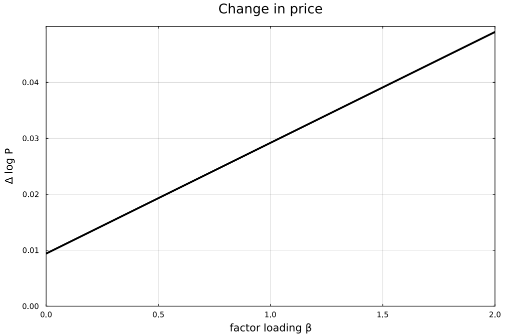
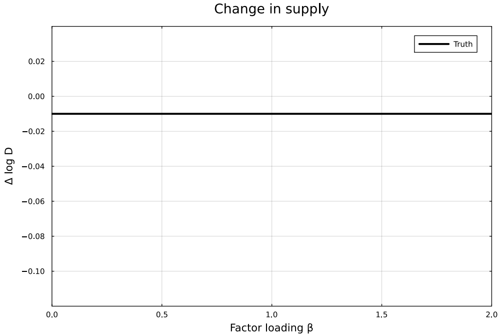
- **Truth:** model of previous slide with one factor, all supply decreased equally
  - factor supply decreased → lower risk premium → price of high β assets increase more





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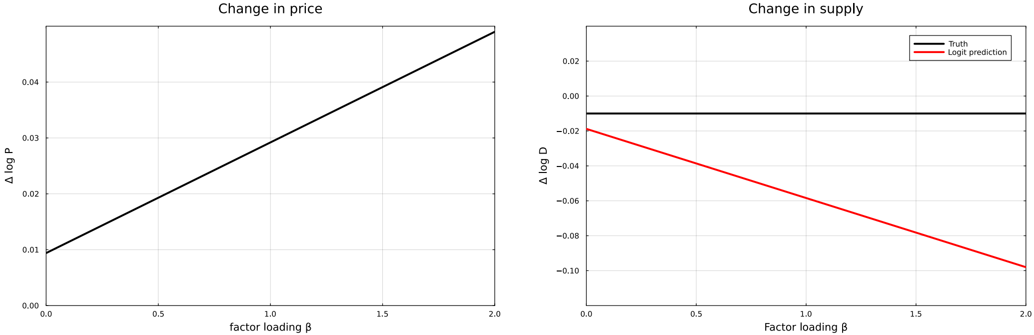

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- **Models:** assuming *perfectly estimated* on simulated data from true model with exogenous supply shocks
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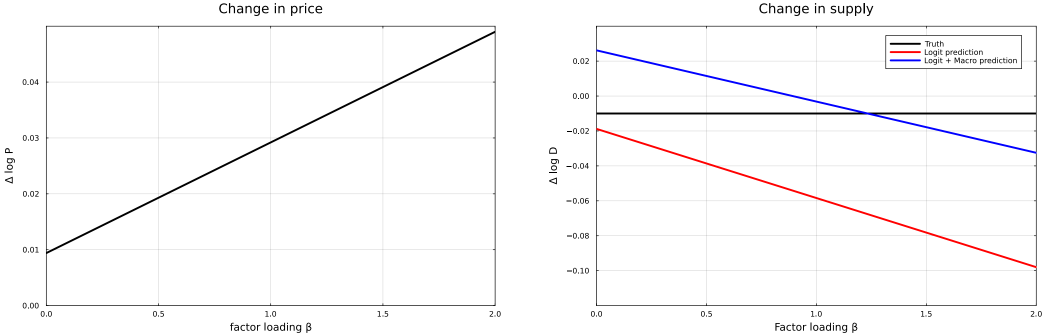
  - Add a macro elasticity (Gabaix Koijen 2023): does not fix it

