Causal Inference in Econometrics Term Project: Replicate *The Causal Effect of Limits to Arbitrage on Asset Pricing Anomalies*

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1 Summary Report and Reviews

This paper (Chu et al., 2020) investigates asset pricing anomalies comes from compensation for bearing factor risk or limits to arbitrage by exploiting a quasi-random natural experiment, Regulation SHO. Employing a Difference-in-Difference (DiD) identification strategy, this paper shows that 11 anomalies survived from the Fama-French 3 factor model are generated by short-sale constraints, a dominated type of limits to arbitrage, in large extent.

Return predictability lies the heart of asset pricing, while does it derives from risk or mispricing remains unclear. This paper provides solid causal evidence on the effect of limits to arbitrage (mispricing) on asset pricing anomalies by capturing pure variations of arbitrage limitations cross-sectionally, i.e., short-sale constraints on pilot stocks are lifted while short-sale constraints on nonpilot remains unchanged during the two-year pilot period of Regulation SHO. Short-sale constraints have been imposed on stocks traded in the US since 1930s as a way to suppress speculation. On July 28, 2004, Security and Exchange Commission (SEC) announced the Regulation SHO pilot to investigate whether short-sale constraints on stocks listed in AMEX/NYSE/NASDAQ make a difference in market quality. Pilot stocks are selected by every third stock ranked by the total volume in the prior year from the Russel 3000 index membership entities. From May 2, 2005 to August 6, 2007, pilot stocks were exempted from short-sale constraints; after the pilot period, nonpilot stocks were also exempted from short-sale constraints; since February 24, 2010, SEC restore a modified short-sale constraints for all stocks. The timeline of the quasi-random natural experiment is shown in Figure 2.

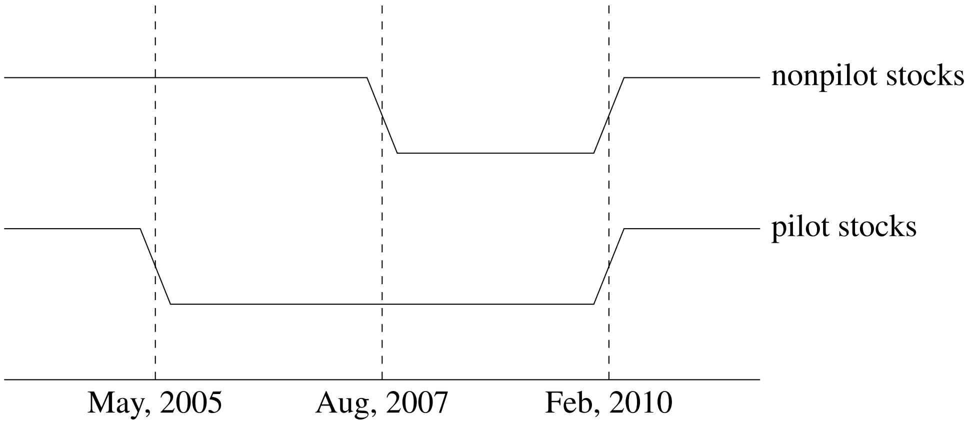

Figure 1: Timeline of Regulation SHO
In May, 2005, only pilot stocks were exempted from short-sale constraints; in August, 2007, nonpilot stocks were exempted from short-sale constraints also; in Feb, 2010, pilot and nonpilot stocks are imposed on modified short-sale constraints.

Following Figure 2, this paper proposes **Hypothesis 1**: relaxation of short-sale constraints reduces anomalies returns for pilot stocks relative to nonpilot stocks during the pilot period. Hypothesis 1 is tested by the following DiD framework,

$$r_{it} = \gamma_t + \beta Pilot_i \times During_t + \beta_1 Pilot_i + \epsilon_{it} \tag{1}$$

where r_{it} is the gross-return-weighted monthly return of portfolio i (the long-short portfolio, the long leg or the short leg) in month t, γ_t denotes time fixed effects, $Pilot_i$ is a dummy variable that equal 1 if portfolio i is formed on pilot firms and 0 otherwise, $During_t$ is a dummy variable that is equal to 1 if month t lies between July 2005 and June 2007 (excluding the two months at the beginning of the pilot period to avoid capturing the price movement in the short time window; excluding the two month at the ending of the pilot period because the Regulation SHO effectively ended on July 6, 2007). Using data between January 1980 and June 2007, estimated results of (1) show that $\hat{\beta}$ of regression for 11 anomalies separately and in combination are negative and 5 of them are significant under the 5% significant level. In the combined regression, $\hat{\beta}$ is equal to -0.72, i.e., annual return of combined portfolio decrease 8.4%, which is economic significant. These results show Hypothesis 1 is accepted statistically and economically.

