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Firm-level Irreversibility

Hang Bai
Erica X. N. Li
Chen Xue
Lu Zhang

[1] *University of Connecticut*
[2] *Cheung Kong Graduate School of Business*
[3] *University of Cincinnati*
[4] *The Ohio State University and NBER*

ABSTRACT

Contradicting Cooper and Haltiwanger (2006), Clementi and Palazzo (2019) report a largely *symmetric* investment rate distribution in Compustat, with a large fraction of negative investment rates, 18.2%, and conclude "no sign of irreversibility (p. 289)." Their evidence is flawed. A data error on depreciation rates understates gross investment and shifts the whole gross investment rate distribution leftward. Nonstandard sample screens on age and acquisitions further curb its right tail, which is subsequently truncated at 0.2. Fixing these problems restores the heavily asymmetric investment rate distribution with a fat right tail. The fraction of negative investment rates is small, only 4.9%–6.2%.

Keywords: Reproduction, replication, reanalysis, investment irreversibility, complex systems, scientific modeling

JEL Codes: E01, E22, E44, G12, G31

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Initiated by Arrow (1968), a prominent theoretical literature on costly reversibility has long been established in the real options framework (Bernanke, 1983; McDonald and Siegel, 1986; Dixit and Pindyck, 1994) and the neoclassical q-theory of investment (Abel, 1983; Abel and Eberly, 1994; Abel and Eberly, 1996; Abel *et al.*, 1996). The basic insight is that firms face higher costs in cutting than in expanding capital stocks, reducing negative investment and raising the hurdle for positive investment.

The available evidence on costly reversibility is mostly at the plant level. In a balanced panel with 7,000 large manufacturing plants from 1972 to 1988, Cooper and Haltiwanger (2006) document a heavily right-skewed investment rate distribution (Panel A in Figure 1), with a fraction of 10.4% for negative investment rates (below −1%) and 81.5% for positive investment rates (above 1%). They write: "This striking asymmetry between positive and negative investment is an important feature of the data that our analysis seeks to match (p. 614)." Their structural estimation establishes a mechanism that costly reversibility causes this asymmetry.[1]

Clementi and Palazzo (2019) (hereafter CP) claim to overturn the Cooper-Haltiwanger plant-level conclusion at the firm level in Compustat. CP "start by documenting investment behavior among publicly traded U.S. firms (p. 282)" in an exercise that is "akin to that conducted by Cooper and Haltiwanger (2006) on manufacturing plants (p. 282)." CP's Figure 1 (copy-and-pasted as Panel B in Figure 1) shows a largely *symmetric* quarterly gross investment rate distribution in their 1978–2016 sample in Compustat, with a large fraction, 18.2%, of negative investment rates.

CP claim that upon "being hit by adverse profitability shocks, large public firms have ample latitude to divest their least productive assets (p. 281)." "[E]ach quarter on average 18.2% of firms record negative gross investment. We take the latter as strong evidence against the assumption of irreversibility (p. 282)." "[C]apital accumulation at public firms is likely to be very different from that emerging from the analysis of a representative

anonymous referee for extensive, insightful comments. We also thank Berardino Palazzo for sharing the codes and data used to generate Figure 1 and Table 1 in Clementi and Palazzo (2019). All remaining errors are our own.

[1]Other plant-level studies on irreversibility include Caballero *et al.* (1995), Doms and Dunne (1998), Cooper *et al.* (1995), Caballero (1999), and Nilsen and Schiantarelli (2003). Extending the Cooper and Haltiwanger (2006) evidence to the firm level in Compustat, Bai *et al.* (2022) show that the firm-level current-cost investment rate distribution is heavily right-skewed, with a small fraction of negative investment rates, 5.51%, but a huge fraction of positive investment rates, 91.64%.

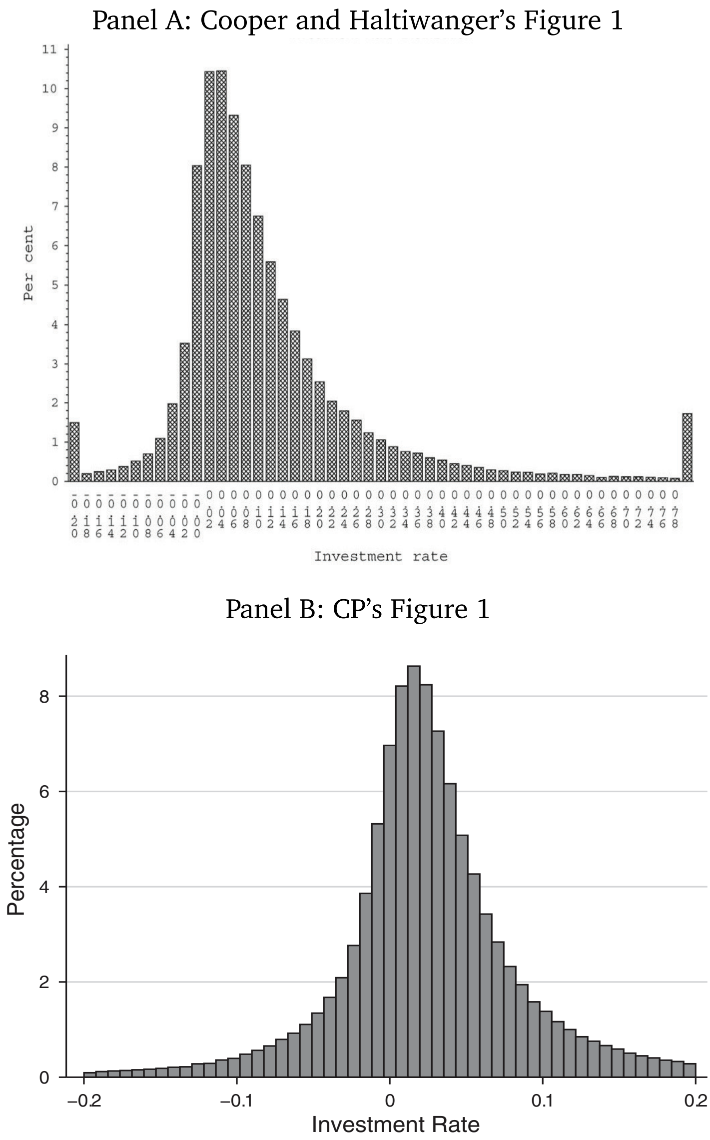


Figure 1: A tale of two gross investment rate distributions.

Description: Panel A shows Figure 1 in Cooper and Haltiwanger (2006) on the plant-level (annual) gross investment rate distribution in 7,000 manufacturing plants in the 1972–1988 balanced panel from Longitudinal Research Database (LRD). Panel B shows CP's Figure 1 on the firm-level (quarterly) gross investment rate distribution in their Compustat sample from the first quarter of 1978 to the fourth quarter of 2016.

Interpretation: The two gross investment rate distributions carry diametrically opposite inferences on the existence of irreversibility, "yes" in Panel A but "no" in Panel B.

sample of manufacturing establishments (p. 285)." "While comprehensive, our study emphasizes features, such as the volatility and reversibility of investment (p. 285)." The 18.2% estimate means that "plenty of firms downsize, at all times (p. 287)." For U.S. public firms, "investment displays substantial volatility and *no sign of irreversibility*. In fact, in each quarter a large fraction of firms reduce their deployment of plant, property, and equipment (p. 289, our emphasis)." All in all, "the irreversibility assumption has no empirical support (p. 303)."