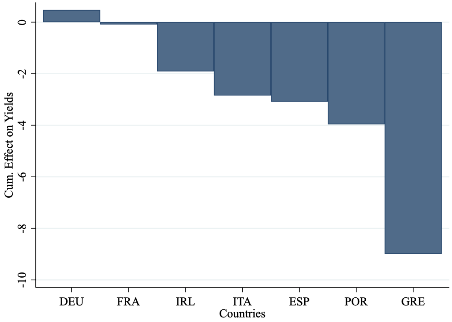


In The Real World

- **QE across maturities** (e.g. Krishnamurthy Vissing-Jorgensen 2011, Haddad Moreira Muir 2024), see also effect of Treasury supply (Greenwood Vayanos 2014)

	(1) 1M	(2) 3M	(3) 6M	(4) 1Y	(5) 2Y	(6) 3Y	(7) 5Y	(8) 7Y	(9) 10Y	(10) 20Y	(11) 30Y
QE Event	-0.10	-0.06	-0.32**	-0.37**	-0.51**	-0.58**	-1.09***	-1.34***	**-1.39*** **	-0.90***	-0.76***
	(0.26)	(0.19)	(0.16)	(0.17)	(0.20)	(0.22)	(0.25)	(0.25)	(0.24)	(0.24)	(0.23)

- **EU asset purchases across countries** (e.g. Haddad Moreira Muir 2025)



Framework

Homogeneous Substitution Conditional on Observables

A simple assumption:

- **Homogeneous substitution conditional on observables**
  - Investors substitute across bonds based on their observables only

$$\begin{aligned} \textit{Ford:} \quad & \Delta D_1 = \mathcal{E}_{11}\Delta P_1 + \mathcal{E}_{12}\Delta P_2 + \sum_{k\geqslant 3} \mathcal{E}_{1k}\Delta P_k \\ \textit{GM:} \quad & \Delta D_2 = \mathcal{E}_{22}\Delta P_2 + \mathcal{E}_{21}\Delta P_1 + \sum_{k\geqslant 3} \underbrace{\mathcal{E}_{2k}}_{=\mathcal{E}_{1k}} \Delta P_k \end{aligned}$$

- **Compare bonds with same observables:** Ford vs. GM
  - E.g.: Investor adjusts Ford and GM equally in response to price of First Solar $\mathcal{E}_{13} = \mathcal{E}_{23}$

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$$\textit{Diff-in-diff:} \quad \Delta D_1 - \Delta D_2 = \widehat{\mathcal{E}}(\Delta P_1 - \Delta P_2) \text{ if same relative elasticity}$$

- **Compare bonds with same observables:** Ford vs. GM
  - E.g.: Investor adjusts Ford and GM equally in response to price of First Solar $\mathcal{E}_{13} = \mathcal{E}_{23}$

$\rightarrow$ *comparing assets with same observables differences out substitution*

Formal Setup

- **Homogeneous substitution conditional on observables X**

$$\boxed{\mathcal{E}_{il} = \mathcal{E}_{jl} \text{ if } X_i = X_j} \quad \text{for all } i, j \in \mathcal{S}, \text{ and } l \neq i, j,$$

  - If price of a 3rd asset moves, response of demand for 2 assets with same observables is the same
  - Parametrize linearly: $\mathcal{E}_{il} = \mathcal{E}_{\text{cross}}(X_i, X_l) = X_i' \boldsymbol{\mathcal{E}}_X X_l$

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- **Decomposition of demand elasticity:**

$$\boldsymbol{\mathcal{E}} = \text{relative elasticity} + \text{substitution}$$

$$= \text{diagonal matrix} + X \underbrace{\boldsymbol{\mathcal{E}}_X}_{K \times K} X'$$

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- **Decomposition of demand elasticity:**

$$\begin{aligned} \boldsymbol{\mathcal{E}} &= \text{relative elasticity} + \text{substitution} \\ &= \underbrace{\widehat{\mathcal{E}}}_{\text{scalar}} I + X \underbrace{\boldsymbol{\mathcal{E}}_X}_{K \times K} X' \end{aligned}$$

  - Assume constant relative elasticity $\widehat{\mathcal{E}}$ for simplicity, relax in the paper

Questions Revisited

$$\mathcal{E} = \text{relative elasticity} + \text{substitution}$$
$$= \hat{\mathcal{E}} I + X \boldsymbol{\mathcal{E}}_X X'$$

Different questions are about different parts of $\mathcal{E}$

- *How does CalPERS adjust its position in 10-year corporate bonds of Ford and GM when their spread changes?*
  - Asset-specific behavior characterized by the relative elasticity $\hat{\mathcal{E}}$
- *How does CalPERS change its green tilt when the price of greenium increases?*
  - Question about substitution characterized by $\boldsymbol{\mathcal{E}}_X$

Many Potential Mechanisms

Key question: What do investors consider when substituting between assets?