To dissect the effect of exemption of short-sale constraints on anomalies return, this paper tests **Hypothesis 2**: the decrease in anomaly returns comes primarily from the short leg anomaly portfolios and short legs of pilot stocks outperform those of nonpilot stocks during the pilot period by run regression (1) on long leg portfolios and short leg portfolios separately. Results show that $\hat{\beta}$ of regressions on long leg portfolios are in significant statistically and economically, instead, $\hat{\beta}$ of regressions on short leg portfolios are positive (5 over 12) significantly and economically, that prove the first part of Hypothesis 2 and moreover, difference-in-mean estimates of treatment effect are positive (all) and significant (5 over 12), that prove the second part of Hypothesis 2.

This paper also provides two extended hypothesis, Hypothesis 3 and 4 to make the proposed mechanism more evident. Hypothesis 3: the difference in anomaly returns between pilot and nonpilot stocks disappears after Regulation SHO ended, is test by

$$r_{it} = \gamma_t + \beta Pilot_i \times During_t + \beta_1 Pilot_i + \beta_2 Pilot_i \times Post_t + \epsilon_{it} \tag{2}$$

where $Post_t$ is a dummy variable and equal to 1 if month t is after August 2007 and 0 otherwise. Needless to say, $\hat{\beta}_2$ is insignificant statistically from results using data between January 1980 and December 2016. Hypothesis 4: at the beginning of the pilot program, short legs of pilot stocks underperform those of nonpilot stocks and at the end of the pilot program, short legs of pilot stocks outperform those of nonpilot stocks, is tested by

$$r_{it} = \gamma_t + \sum_{j=1}^{9} \beta_{wj} Pilot_i \times Window_{jt} + \beta_1 Pilot_i + \epsilon_{it} \tag{3}$$

where $Window_{jt}$ is equal to 1 if month t lies in Window j and two windows cover the beginning and the ending of the pilot program. Results comply with Hypothesis 4.

This paper provides rich robustness checks, including using shorter sample periods, placebo tests (random assignment of pilot and nonpilot stocks, pseudo-event), using NASDAQ stocks, testing on different kinds of stocks, using value-weighted strategies and so on.

Comment 1. ***[Robust Causal Evidence]*** *This paper provides clear and robust causal evidence for the explanation that mispricing derives well-known anomalies in large part. Although the pilot period is short, 2 years, and only 11 anomalies are considered, the paper tries its best to improve the power of tests.*

Comment 2. ***[Econometric Concerns of Equation 2]*** *Equation 2 does not follow the typical DiD framework indeed. If we are interested in whether anomalies diminish after the pilot program, it is better to include the during and post period only. However, Hypothesis 3 asks whether anomalies come back to the level before the pilot program. Difference-in-mean estimates are not capable to identify the effect because of the existence of return dynamics (if we add a time-fixed effect term, there will be collinearity between it and $Post_t$). It is feasible to adopt the DiD framework like* (1) *with data in the pre and post period,*

$$r_{it} = \gamma_t + \beta_1 Pilot_i + \beta Pilot_i \times Post_t + \epsilon_{it} \tag{4}$$

which produces the actual results with (2)*. Hence, Equation 2 can reach the goal of testing Hypothesis 3, although it is somewhat bloated.*

Comment 3. ***[Contradicted Explanations of Hypothesis 1, 2 and Hypothesis 4]*** *This paper proposes that anomalies are driven by mispricing to a large extent and this mechanism is tested by Hypothesis 1, furthermore, in the pilot period, short-leg of pilot stocks outperform those of nonpilot stocks. However, at the beginning of pilot period, Hypothesis 4 indicates the overpricing of pilot stocks is reduced, which causes that short-leg pilot stocks underperform those of nonpilot stocks. Theoretically, under the short-sale constraints, investors who believe the stock is overpricing, can not make profits by short selling the stock (only buy-and-hold is allowed), thus, the stock is overpriced. In this case, mispricing related to short-sale constraints makes stocks overpriced.*

If the overpricing-diminishment explanation dominates, there must be alternative explanations for Hypothesis 1 and 2. If the mispricing explanation dominates, we have to search for the reason of decreasing of short-legs of pilot stocks at the beginning of pilot program. Unfortunately, this paper can not discriminate which one mechanism should prevail.