The Replication Network defines a replication "as any study whose primary purpose is to establish the correctness of a previous study" but accepts "many gradations of replications, stretching from pure reproduction of key finding(s) of a previous study; to checking the robustness of those findings to changes in data, estimation procedure, model specification, etc."[2] Specifically, we distinguish reproduction, replication, and reanalysis. Reproduction means redoing a prior study in exactly the same way as pure replication in Hamermesh (2007). We treat replication as his scientific replication, which means "different sample, different population, and perhaps similar, but not identical model (p. 716)." We define reanalysis to be reanalysis and extension tests in Clemens (2017), tests that materially alter the model specifications of the original study and use new data.

In Section 1, we identify three design problems and five discrepancies in CP's reporting, coding, and data. First, CP measure gross investment rates as the net growth rates of net property, plant, and equipment (PPE) plus depreciation rates. However, instead of accounting depreciation rates embedded in net PPE, CP add back geometric depreciation rates from Bureau of Economic Analysis (BEA). Because the BEA rates are lower, CP underestimate gross investment flows and shift the whole investment rate distribution leftward. This data error gives rise to a high fraction of negative investment rates, 18.2%. Fixing this error reduces it to only 6.08%.

Also, the BEA depreciation rates are industry-specific, whereas accounting depreciation rates from Compustat are firm-specific. The accounting depreciation rates are much more right-skewed than the BEA rates assigned to individual firms. Adding back the BEA rates in the gross investment rates misses the cross-firm gross investment heterogeneity (not captured by net growth rates of net PPE) in a given industry. As such, in addition to inflating the fraction of negative investment rates, CP's data

[2] https://replicationnetwork.com/why-replications/

error also curbs the right tail of the gross investment rate distribution.

Two nonstandard sample criteria further restrict the right tail of the gross investment rate distribution: (i) dropping the first 12 quarters for each firm; and (ii) dropping firm-quarters associated with acquisitions larger than 5% of assets. Removing the former raises the investment rate skewness from 2.29 to 3.39, and eliminating the latter from 2.29 to 3.46.

We further identify five discrepancies between CP's reporting, coding, and data: (i) imposing lifetime exchange code restrictions; (ii) requiring lifetime net PPE; (iii) merging investment rates with stock returns; and (iv) deflating net PPE. Discrepancy (iv) shifts the investment rate distribution further leftward. Adjusting for all four reproduces CP's Table I closely.

Despite all the issues and discrepancies, the right tail of the investment rate distribution still survives, albeit weakly. In discrepancy (v), CP impose a truncation at 0.2 on the right tail to arrive at their largely symmetric Figure 1. After failing to reproduce their Figure 1, we have requested and obtained CP's codes and data for their Table I and Figure 1. The Stata codes in question are "gen hist = inv_rate," "replace hist = . if hist > 0.2," and "replace hist = . if hist < −0.2."[3]

A further discrepancy is that CP's Figure 1 is based on a different sample from their Table I. The key differences are: (a) not requiring share code to be 10 or 11; (b) not requiring exchange code to be 1, 2, or 3; (c) not merging with monthly stock returns; and (d) not requiring book-to-market.[4] As a result, their Figure 1 sample is 23% larger than their Table I sample (364,429 vs. 296,226 firm-quarters). In the Figure 1 sample, the investment rate skewness is 2.08, and the fraction of negative investment rates is 19.96% (2.18 and 18.24% in their Table I sample, respectively).

In CP's Figure 1 sample, the truncated right tail (> 0.2) contains 14,867 firm-quarters (4.08% of the sample), with a mean of 36.21% and a median of 29.72%. The truncated left tail (< −0.2) contains 5,340 firm-quarters (1.47% of the sample), with a mean of −30.88% and a median of −28.98%. Because the truncation cuts deeper into the right tail, it reduces the investment rate skewness to −0.08. CP do not report the skewness of 2.18 in Table I, but their Figure 1 is weakly *left*-skewed.

In Section 2, we replicate CP's Table I and Figure 1. Within CP's em-

[3]See our second annotation on p. 9 in the Internet Appendix D.1 on CP's "investment_rate_bea.do."

[4]See our first annotation on p. 9 in the Internet Appendix D.1 on CP's "investment_rate_bea.do."

pirical setup, after we fix all their design issues and discrepancies, the investment rate skewness rises from 2.18 to 4.8, and the negative investment fraction drops from 18.24% to 5.89%. After we further adjust for small differences in sampling criteria and treatment for outliers (for more reliable estimates), the skewness is 3.53, and the negative investment fraction 6.17%. With gross PPE (not net PPE) as the deflator, the investment rate skewness remains at 3.59, and the negative investment fraction falls to 4.94%. All three replications produce a heavily asymmetric investment rate distribution with a fat right tail.

How to measure the firm-level investment rate is an open challenge. Bai *et al.* (2022) conduct a meta-study of the published literature from 2000 onward at top finance journals, containing 347 articles with 40 different investment rates based on Compustat. The 40 investment rates show enormous heterogeneity, with the mean ranging from 3.38% to 64.03% per annum, and the standard deviation from 7.13% to 128.63%.

However, CP's investment rate is not from this prior literature. The error of mixing up accounting and economic depreciation rates is unique to CP. None of the 40 investment rates in Table 3 in Bai *et al.* (2022) make this mistake. Their Table 3 shows that asymmetry is robust across *all* 40 measures. Across the 26 gross investment rates, skewness varies from 1.64 to 4.49, with a mean of 3.07 and a median of 3.12. CP's (unreported) skewness of 2.18 in their Table I ranks the second lowest.[5] The weakly negative skewness of −0.08 implicit in CP's Figure 1 is an extreme outlier.

In Section 3, we conduct a reanalysis on the baseline investment model. Estimates from simulated method of moments strongly indicate the presence of costly reversibility and operating leverage, which are a good start to explaining the average value premium and investment moments simultaneously. Section 4 concludes. A separate Internet Appendix furnishes supplementary results and CP's codes (annotated by us).[6]

[5]Among the 14 net investment rates in Table 3 in Bai *et al.* (2022), skewness ranges from 1.48 to 3.42, with a mean of 2.59 and a median of 2.62. CP's unreported 2.18 estimate ranks the fourth lowest even among the net investment rates.

[6]The discrepancies between CP's reporting, coding, and data are only visible in their codes (not described in their paper). Because the discrepancies are essential for us to closely reproduce their Table I and Figure 1, we include the annotated codes in the Internet Appendix. By providing the details, we strive to establish reproducibility of our own work.

1 Reproduction

Reproducing CP's Table I and Figure 1, we identify three design issues in their empirical procedure in Section 1.1 and five discrepancies between their reporting and coding in Section 1.2.

1.1 Three Design Issues

The column "Table I" in Panel A of Table 1 shows the quarterly investment rate moments in CP's Table I. The column "CP's data" shows the moments that we calculate with their Table I sample. While emphasizing the fraction of negative investment rates of 18.2%, CP do not report the skewness of 2.18, the 5th percentile of −6.85%, the median of 2.46%, or the 95th percentile of 16.81%. These moments show that the investment rate distribution is already right-skewed in their original data. This right-skewness undercuts their conclusion of "no sign of irreversibility (p. 289)."

Panel B in Table 1 shows our reproduction based on CP's description of their procedures in their paper. The column denoted "moments" shows that we get close but not exact. Our reproduction sample contains 379,923 firm-quarters. The sample size is 28.25% larger than 296,226 in CP's data. In Panel C, we identify four discrepancies between CP's description and codes. As we detail in Section 1.2, after adjusting for these four discrepancies, we reproduce CP's Table I almost exactly.

The remaining three columns in Panel B identify three design issues in CP's procedure and quantify their respective impact on CP's results. These issues are: (i) Combining BEA depreciation rates with accounting net investment rates; (ii) dropping the first 12 quarters for each firm; and (iii) dropping firm-quarters with acquisitions larger than 5% of total assets.