- *Investor manages portfolio-level statistic, so substitution depends on asset i's contribution*

This matters for what observables X_i to include

- *Risk based motives*: care about portfolio-level factor exposure, so $X_i = \beta_i$ are factor loadings or characteristics that proxy for them

- *Broad categories*: X_i are group dummies say on durations or industries

- *Non-risk motives*: X_i is asset weight in this objective

$$\max_{D} \quad D'(\mu - P) - \frac{\gamma}{2} D'\Sigma D - \frac{\kappa}{2}\left(D'X^{(1)}\right)^2$$
$$\text{such that} \quad D'X^{(2)} \leqslant \Theta$$

  – Binding constraints (leverage), regulatory score (capital ratio), or stakeholders pressure (greenness)

Estimation

Cross-Sectional Identification

- **Data-Generating-Process:** Elasticity matrix $\mathcal{E}$ + *homogeneous substitution conditional on observable* X

$$\Delta \mathbf{D} = \mathcal{E} \Delta \mathbf{P} + \epsilon$$

  - Demand shift ϵ correlated with prices: Ford is more expensive because the new F150 is amazing, change in CalPERS financial health, ...

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- **Proposition 1** Under our assumption, and the *usual exclusion and relevance restrictions*, the IV estimator identifies the **relative elasticity** $\widehat{\mathcal{E}} = \boldsymbol{\mathcal{E}}_{ii} - \boldsymbol{\mathcal{E}}_{ji}$ for $X_i = X_j$

$$\Delta D_i = \widehat{\mathcal{E}} \Delta P_i + \theta' X_i + e_i$$
$$\Delta P_i = \lambda Z_i + \eta' X_i + u_i$$

  with Z_i instrument for prices ($Z_i \perp \epsilon_i | X_i$)

  – E.g.: Fed buys some bonds but not others

Absorbing Substitution

- Key step: coefficient on observables θ absorbs substitution from other assets

$$\Delta D_i = \mathcal{E}_{ii}\Delta P_i + \sum_{j\neq i} X_i'\mathcal{E}_X X_j \Delta P_j + \epsilon_i$$

$$= \left(\mathcal{E}_{ii} - X_i'\mathcal{E}_X X_i\right)\Delta P_i + \sum_j X_i'\mathcal{E}_X X_j \Delta P_j + \epsilon_i$$

$$= \underbrace{\left(\mathcal{E}_{ii} - X_i'\mathcal{E}_X X_i\right)}_{\text{relative elasticity}}\Delta P_i + X_i' \underbrace{\sum_j \mathcal{E}_X X_j \Delta P_j}_{\text{constant across assets, absorbed in } \theta} + \epsilon_i$$

- **Relative elasticity:** difference between own-price and cross-price elasticity for assets with same observables
  - How does the relative demand for Ford and GM respond to their relative price?
  - Useful to answer relative Qs and construct relative counterfactuals
  - In large cross-sections with substantial idiosyncratic risk $\approx$ own-price elasticity
  - What GE theorists call the Morishima elasticity, Gabaix Koijen 2025 the micro elasticity

Substitution: The Missing Coefficient Problem

Proposition 2 **Impossible to identify substitution with the cross-section alone**

$$\Delta D_i = \widehat{\mathcal{E}}\Delta P_i + X_i' \sum_j \boldsymbol{\mathcal{E}}_X X_j \Delta P_j + \underbrace{\epsilon_i}_{=X_i'\theta_0+\eta_i} = \widehat{\mathcal{E}}\Delta P_i + X_i' \underbrace{\left[\sum_j \boldsymbol{\mathcal{E}}_X X_j \Delta P_j + \theta_0\right]}_{\textbf{BOTH absorbed in } \theta} + \eta_i$$

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- Coefficient on X_i measures both substitution and shift in demand for observable
  - Does CalPERS reduce its green tilt because of expensive green bonds or weaker environmental priorities?