2 Replication Package

I replicate main results of this paper, i.e., Table 2-5 and Figure 1 to test the four hypothesis listed in section 1. The replication package contains constructed data, codes and results. Original data is excluded because of the copyright and big volume, but I will provide detailed information for reference. Results generated by the replication package fit modestly into the paper with slightly weaker empirical evidence.

2.1 Data and Code

There are three steps to complete the replication, construction of stock characteristics and identification of treatment group, construction of anomaly portfolios, and regression.

First, to construct characteristics of stocks, original files are extracted from WRDS, included monthly stock file: msf, mseall, msedelist and msenames, daily stock file: dsf, dseall, dsenames, Compustat file: funda, fundq, Fama-French 3 factors: factors_monthly, linktable: ccmxpf_linktable, index file: mcti. Monthly stock file and daily stock file is merged by 'crspmerge.sas' file which is provided by WRDS also separately. Following instructions of this paper, I construct 9 kind of stock characteristics, i.e., momentum (pret), gross profitability (gpa), asset growth (ag), investment to assets (iva), return on assets (roa), net operating assets (noa), accruals (ac), net stock issues (nsi) and O-score (osc); composite equity issues and failure probability are abandon since its construction process is dubious and results vary a lot across different versions. 'anomaly_1, anomaly_234678, anomaly_511' files complete this work.

Russel 3000 index (Ray) membership stocks are not easily accessible in WRDS for it is not purchased and manually downloaded copy form Bloomberg proved to produce too much missing stocks. Hence, according to the selection rule of Ray, pilot stocks official announced by SEC (total 983 stocks) and the 2017 largest market capitalization stocks (excluding pilot stocks) on 25th June, 2005 as nonpilot stocks consist the sample. Excluding stocks initial-public-offer (IPO) after 30th April, 2004 and not traded in NYSE / AMEX and combining with stock characteristics, left 513 pilot and 1342 nonpilot consist the final sample. Time period is between January 1980 and December 2016. 'sample, merge' files complete this work.

Second, long-short portfolios, long-leg portfolios and short-leg portfolios across different time period are constructed by 'Table2, Table4' files. Stock characteristics at the end 2003 across the whole sample, long-leg portfolios and short portfolios are produced by the 'Table3' file.

Third, 'maindo, fig1' files do compute statistics, run regressions and generate figures.

2.2 Results

Table 1: Summary of Anomaly Returns in Our Sample
Robust t-statistics are presented in parentheses below the coefficient estimates. ** and *** denote significance at the 5% and 1% levels, respectively.

	Raw	CAPM α	Fama-French α
pret	1.22***	1.21***	1.40***
	(3.7)	(3.77)	(3.84)
gpa	0.24	0.14	0.51***
	(1.38)	(0.84)	(3.34)
ag	0.42***	0.50***	0.26
	(2.83)	(3.43)	(1.90)
iva	0.29**	0.32**	0.25
	(2.09)	(2.29)	(1.7)
roa	0.43**	0.50**	0.85***
	(2.06)	(2.46)	(4.40)
noa	0.39***	0.44***	0.35**
	(2.75)	(3.11)	(2.56)
ac	0.21	0.29**	0.24
	(1.38)	(2.00)	(1.59)
nsi	0.43***	0.46***	0.42***
	(3.12)	(3.36)	(2.99)
osc	0.34	0.41	-0.02
	(1.61)	(1.95)	(-0.11)

Table 3: Main Difference-in-Differences Results
Robust t-statistics are presented in parentheses below the coefficient estimates. ** and *** denote significance at the 5% and 1% levels, respectively.

Panel A: Long-Short Anomaly Returns							
	Nonpilot Pre	Pilot Pre	Diff.	Nonpilot During	Pilot During	Diff.	DiD (β)
pret	1.196	1.277	0.08	1.0	0.467	-0.53	-0.61
			(0.34)			(-0.85)	(-0.93)
gpa	0.178	0.454	0.28	0.064	-0.205	-0.27	-0.55
			(1.37)			(-0.58)	(-1.09)