1.1.1 Combining BEA Depreciation Rates with Accounting Net Investment Rates

CP measure capital stock as "item $PPENTQ$, defined as the net value of property, plant, and equipment. Net quarterly investment is the difference between two consecutive values of this variable (p. 286)." CP acknowledge: "Our convention amounts to assuming that *accounting depreciation is an accurate proxy for economic depreciation* (p. 286, our emphasis)."

However, in the same paragraph, CP go on to say: "The gross invest-

Table 1: Reproduction of CP's Table I on quarterly investment rates, 1978Q1–2016Q4.

	Panel A: CP		Panel B: Reproduction per CP's description			
	Table I	CP's data	moments	acct. δ	no age>3	with M&A
#Firm-quarters	296,218	296,226	379,923	364,234	471,943	391,808
Mean	3.5	3.47	3.92	7.46	5.03	4.54
Standard deviation	9.5	9.54	9.94	11.96	12.62	11.70
Skewness		2.18	2.29	3.37	3.39	3.46
Autocorrelation	26.2	26.22	25.43	33.84	27.08	19.38
Negative investment	18.2	18.24	16.91	6.08	16.98	16.54
Inaction rate	16.5	16.53	14.56	9.14	13.78	14.24
Positive spikes	3.8	3.77	4.22	7.90	6.30	5.16
Negative spikes	1.2	1.18	1.21	0.78	1.24	1.19
5th percentile		−6.85	−6.90	−1.98	−6.99	−6.78
Median		2.46	2.81	4.96	3.04	2.92
95th percentile		16.81	18.00	25.70	23.21	20.44

	Panel C: Reproduction per CP's description and codes				
	lifetime ex. code	lifetime PPE	require returns	deflate PPE	all
#Firm-quarters	346,710	325,746	372,003	379,923	296,185
Mean	3.89	3.92	3.92	3.51	3.52
Standard deviation	9.44	9.86	9.92	9.91	9.44
Skewness	2.16	2.27	2.30	2.31	2.18
Autocorrelation	26.00	25.89	25.53	25.34	26.28
Negative investment	16.27	16.87	16.95	18.98	18.33
Inaction rate	14.52	14.37	14.58	16.44	16.25
Positive spikes	3.96	4.18	4.21	4.07	3.87
Negative spikes	1.10	1.19	1.20	1.24	1.13
5th percentile	−6.55	−6.88	−6.90	−7.27	−6.98
Median	2.85	2.84	2.82	2.41	2.49
95th percentile	17.39	17.91	17.98	17.54	17.05

Description: In Panel A, Column "Table I" reports CP's Table I. Column "CP's data" shows the moments on CP's Table I dataset. Panel B shows our reproduction based on CP's procedure described in their paper. Column "moments" shows our reproduction of the moments. The remaining three columns show comparative statics by changing one aspect of CP's procedure, while keeping all others unchanged: (i) Using accounting depreciation rates (acct. δ); (ii) keeping the first 12 quarterly observations (no age>3); and (iii) not dropping firm-quarters with acquisitions larger than 5% of total assets (with M&A). Panel C shows our reproduction based on CP's description *and codes*, with four discrepancies not described in their paper: (i) imposing lifetime exchange code restrictions (lifetime ex. code); (ii) requiring lifetime PPE data (lifetime PPE); (iii) requiring stock returns when merging with investment rates (require returns, losing 1978Q1–Q2 and 2016Q3–Q4); and (iv) deflating PPE data (deflate PPE). The last column "all" incorporates all four discrepancies.

Interpretation: This table details our specific steps in reproducing CP's Table I.

ment rate is set equal to

$$\frac{PPENTQ_t - PPENTQ_{t-1}}{PPENTQ_{t-1}} + \delta_j$$

where δ_j is *the average depreciation rate of industry j estimated using data from the U.S. Bureau of Economic Analysis (BEA)* (p. 286, our emphasis)." As such, CP mix up accounting and economic depreciation rates in the same paragraph, giving rise to a flawed gross investment rate measure. Because accounting depreciation rates are embedded in net PPE (as CP acknowledge), one should add back accounting, not BEA's geometric, depreciation rates when calculating gross investment rates.

When measuring economic depreciation rates, accounting depreciation rates underperform BEA's geometric depreciation rates. However, as a matter of logical consistency, when measuring gross *investment* rates, if one uses net PPE as capital (as CP do), one must add back accounting depreciation rates embedded in net PPE. Capital stocks and depreciation rates in CP's gross investment rates are not independent of each other. Financial accountants use accounting depreciation, together with investment flows, to calculate net PPE per the capital accumulation equation.

Most U.S. firms use straight-line depreciation for financial accounting (Wahlen *et al.*, 2018, p. 506), whereas BEA estimates geometric depreciation rates (Hulten and Wykoff, 1981; Fraumeni, 1997). From Figure 2, accounting and geometric depreciation rates are quite different. Panel A shows the average quarterly BEA industry-level depreciation rates assigned to the firm level based on the NAICS or SIC codes.[7] The distribution is largely symmetric, ranging from 0.57% to 4.42% per quarter, with a mean of 2.51% and a median of 2.33%.

[7]The data on the BEA's average industry-level depreciation rates used in CP are from Berardino Palazzo. These depreciation rates (constant over time) are for the 2- or 3-digit NAICS industries. We assign firms to the NAICS industries based on their NAICS codes from Compustat (item NAICSH). When NAICS codes are not available (especially prior to June 1985), we use SIC codes (item SICH) and convert them into NAICS codes via the mapping tables from the Census Bureau. Because the conversion from SIC to NAICS codes might not be unique, there exist multiple assigned NAICS industries for a given firm. In these cases, we use the average depreciation rate across the assigned industries. We find CP's documentation in their paper to be unclear on how CP process BEA's raw data to obtain their depreciation rates or how they apply NAICS-based industry depreciation rates to SIC industries. Bai *et al.* (2022) construct BEA industry-specific, time-varying economic depreciation rates from scratch. However, for our reproduction purpose, we opt to use CP's depreciation rates data directly to ease comparison.

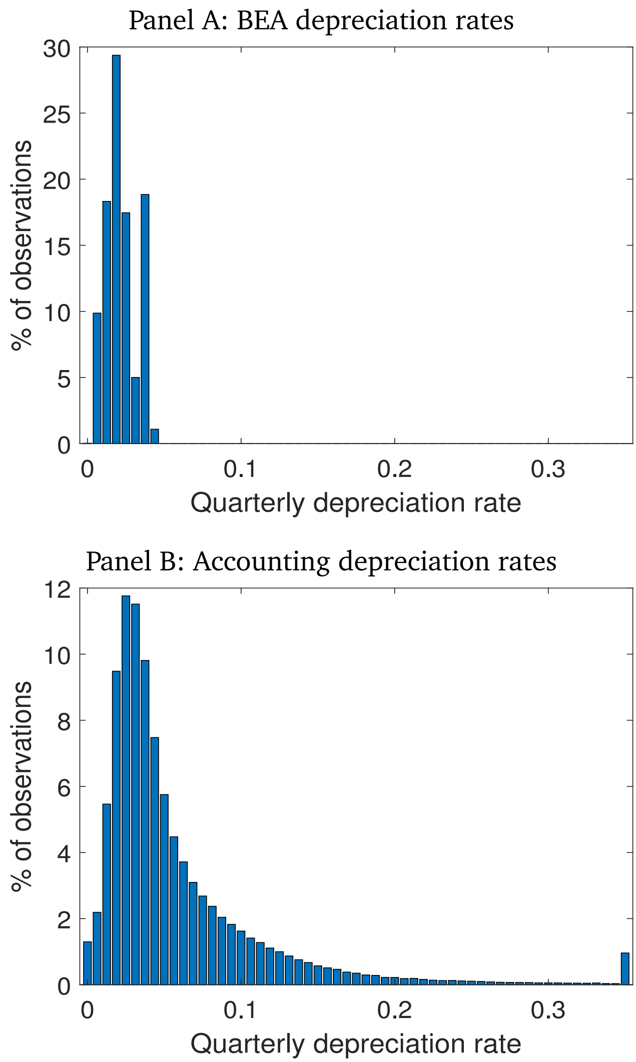


Figure 2: The distributions of quarterly BEA and accounting depreciation rates, 1978:Q1–2016:Q4.