  $\Rightarrow$ **missing coefficients** problem: the cross-section is not enough to learn about cross-sectional demand

- Logit: makes θ a structural parameter ... and cannot capture this substitution

Re-Packaging Substitution

Classic strategy: construct portfolios sorted on observables, and measure their price and demand (= portfolio tilt)

- Form Fama–MacBeth portfolios:

$$\Delta D_X = (X'X)^{-1} X' \Delta D \qquad \Delta P_X = (X'X)^{-1} X' \Delta P$$

$$\Delta D_{idio,i} = \Delta D_i - X_i' \Delta D_X \qquad \Delta P_{idio,i} = \Delta P_i - X_i' \Delta P_X$$

- *Decompose between the relative part and substitution between the K portfolios:*

Micro: $\Delta D_{idio,i} = \widehat{\mathcal{E}} \Delta P_{idio,i}$

Meso-Macro: $\Delta D_X = \check{\boldsymbol{\mathcal{E}}} \Delta P_X$

where $\check{\boldsymbol{\mathcal{E}}} = \widehat{\mathcal{E}} \mathbf{I}_K + \boldsymbol{\mathcal{E}}_X X'X$

Estimating Substitution with the Time Series

- **Proposition 3** Regressing portfolio tilts on portfolio prices with **time series instruments** identifies substitution $\mathcal{E}_X$

$$\Delta D_{X,t} = \check{\mathcal{E}} \Delta P_{X,t} + \epsilon_{X,t}$$

  - Effectively only K assets = portfolios
  - E.g. Fed does more or less QE and operation twist over time
  - E.g. granular IVs for different portfolios (Gabaix Koijen 2024)

- No more separation, even for macro elasticity
  - Is your shock to the "price of stocks" a parallel shift, or concentrated in small stocks? tech stocks?

Summary

Homogeneous substitution conditional on observables X:

$$\mathcal{E} = \text{relative elasticity} + \text{substitution}$$
$$= \hat{\mathcal{E}} I + X \boldsymbol{\mathcal{E}}_X X'$$

Consistent with many motives: risk, constraints, non-pecuniary preferences, irrational, ...

Identification:

- Relative elasticity: compare similar assets = cross-sectional IV controlling for X
- Substitution: demand for portfolios based on X = time-series portfolio level instruments
- Even purely cross-sectional questions rely on both relative elasticity AND substitution

Price Impact in Corporate Bonds

Price Impact

- **Price impact**: impact of an exogenous shift in demand on prices

$$\Delta P = \boldsymbol{\mathcal{M}} \Delta Z, \qquad \boldsymbol{\mathcal{M}} = -\boldsymbol{\mathcal{E}}_{agg}^{-1}$$

- Multiplier shares same structure as elasticity

$$\boldsymbol{\mathcal{M}} = \widehat{\mathcal{M}} \mathbf{I} + X \boldsymbol{\mathcal{M}}_X X'$$

- Same estimation
  - Cross-section reveals relative multiplier $\widehat{\mathcal{M}}$
  - Time series of portfolios reveals spillovers $\boldsymbol{\mathcal{M}}_X$

Price Impact for Corporate Bonds

- U.S. corporate bonds, 2010–2024 (from WRDS Bond Returns) (following Chaudhary Fu Li 2024)
- *Source of demand shocks:* flow-induced trading (Coval Stafford 2007, Lou 2012, Chaudhry 2025)

$$Z_{it} = \sum_k \frac{A_{k,t-1}\widetilde{w}_{i,k,t-1}}{P_{i,t-1}S_{i,t-1}} f_{kt}$$