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ag	0.425	0.513	0.09	0.624	-0.145	-0.77**	-0.86**
			(0.41)			(-2.23)	(-2.14)
iva	0.303	0.23	-0.07	-0.218	0.467	0.68	0.76
			(-0.32)			(1.23)	(1.28)
roa	0.516	0.348	-0.17	0.304	0.328	0.02	0.19
			(-0.80)			(0.05)	(0.35)
noa	0.367	0.414	0.05	0.663	-0.342	-1.01**	-1.05**
			(0.23)			(-2.42)	(-2.31)
ac	0.182	0.198	0.02	0.118	-0.87	-0.99*	-1.00*
			(0.07)			(-1.84)	(-1.75)
nsi	0.397	0.47	0.07	0.164	-0.323	-0.49	-0.56
			(0.39)			(-1.49)	(-1.51)
osc	0.304	0.4	0.1	-0.398	0.244	0.64	0.55
			-0.37			(1.09)	(0.86)
combination	0.43	0.478	0.05	0.258	-0.042	-0.3	-0.35
			(0.48)			(-1.38)	(-1.45)
Panel B: Long-Leg Portfolio Returns							
	Nonpilot Pre	Pilot Pre	Diff.	Nonpilot During	Pilot During	Diff.	DiD (β)
pret	2.44	2.628	0.19	1.955	1.652	-0.3	-0.49
			(1.23)			(-0.65)	(-1.02)
gpa	2.005	2.004	0.0	1.266	1.13	-0.14	-0.13
			(-0.01)			(-0.52)	(-0.46)
ag	1.974	1.86	-0.11	2.076	1.462	-0.61*	-0.5
			(-0.66)			(-1.79)	(-1.32)
iva	1.935	1.955	0.02	1.751	1.91	0.16	0.14
			(0.13)			(0.46)	(0.37)
roa	1.949	2.079	0.13	1.768	1.579	-0.19	-0.32
			(1.02)			(-0.61)	(-0.97)
noa	1.889	1.827	-0.06	1.649	1.224	-0.42	-0.36
			(-0.45)			(-1.08)	(-0.89)
ac	1.898	1.822	-0.08	1.917	1.173	-0.74*	-0.67
			(-0.44)			(-1.94)	(-1.61)
nsi	1.889	1.824	-0.07	1.576	1.241	-0.33	-0.27
			(-0.54)			(-1.28)	(-0.95)
osc	1.828	1.923	0.09	1.341	1.772	0.43	0.34
			-0.41			(0.87)	(0.63)
combination	1.978	1.991	0.01	1.7	1.46	-0.24	-0.25
			(0.2)			(-1.50)	(-1.47)
Panel C: Short-Leg Portfolio Returns							
	Nonpilot Pre	Pilot Pre	Diff.	Nonpilot During	Pilot During	Diff.	DiD (β)

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pret	1.244	1.351	0.11	0.955	1.185	0.23	0.12
			(0.53)			(0.55)	(0.27)
gpa	1.827	1.55	-0.28*	1.201	1.335	0.13	0.41
			(-1.91)			(0.31)	(0.92)
ag	1.548	1.347	-0.2	1.451	1.607	0.16	0.36
			(-1.42)			(0.52)	(1.09)
iva	1.632	1.725	0.09	1.969	1.444	-0.53	-0.62
			(0.54)			(-1.35)	(-1.47)
roa	1.434	1.731	0.30*	1.464	1.25	-0.21	-0.51
			(1.69)			(-0.53)	(-1.18)
noa	1.522	1.413	-0.11	0.985	1.566	0.58***	0.69***
			(-0.72)			(3.24)	(2.98)
ac	1.716	1.624	-0.09	1.799	2.043	0.24	0.34
			(-0.54)			(0.7)	(0.88)
nsi	1.492	1.353	-0.14	1.412	1.564	0.15	0.29
			(-0.92)			(0.75)	(1.16)
osc	1.524	1.522	0.0	1.739	1.528	-0.21	-0.21
			(-0.01)			(-0.75)	(-0.68)
combination	1.549	1.513	-0.04	1.442	1.502	0.06	0.1
			(-0.53)			(0.41)	(0.6)

3 Extensive Exploration

China launched a counterpart pilot program in March 2010 to exempt the ban on short-selling and margin-trading for a design-selected list. Stocks experience negative returns when added to the list (Chang et al., 2014), that is consistent with Hypothesis 4 of this paper, i.e., overpricing driven by short-sale constraints is reduced by the lift of the ban on short selling. Moreover, the relaxation of short-sale constraints improve the price efficiency and shortable stocks experience more improvement in price efficiency (Chen et al., 2023). These evidences indicate that the empirical causal evidence and implied mechanism also function in Chinese markets.