Description: Panel A shows the histogram of BEA depreciation rates assigned to the firm level in our reproduction sample (column "moments" in Table 1). Panel B shows the histogram of accounting depreciation rates in our reproduction sample with accounting depreciation (column "acct. δ" in Table 1).

Interpretation: The distribution of the BEA industry-level geometric depreciation rates assigned to individual firms is concentrated and (largely) symmetric, whereas the distribution of firm-specific accounting depreciation rates is much more dispersed and heavily right-skewed. Adding back BEA depreciation rates, instead of accounting depreciation rates, to the net growth rates of net PPE to measure gross investment rates substantially underestimates the cross-firm investment heterogeneity within a given industry.

Panel B shows the quarterly accounting depreciation rates as the amount of depreciation and amortization (item DPQ) minus the amortization of intangibles (annual item AM divided by four, zero if missing; the quarterly version of item AM is unavailable), scaled by item PPENTQ. The linear interpolation works because of the straight-line depreciation. The accounting rate distribution is much more dispersed, ranging from 0% to more than 35%, and heavily right-skewed. Its mean is 6.09%, and 5th, 50th, and 95th percentiles are 1.48%, 4.27%, and 16.54%, respectively.

Most important, by adding the lower BEA depreciation rates back to the net growth rates of net PPE, which embeds higher accounting depreciation rates, CP shift the whole gross investment rate distribution leftward, giving rise to a higher fraction of negative investment rates, 18.2%. This data error paints an inaccurate picture of investment reversibility in U.S. public firms. Fixing this data error reduces the negative investment fraction to only 6.08% (column "acct. δ" in Panel B of Table 1).

Also, by adding back the largely symmetric (industry-specific) BEA depreciation rates, instead of the right-skewed (firm-specific) accounting depreciation rates, CP miss a substantial amount of cross-firm investment heterogeneity within a given industry, thereby weakening the right-skewness of the gross investment rate distribution. Fixing this data error raises the investment rate skewness from 2.18 to 3.37.

1.1.2 The Conceptual Challenge of Measuring Firm-level Investment Rates

The enormous heterogeneity of the investment rate measures in the prior literature undergirds the challenge of their economic (not just financial) accounting. From the capital accumulation equation, one can take investment as given to measure capital, or take capital as given to measure investment. Cooper and Haltiwanger (2006) take the former approach in a balanced panel with 7,000 large manufacturing establishments in the 1972–1988 sample. Investment is real gross expenditures net of real gross retirements of equipment. This investment is combined with industry-specific capital deflators and economic depreciation rates to form current-cost capital. Alas, this approach is no longer feasible because the Census Bureau has stopped collecting capital retirements data since 1987.

Bai *et al.* (2022) solve the chicken-or-egg problem by taking the indirect approach. Gross investment is the sum of net investment (change in net PPE) and accounting depreciation. Net PPE and accounting depreciation are far from perfect (economic) measures of capital and depreciation, respectively, but their combination accurately measures gross investment.

Bai *et al.* (2022) provide detailed evidence on why their investment measure is arguably the best option given a myriad of data limitations in Compustat. A popular measure is capital expenditure (item CAPX) minus sales of PPE (item SPPE). However, CAPX misses acquired fixed assets via mergers and acquisitions (M&As) that are prevalent for U.S. public firms. A breakdown of cash payment across different assets, including PPE, is not available for M&As. For disinvestment, item SPPE misses all the disposal methods that do not involve cash, such as asset-for-equity and asset-for-debt sales, retirements, exchanges of assets, and spin-offs.

Bai *et al.* (2022) combine their Compustat gross investment with BEA economic depreciation rates and price deflators to construct current-cost capital via perpetual inventory method. Most important, gross investment and economic depreciation are derived from separate data sources. Their procedure avoids CP's trap of mixing up accounting and economic depreciation rates in calculating gross investment rates.

1.1.3 Dropping the First 12 Quarters for Each Firm

In column "moments" in Panel B of Table 1, we impose CP's sample criteria: (i) Excluding financial firms, utilities, and unclassified firms; (ii) dropping the first 12 quarters for each firm;[8] (iii) dropping firm-quarters associated with acquisitions larger than 5% of total assets; (iv) discarding firm-quarters in the top and bottom 0.5% of the pooled distribution of quarterly investment rates; and (v) dropping firm-quarters with missing values of investment rates or book-to-market.

Criterion (ii) and (iii) are not standard. From column "no age>3," removing the age screen (adding back the first 12 quarters for every firm) raises the investment rate skewness from 2.29 to 3.39. Because younger firms invest faster than older firms (Lyandres *et al.*, 2008), the age screen curbs the right tail of the investment rate distribution.

[8]CP exclude "companies that have fewer than 12 quarters of data (p. 286)." This sentence might be interpreted differently, but we verify in their codes that CP drop the first 12 quarters for each firm. See our first annotation on p. 8 in the Internet Appendix D.1 on CP's "investment_rate_bea.do."

1.1.4 The M&A Screen at 5% of Total Assets

It is stringent to impose criterion (iii) that drops firm-quarters associated with acquisitions larger than 5% of total assets. CP's is the only paper that uses the 5% cutoff. In asset pricing, it is standard to keep M&As, which are not random corporate events. Firms with M&As tend to be growth firms, momentum winners, high investment firms, and high profitability firms, and firms without M&As tend to be value firms, momentum losers, low investment firms, and low profitability firms. In corporate finance, it might be informative to separate internal from external growth, but the common cutoff is 15% of assets (Whited, 1992), not CP's 5%.[9]

Column "with M&A" in Panel B of Table 1 shows the impact of removing CP's 5% M&A screen. The investment rate skewness rises from 2.29 (column "moments") to 3.46. (In untabulated results, with the 15% M&A screen, the investment rate skewness is 2.53.) As such, the 5% M&A screen also curbs the right tail of the investment rate distribution.

1.2 Discrepancies

We further document four discrepancies between CP's reporting and coding in order to closely reproduce their Table I and several more discrepancies to fully reproduce their Figure 1. All the discrepancies are implemented in their codes but not described in their paper.