- *Exogeneity condition:* $Z_{it} \perp \epsilon_{it} | X_{it}$
  - Example threat to identification: bonds with high mutual fund ownership might also attract demand from other institutional investors, such as insurance companies, pursuing similar strategies

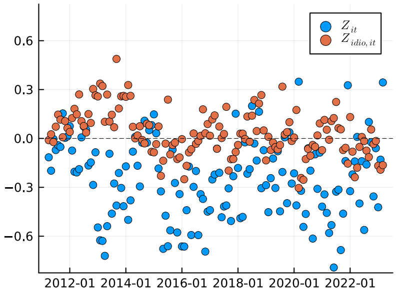
Diagnostic: Balance on Covariances

Plausibility of the assumption: *homogeneous substitution conditional on observables*

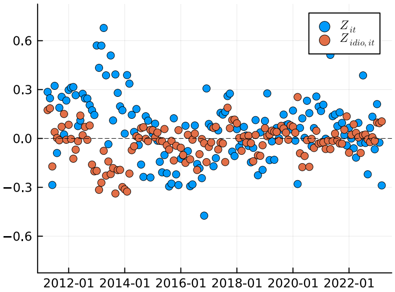
Do treated & control bonds with the same values of observables comove the same way with broad portfolios?

1. At each date t, form a long-short portfolio based on treatment status
   - $Z_{idio,it}$: residual of instrument regressed on duration $\times$ date and credit rating $\times$ date fixed effects
2. Compute the β of the long-short return on broad indices in a window around t (here: 2y)
3. β different from zero $\Rightarrow$ substitution likely not homogeneous

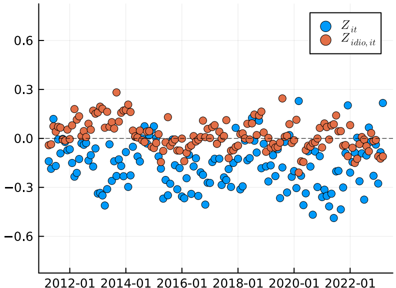
A. Corporate Bond Index



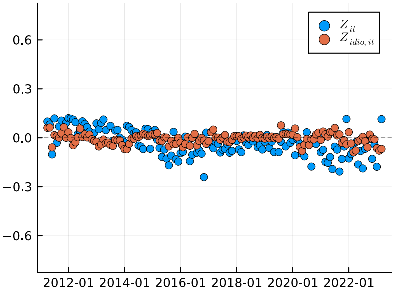
B. High—Low Credit Rating



C. Long—Short Term Bonds



D. Stock Index



Relative Multiplier

Relative multiplier $\widehat{\mathcal{M}}$

	Return R_{it}				
	(1)	(2)	(3)	(4)	(5)
Demand shock:					
Z_{it}	0.055			0.492***	2.080***
	(0.084)			(0.128)	(0.387)
$Z_{idio,it}$		0.055	0.055		
		(0.084)	(0.087)		
Date Fixed Effects	Yes	Yes	Yes	Yes	
Duration × Date Fixed Effects	Yes	Yes			
Credit Risk × Date Fixed Effects	Yes	Yes			
N	1,041,985	1,041,985	1,041,985	1,041,985	1,041,985
R^2	0.464	0.464	0.293	0.293	0.018

→ A change in demand for one bond vs. another with the same duration and credit rating does not move their relative spread

Spillovers: Cross-Multipliers

	Return				
	$R_{agg,t}$	$R_{DUR,t}$	$R_{PD,t}$	R_{it}	$R_{agg,t}$
	(1)	(2)	(3)	(4)	(5)
$Z_{agg,t}$	14.430***	7.773***	3.764**	14.430***	15.032***
	(2.707)	(1.803)	(1.392)	(2.689)	(2.393)
$Z_{DUR,t}$	0.425	4.531	-5.789	0.425	
	(6.713)	(4.293)	(3.948)	(6.646)	
$Z_{PD,t}$	1.127	-0.868	3.383**	1.127	
	(1.866)	(1.404)	(1.025)	(1.854)	
$Z_{idio,it}$				0.055	
				(0.087)	
N	168	168	168	1,041,985	168
R^2	0.343	0.173	0.384	0.100	0.342