To reconcile the mispricing explanation and overpricing-diminishment explanation, we first explore the long-leg return dynamics by estimating Equation 3 with long-log portfolios, illustrated in Figure 3. Figure 3 shows that long-leg portfolios also experience negative returns with a smaller magnitude compared with short-leg. This evidence implies that not only does the lift of short-sale constraints reduce the overvaluation of short-leg stocks, but also it make a difference on the pricing of long-leg stocks, and this mechanism remains unexplored. A possible explanation is that the relaxation of short-sale constraints relive the financial constraints of arbitrageurs. At the beginning of the pilot program, arbitrageurs made massive profits by shorting the short-leg stocks, and from then on, arbitrageurs can exploit long-leg stocks to earn profits with money saved or earned from short-leg stocks, which is able to improve the pricing efficiency, causing the diminishment of anomalies.

Table 2: Comparing Nonpilot and Pilot Firms: Anomaly Variables
Robust t-statistics are presented in parentheses below the coefficient estimates.

	Panel A: Whole Sample		Panel B: Long Leg		Panel C: Short Leg	
	Nonpilot Pilot	Diff.	Nonpilot Pilot	Diff.	Nonpilot Pilot	Diff.
pret	0.322	-0.021	1.206	0.072	-0.187	0.037
	0.301	(-1.05)	1.279	(1.16)	-0.15	(2.56)
gpa	0.244	0.043	0.764	-0.012	0.024	(0.002)
	0.287	(3.41)	0.752	(-0.49)	0.026	(1.03)
ag	0.115	-0.036	-0.175	-0.01	0.70	-0.028
	0.079	(-2.60)	-0.185	(-0.82)	0.672	(-0.33)
iva	0.049	-0.013	-0.124	-0.01	0.256	-0.018
	0.036	(-2.29)	-0.113	(-0.82)	0.239	(-1.04)
roa	0.012	-0.001	0.048	-0.002	-0.016	0.00
	0.011	(-1.03)	0.046	(-0.75)	-0.017	(-0.15)
noa	0.711	-0.018	0.105	0.03	1.79	-0.294
	0.693	(-0.67)	0.135	(1.43)	1.495	(-1.41)
ac	-0.056	0.006	-0.172	0.0	0.065	-0.019
	-0.050	(1.43)	-0.172	(0.04)	0.046	(-1.70)
nsi	0.044	-0.011	-0.058	0.009	0.331	-0.004
	0.033	(-1.79)	-0.05	(1.53)	0.327	(-0.11)
osc	0.044	-0.003	1.475	0.115	-2.63	0.01
	0.033	(-0.04)	1.590	(0.83)	-2.62	(0.16)

Table 4: Postpilot-Program Results
Robust t-statistics are presented in parentheses below the coefficient estimates. ** and *** denote significance at the 5% and 1% levels, respectively.

	Long Leg	Short Leg	Long-Short
pret	-0.12	0.53	-0.66
	(-0.43)	(1.04)	(-1.15)
gpa	0.15	0.23	-0.07
	(0.62)	(0.65)	(-0.17)
ag	0.55*	0.11	0.44
	(1.67)	(0.38)	(0.99)
iva	0.11	0.48	-0.37
	(0.31)	(1.41)	(-0.75)
roa	0.18	0.0	0.17
	(0.81)	(0.01)	-0.37
noa	0.08	0.19	-0.11
	(0.25)	(0.7)	(-0.27)
ac	0.3	0.04	0.26
	(0.74)	(0.14)	(0.55)
nsi	0.13	0.3	-0.18
	(0.53)	(0.99)	(-0.44)
osc	0.32	0.0	0.32
	(0.62)	(0.0)	(0.53)
combination	0.19	0.21	-0.02
	(1.24)	(1.17)	(-0.08)