1.2.1 Reproducing CP's Table I

Our reproduction sample in column "moments" in Panel B of Table 1 is 28.26% larger than CP's Table I data. Panel C identifies four discrepancies to reconcile the differences (column "all"). First, CP require a firm to be listed and traded continuously on one of the three major exchanges (NYSE, Amex, and NASDAQ) throughout its life to be included in their

[9]A subtlety arises because the common 15% cutoff is on annual data, but CP's 5% is on quarterly data. However, acquisitions are not smoothly distributed across quarters in a year but are lumpy (concentrating in a single quarter). In the 1978–2016 Compustat sample with nonmissing annual acquisitions (item AQC) and quarterly acquisitions (computed from year-to-date item AQCY), for a median firm-year with acquisitions, 98.5% of the annual acquisition amount occurs within one quarter. The 15% annual cutoff excludes 7,637 firm-years. For comparison, the 15% quarterly cutoff excludes 6,511 firm-quarters, while the 5% quarterly cutoff excludes 16,750 firm-quarters. All in all, the 5% quarterly cutoff is indeed a more stringent M&A screen than the common 15% annual cutoff.

sample. Second, CP go through an empty, redundant capital accumulation recursion to build net PPE by accumulating past changes in net PPE. Third, CP merge investment rates with monthly CRSP stock returns from 1979 to 2016 with a two-calendar-quarter lag. Fourth, CP adjust for inflation by deflating net PPE with an aggregate (nonresidential fixed assets) price deflator from BEA. Column "all" in Panel C adjusts for all four discrepancies simultaneously and reproduces column "CP's data" almost exactly.[10]

1.2.2 Reproducing CP's Figure 1

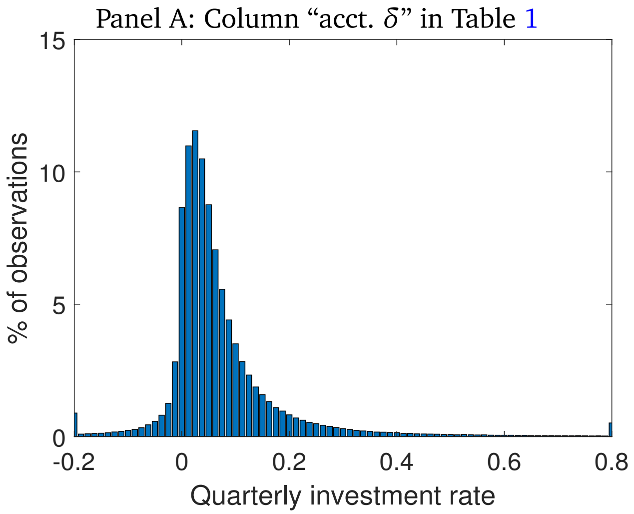
Figure 3 quantifies the impact of the three design issues identified in Section 1.1 on the right tail of the investment rate distribution in CP's Figure 1. Comparing Panel A (based on column "acct. δ" in Table 1) with CP's Figure 1 (Panel B in our Figure 1) shows that using BEA depreciation rates has the largest impact on curbing the right tail of the investment rate distribution. From Panels B and C, imposing the 3-year age screen and the 5% M&A screen further curbs the right tail.

Figure 4 attempts to reproduce CP's Figure 1 on the investment rate distribution. Even after imposing the three design issues and the four discrepancies in Section 1.2, the right tail of the investment rate distribution still survives, albeit weakly. CP truncate whatever remains at the right tail beyond 0.2 to arrive at their largely symmetric Figure 1. As noted, the investment rate skewness is 2.18 in CP's Table I data and 2.08 in CP's Figure 1 data. Neither is reported in their article. However, the skewness implicit in their truncated Figure 1 is weakly negative, −0.08, which, if true, would be a shocking refutation of Cooper and Haltiwanger (2006).

1.2.3 Why Truncating the Right Tail Might Be Questionable

CP's truncating the right tail of the investment rate distribution might be questionable. CP position their work as "documenting investment behavior among publicly traded U.S. firms (p. 282)" in an exercise that is "*akin to that conducted by Cooper and Haltiwanger (2006) on manufacturing plants* (p. 282, our emphasis)." "Studies of the plant-level investment process such as Doms and Dunne (1998) and Cooper and Haltiwanger (2006) provide empirical evidence needed to discipline quantitative studies on

[10] Section A.1 in the Internet Appendix details the impact of these discrepancies on our reproduction of CP's Table I.



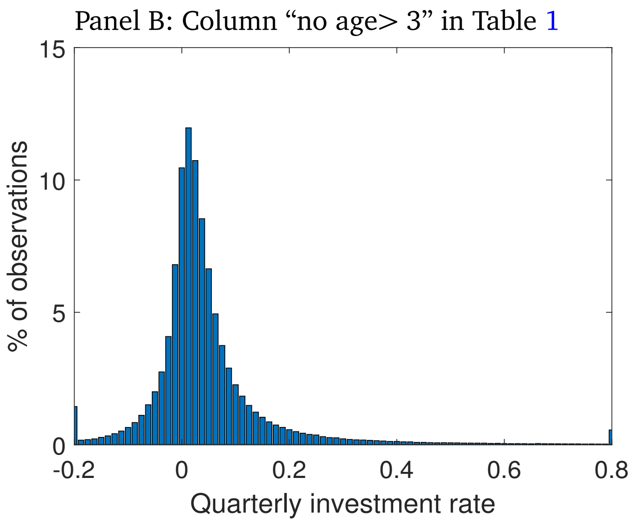
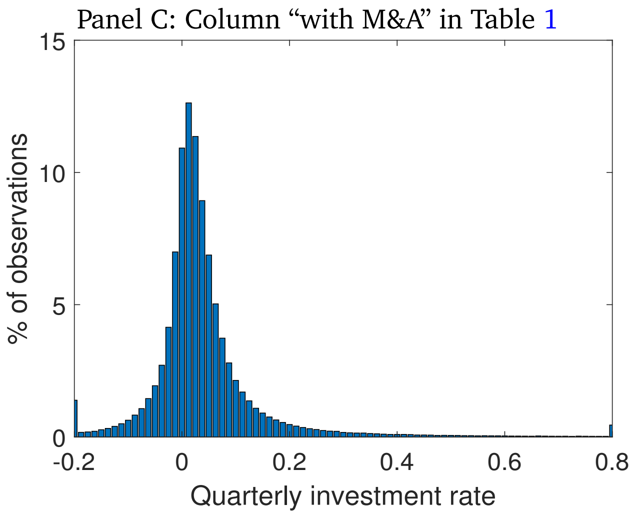


Figure 3: The impact of BEA depreciation rates, the age screen, and the M&A screen on CP's Figure 1 on the gross investment rate distribution, 1978Q1–2016Q4.

(Continued)

Figure 3: (*Continued*)



Description: Panels A–C are based on our data in columns "acct. δ," "no age>3," and "with M&A" in Table 1, respectively.

Interpretation: Using BEA depreciation rates has the largest impact on curbing the right tail of the investment rate distribution, followed by the 3-year age and 5% M&A screens.

the role of cross-sectional heterogeneity in macroeconomic models. In an analogous fashion, in this section we carefully describe investment at U.S. public companies for the purpose of informing modeling choices in the quantitative analysis of production-based asset pricing models (p. 285)." Above all, CP conclude "*no sign of irreversibility* (p. 289, our emphasis)."

In contrast, Cooper and Haltiwanger (2006) emphasize repeatedly, like a broken record, that the fat right tail of the investment rate distribution is the *decisive* evidence on irreversibility. "It is transparent that the investment rate distribution is non-normal having a considerable mass around 0, fat tails, and is highly skewed to the right (standard tests for non-normality yield strong evidence of skewness and kurtosis) (p. 614)." "These properties of the investment distribution illustrates a key feature of the micro-data: investment rates are highly asymmetric (p. 614)." "This striking asymmetry between positive and negative investment is an important fea-