- Spillovers are not uniform: line up with duration and credit rating
- Fed buys 1% of supply of all corporate bonds → long-duration bonds rise ∼22%, short-duration ∼7%
- Fed buys 1% long, sells 1% short duration (operation twist) → long-duration +5%, short-duration −4%

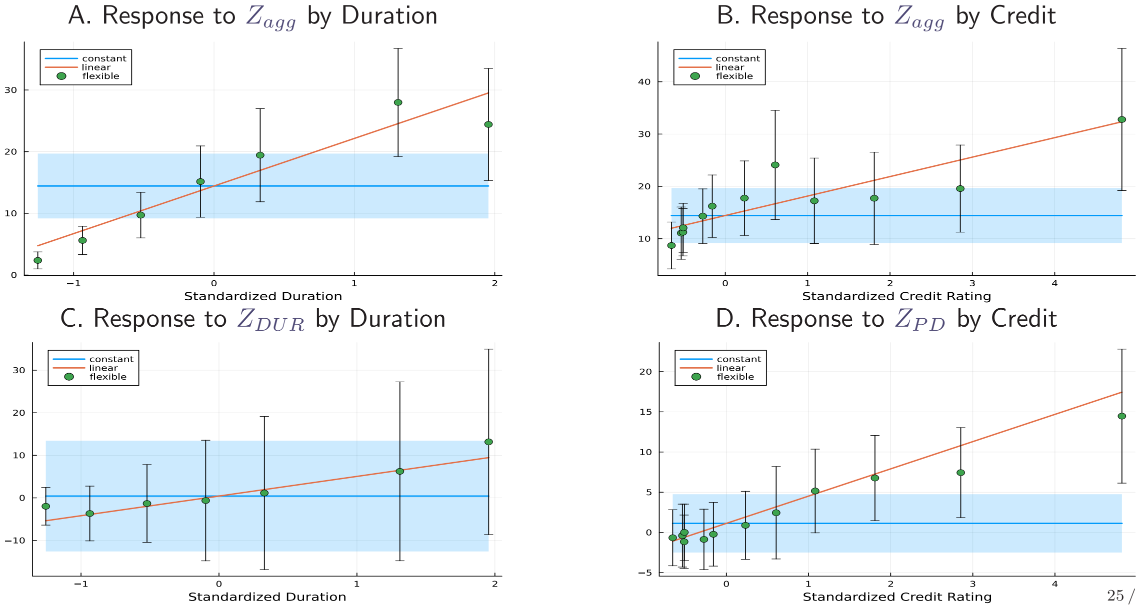
Falsifying the Assumptions

After estimation, there are a set of diagnostics to validate or falsify the assumptions

- Hausman/Mundlak: elasticity invariant to source of variation
  - Pooled vs. within-issuer should agree
- Sensitivity to the choice of observables
  - Adding more (or different) X's should not move the estimate $\hat{\mathcal{E}}$
  - If it does, omitted dimension of substitution
- Overidentification from the linear in observables assumption $X\boldsymbol{\mathcal{M}}_X X'$
  - Group-level estimates line up with characteristics
  - Response to Z_{DUR} rises *linearly* with duration, response to Z_{PD} with credit

- Complements the ex-ante *balance diagnostics*: covariance with broad portfolios

Unpacking the Spillovers (Overidentification)



Conclusion

- To draw causal inference about demand elasticity, need flexible substitution = portfolio management
  - A simple assumption: **homogeneous substitution conditional on observables**
    - CalPERS substitutes based on duration and greenness
  - (Standard) source of exogenous variation
    - Fed randomly buys more of some bonds than others, Fed surprisingly engages in QE
- Relative elasticity for similar assets: cross-sectional IV
  - Ford vs GM?
- Substitution = demand for portfolios: time-series IV
  - Green vs brown? Aggregate price?
- Need both dimensions even for cross-sectional questions
- Standard structural models of demand rule out most factor-style substitution