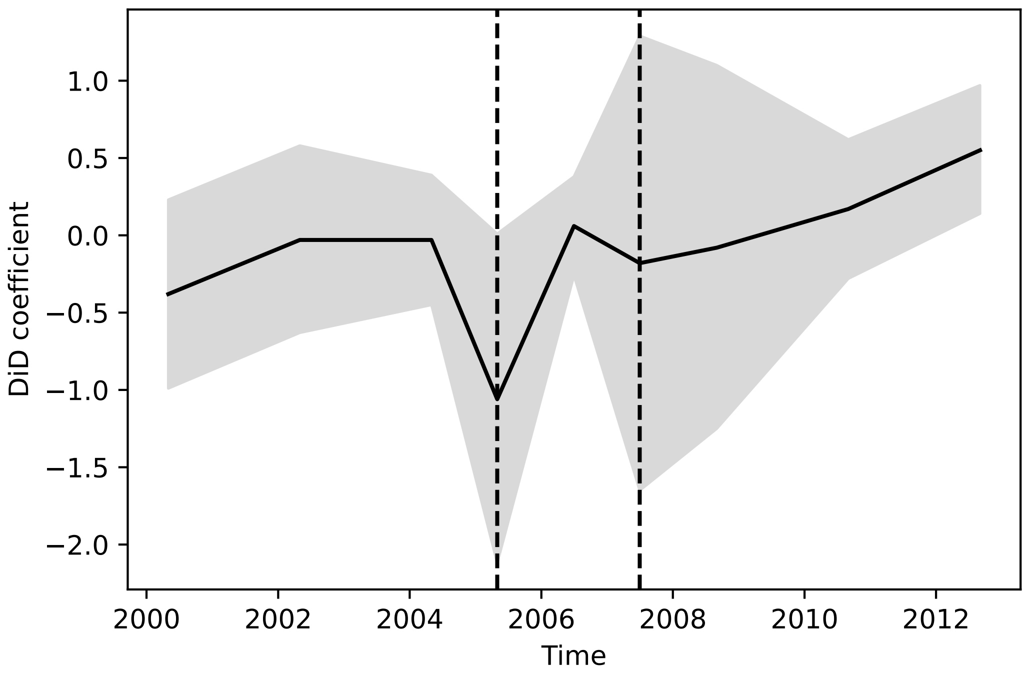

Figure 2: Return dynamics of short-leg portfolios.
The solid line plots the nine DiD coefficients β_{wj} in percent terms. The shaded area show their 90% confidence intervals. The two dashed vertical lines denote the beginning and the end of the pilot program.

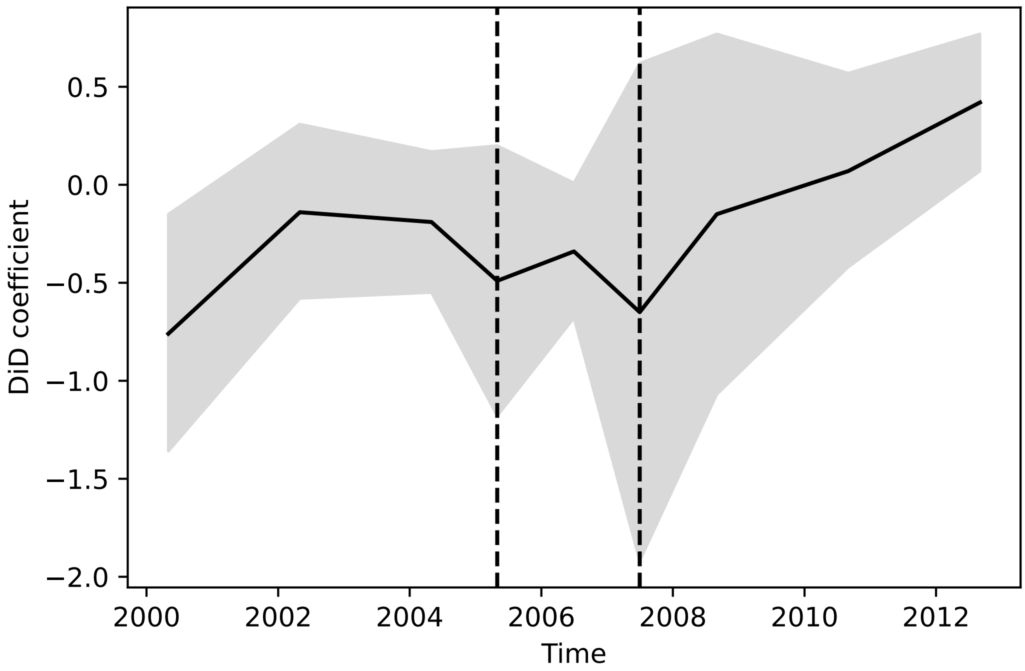

Figure 3: Return dynamics of long-leg portfolios.
The solid line plots the nine DiD coefficients β_{wj} in percent terms. The shaded area show their 90% confidence intervals. The two dashed vertical lines denote the beginning and the end of the pilot program.

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