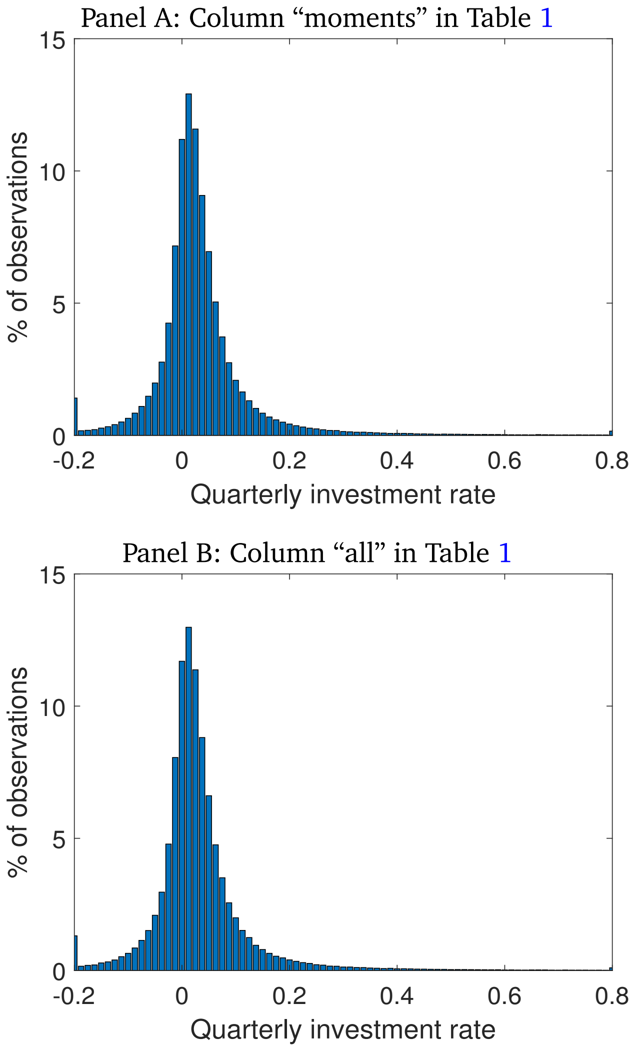
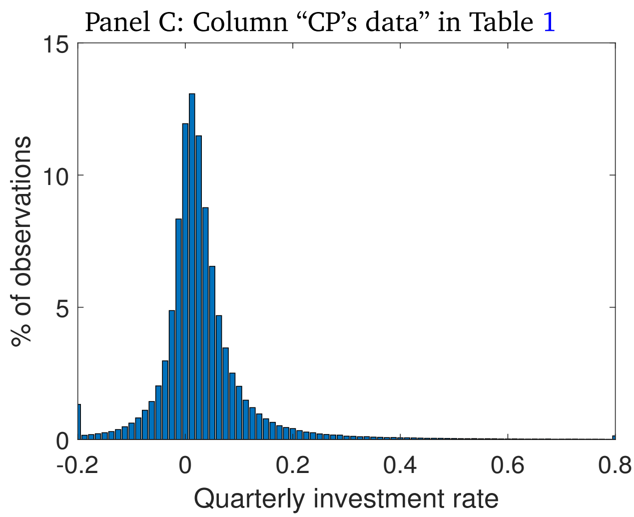
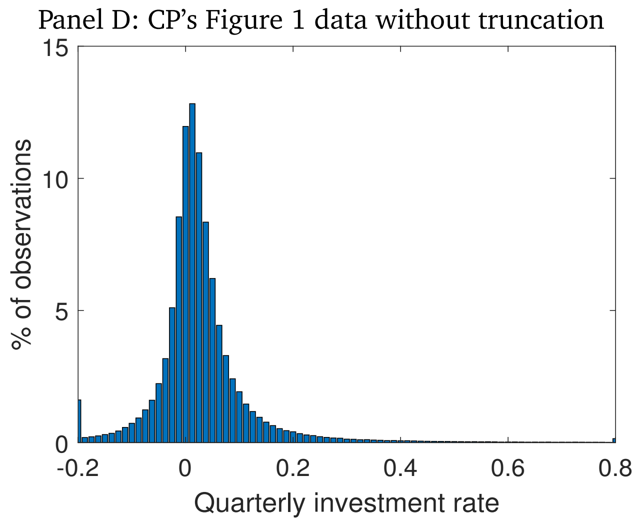


Figure 4: Reproduction of CP’s Figure 1 on the gross investment rate distribution, 1978Q1–2016Q4.
(Continued)

Figure 4: (*Continued*)





Description: Panels A and B are based on our reproduction samples in columns "moments" and "all" in Table 1, respectively. Panels C and D are based on CP's data in their Table I and Figure 1, respectively.

Interpretation: Truncating at 0.2 is necessary to fully reproduce CP's symmetric Figure 1.

ture of the data that our analysis seeks to match (p. 614)." "[T]he investment distribution at the micro-level is very asymmetric and has a fat right tail (p. 616)." "While Table 1 shows some range of inaction, the more robust finding in Figure 1 and Table 1 is that the distribution of investment is skewed and kurtotic with a fat right tail (p. 616)."

On irreversibility causing asymmetry: "All of the models are able to produce both positive and negative spikes but, naturally, the asymmetry in spike rates is most prominent in the irreversibility specification (p. 620)." "Further, with the non-convex adjustment and the irreversibility, the model produces both positive and negative investment bursts of the frequency found in the data (p. 623)." "The average 90th percentile from the LRD is 0.299 and the 10th percentile is given by -0.014. These moments capture the asymmetry and fat right tail of the investment distribution (p. 627)." "The LRD indicates that plants exhibit periods of inactivity as well as large positive investment bursts but little evidence of negative investment. The resulting distribution of investment rates at the micro-level is highly skewed even though the distribution of shocks is not. A model, which incorporates both convex and non-convex aspects of adjustment, including irreversibility, fits these observations best (p. 629)." "In the actual micro-data, while we do observe some range of inaction as we report in Table 1, the more robust finding is that the distribution of investment is skewed and kurtotic with a mass around 0 and a fat right tail (p. 630)."

2 Replication

2.1 Replicating CP's Table I

To replicate CP's Table I, we fix all the design issues and discrepancies identified in Section 1. Table 2 shows the results. We start with our reproduction in column "moments" in Table 1 that already adjusts for the discrepancies between CP's reporting and coding.

First, we fix CP's data error in the gross investment rates by changing BEA depreciation rates to accounting depreciation rates. Column "acct. δ" in Table 1 (the same column in Table 2) already performs this step. Second, in column "no age>3" we remove the 12-quarter age screen from column "acct. δ" to its left in Table 2, thereby showing the cumulative impact of fixing the first two design issues in CP. Removing the age screen raises the investment rate skewness from 3.37 to 4.18.

Table 2: Replication of CP's Table I on quarterly investment rate moments, 1978Q1–2016Q4.

	moments	acct. δ	no age> 3	with M&A	others	1%–99%	/gross PPE
#Firm-quarters	379,923	364,234	460,050	475,788	504,692	509,788	378,122
Mean	3.92	7.46	9.09	9.96	9.61	9.89	5.03
Standard deviation	9.94	11.96	15.67	18.13	17.64	18.14	9.48
Skewness	2.29	3.37	4.18	4.80	4.80	3.53	3.59
Autocorrelation	25.43	33.84	35.55	29.69	30.22	31.73	34.52
Negative investment	16.91	6.08	6.00	5.89	5.76	6.17	4.94
Inaction rate	14.56	9.14	8.87	8.65	8.65	8.57	18.08
Positive spikes	4.22	7.90	10.94	12.10	11.58	11.92	4.82
Negative spikes	1.21	0.78	0.83	0.82	0.79	1.02	0.12
5th percentile	−6.90	−1.98	−1.96	−1.86	−1.76	−2.31	−1.10
Median	2.81	4.96	5.39	5.57	5.29	5.29	2.61
95th percentile	18.00	25.70	32.67	36.23	35.20	37.64	19.50

Description: Column "moments" is the same in Table 1 after adjusting for all the discrepancies between CP's reporting and coding. Column "acct. δ" is the same column in Table 1 that fixes the depreciation rate issue in column "moments." Column "no age>3" removes the 12-quarter age screen from column "acct. δ." Column "with M&A" removes the 5% M&A screen from column "no age>3." Column "others" adjusts for other differences in sampling criteria from column "with M&A." CP drop financials, utilities, and unclassified firms, while we drop financials, firms with negative book equity, firm-quarters with negative or zero assets, net PPE, or sales. CP also require nonmissing book-to-market, while we do not. From column "others," column "1%–99%" changes CP's 0.5%–99.5% truncation to 1%–99% winsorization. Finally, column "/gross PPE" perturbs column "1%–99%" by changing the scaler from net PPE to gross PPE.

Interpretation: Columns "with M&A," "1%–99%," and "/gross PPE" all produce a heavily asymmetric gross investment rate distribution with a fat right tail.

Third, in column "with M&A" we further remove the 5% M&A screen from column "no age>3" to its left in Table 2, showing the cumulative impact of fixing all three design issues in CP. The investment rate skewness goes up further to 4.8. Next, starting from column "with M&A", column "others" adjusts for small differences between CP's sampling and what we view as more standard practice. The last step is to adjust for the treatment of outliers. CP drop firm-quarters in the top and bottom 0.5% of the pooled distribution of gross investment rates. We view winsorization as more reliable. For the pooled firm-quarters of the fiscal quarters ending in a given calendar quarter, we winsorize gross investment rates at the 1%–99% level. From column "1%–99%," the investment rate skewness is 3.53, and the fraction of negative investment rates 6.17%.

The last column "/gross PPE" shows the moments of gross investment scaled by gross PPE.[11] Because of the lower coverage of item PPEGTQ, the sample size drops to 378,122 firm-quarters. The mean investment rate is 5.03%, and the standard deviation 9.48%. The skewness remains high, 3.59, and the negative investment fraction stays low, 4.94%.

2.2 *Replicating CP's Figure 1*

To replicate CP's Figure 1 on the gross investment rate distribution, we plot Panels A, C, and D in Figure 5 based on our replication samples in columns "with M&A," "1%–99%," and "/gross PPE" in Table 2, respectively. After fixing all CP's design issues and discrepancies, Panel A shows a heavily asymmetric distribution of gross investment rates with a fat right tail.

Panel B perturbs on Panel A by removing the 12-quarter age and 5% M&A screens but using BEA depreciation rates.[12] Panel B still shows a long

[11] Gross PPE is much closer to the replacement cost of capital than net PPE, as shown in Table 8 in Bai *et al.* (2022). The ratio of the replacement cost over gross PPE is on average 0.98, but that over net PPE ratio is 2.11. Intuitively, as a proxy for the replacement cost of capital, gross PPE ignores both depreciation and capital price inflation. Ignoring depreciation creates an upward bias, but ignoring price inflation creates a downward bias. On average, the two biases largely offset each other in the data.

[12] Results from this combination are not reported in Table 1, which shows each screen separately, or in Table 2, which shows cumulative impact with the data error on depreciation rates. For completeness, the sample size of this combination is 488,042 firm-quarters. The mean investment rate is 5.8%, standard deviation 14.86%, skewness 4.31, and autocorrelation 21.36%. The fraction of negative investment rates is 16.57%, inactive rates 13.46%, positive spikes 7.35%, and negative spikes 1.21%. Finally, the 5th, 50th, and 95th percentiles are −6.85%, 3.17%, and 26.35%, respectively.

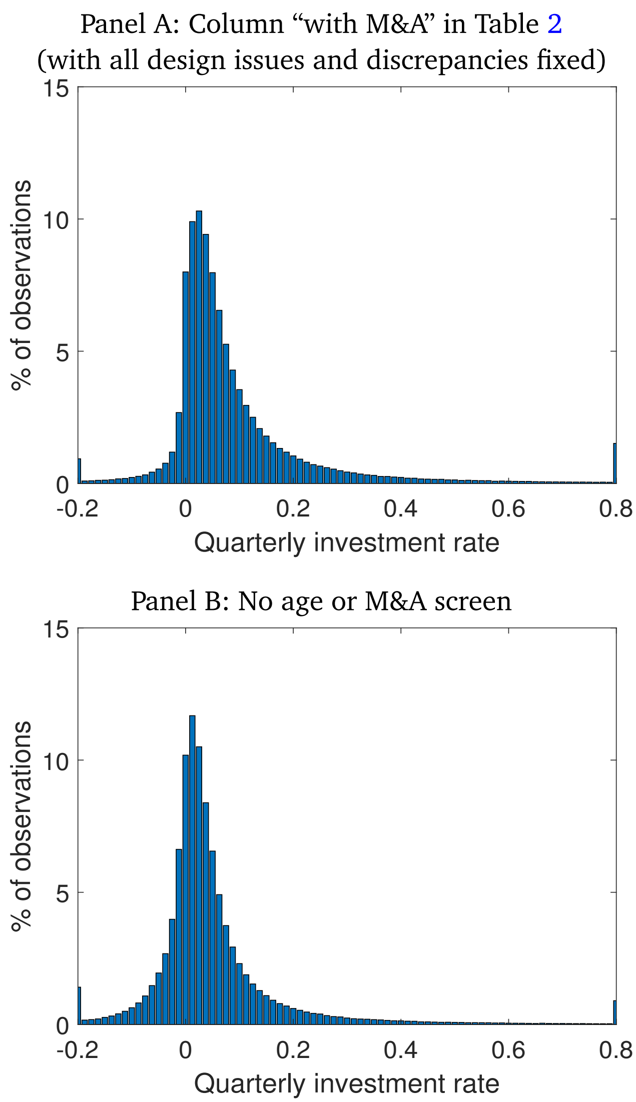
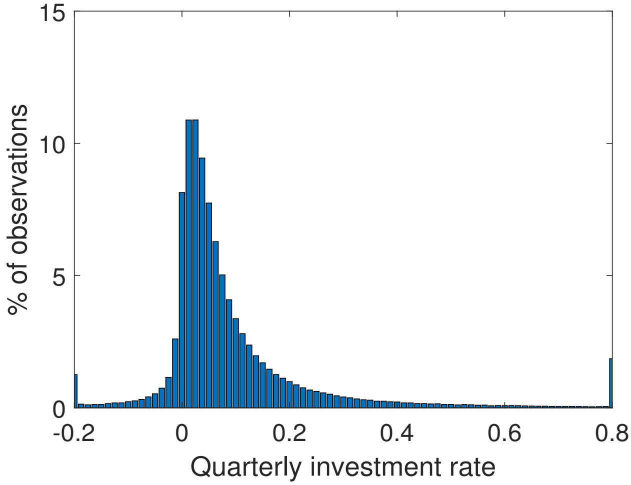


Figure 5: Replication of CP's Figure 1 on the gross investment rate distribution, 1978Q1–2016Q4.

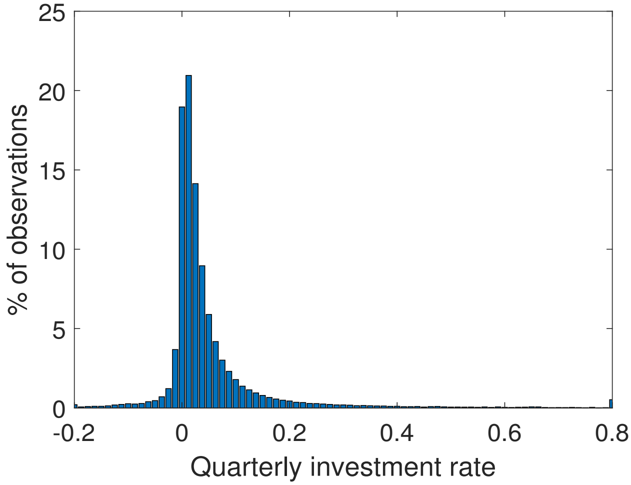
(Continued)

Figure 5: (*Continued*)

Panel C: Column “1%–99%” in Table 2 (scaled by net PPE)



Panel D: Column “/gross PPE” in Table 2 (scaled by gross PPE)



Description: Panel A is from our replication sample in column “with M&A” in Table 2, in which we cumulatively fix all CP’s design issues and discrepancies. Panel B performs a perturbation on Panel A by only removing the 12-quarter age and the 5% M&A screens but still using BEA depreciation rates as in CP. Panel C is from our replication sample in column “1%–99%” and Panel D from column “/gross PPE” in Table 2.

Interpretation: Fixing CP’s design issues and discrepancies restores the fat right tail of the gross investment rate distribution to its full glory.

right tail. (This panel combines Panels B and C in Figure 3 that show the impact of each screen separately.) As such, CP's data error on depreciation rates alone cannot fully explain the thin (missing) right tail in their Figure 1. Their age and M&A screens (and truncation) all combine to play a role.

Panel C shows the investment rate distribution in our complete replication, with net PPE as the deflator, and Panel D with gross PPE as the deflator. Most important, Panels A, C, and D restore the fat right tail of the gross investment rate distribution to all its glory.[13]

3 Reanalysis

CP's flawed evidence has adversely affected their theoretical work, which focuses exclusively on their fraction of negative investment rates, 18.2%, while turning a blind eye to the right-skewness. CP state: "Our calibration strategy sets our study apart from any other investigation of equity prices in production-based models, as we do not target any feature of the cross-section of returns. Rather, we require the model to be consistent with our evidence on investment and we evaluate its implications for equity returns (p. 292)." Throughout their Tables II, VI and VII, CP force their model to match the 18.2% fraction but not the investment rate skewness.

CP claim: "The investment-based one-factor model does not explain investment (p. 285)," once requiring that "the investment process implied by the asset pricing models under consideration conform closely with this evidence [the 18.2% fraction] (p. 289)." "[A]s long as we require it to be consistent with the cross-sectional evidence on investment, the model simply cannot generate greater dispersion in returns (p. 301)!" "The data strongly suggest that U.S. public firms do adjust to adverse profitability shocks by divesting capital. When capital adjustment costs are parameterized to reflect this feature of the data, states of nature characterized by low aggregate productivity (high marginal utility) see value firms disinvest. This makes them safer, leading to a lower value premium (p. 307)."

Because the counterfactual 18.2% fraction of negative investment rates is hardwired into CP's model, their quantitative results are also, most likely,

[13] In Section A.2 in the Internet Appendix, we perform a battery of robustness tests on our replication. Without going through the details, we can report robustness from sample-split (in mid 1996), various M&A and age screens, size split on market equity or capital, as well as across 19 NAICS nonfinancial sectors.

problematic. As such, we do not reproduce or replicate them further.[14] More important, CP's claim *that no asymmetry necessitates a low value premium is logically equivalent to that a high value premium necessitates asymmetry*, as argued in prior studies. Paradoxically, CP's theoretical results lend strong support to the prior studies that they set out to refute.

Following Clemens (2017), we perform a reanalysis by asking whether a baseline investment model can explain the value premium and investment dynamics jointly. In the Internet Appendix (Section B), we implement a baseline investment model via simulated method of moments. We estimate four parameters (the upward and downward adjustment cost parameters, the fixed cost of production, and the conditional volatility of firm-specific productivity), while targeting seven data moments (the average value premium, the volatility and skewness of individual stock excess returns, the volatility, skewness, and autocorrelation of investment rates, and the fraction of negative investment rates). The point estimates strongly indicate costly reversibility and operating leverage, which are a good start to explaining the value premium and investment moments.

Our reanalysis embodies what philosopher of science Michael Weisberg (2013, p. 100) calls "minimalist idealization," which is the practice of constructing and studying models that include only the core causal forces. A minimalist model has a special place in science because it can reveal the most important causal powers at the heart of a phenomenon. Adding more details to the model does not improve the explanation but only allows a more thorough characterization of a specific event.

Replicating a theoretical study is more challenging than replicating an empirical study. The target in the latter is a statistic, such as the fraction of negative investment rates, which dwells in what Bhaskar (1975) calls the (observable) empirical domain. However, the target in the former is a causal mechanism, which resides in the Bhaskarian (unobservable) real domain. And an empirical pattern can be caused by multiple, unobservable mechanisms, whose relative strength varies over time.

[14]CP's model includes many features that are not the most standard (or simplest) specifications, such as labor and wage rate, maintenance investment (with zero adjustment costs), a wedge in the purchasing price of investment higher than maintenance investment, and an exogenous stochastic depreciation rate process, among others. CP do not document exactly how each departure from the more standard model affects their quantitative results. Finally, because CP's article predates code sharing policy at *Journal of Finance*, we do not have access to their codes for the theoretical analysis.

To study a causal mechanism, a theorist must formulate a model (a thought experiment) (Mäki, 2005). As in a material experiment, one makes (false) assumptions to shield the targeted mechanism from other, potentially interfering ones. Following Mäki (2004), we view truth as correspondence with mind-independent reality and nominate a model's targeted mechanism (not its assumptions) as its truth-bearer.

Alas, the economy is not a machine, in which one can study the mechanisms separately and then piece them back together additively, without ever needing to change parameter values (Lucas, 1980).[15] Rather, the economy is a complex adaptive system, in which one chooses which mechanism to target and which to ignore based on one's perspective (Wimsatt, 2007). However, one perspective can be incompatible with others. How should we decide on what is real? What are a model's truth-makers?

Besides evidential truth-making, we adopt the Levins-Wimsatt robustness criterion: "[W]e attempt to treat the same problem with several alternative models, each with different simplifications, but with a common biological assumption. Then, if these models, despite their different assumptions, lead to similar results we have what we can call a robust theorem that is relatively free of the details of the model. Hence, our truth is the intersection of independent lies (Levins, 1966, p. 423)."[16]

We should probably clarify that we only nominate the asymmetry causal mechanism as the truth-bearer, as opposed to the specific assumptions in the original model. Bai *et al.* (2022) provide broad evidential truth-making. For the "robustness theorem," the Internet Appendix (Section C) lists 28 articles published since 1999 on asset pricing theory, articles all of which are built on the asymmetry mechanism, but are derived under a diverse set of specific assumptions and environments.

For robustness within the neoclassical investment framework, since

[15]Browning *et al.* (1999, p. 546) emphasize the model-dependence of point estimates: "Different microeconomic studies make different assumptions, often implicit, about the economic environments in which agents make their decisions. They condition on different variables and produce parameters with different economic interpretations. A parameter that is valid for a model in one economic environment cannot be uncritically applied to a model embedded in a different economic environment."

[16]This robustness criterion is broadly aligned with Whewell's consilience in his 1840 "The Philosophy of the Inductive Sciences." Laudan (1971, p. 369) quotes Whewell: "The Consilience of Inductions takes place when an Induction, obtained from one class of facts, coincides with an Induction, obtained from another different class. This Consilience is a test of the truth of the Theory in which it occurs."

Zhang (2005), the asymmetry mechanism has appeared in diverse specifications, often to address different questions. For example, Tuzel (2010) shows that firms with higher real estate holdings earn higher average returns because real estate faces higher disinvestment costs and depreciates more slowly than other capital. Lin and Zhang (2013) embed the asymmetry mechanism to study the covariance versus characteristic tests. Kuehn and Schmid (2014) show that asymmetry helps explain the credit spread puzzle. Bai *et al.* (2019) embed the mechanism in a disaster model to explain the CAPM failure. Herskovic *et al.* (2023) show the asymmetry mechanism at work in a long-run risks model.

For robustness with respect to different modeling approaches, Carlson *et al.* (2004) derive the asymmetry mechanism from irreversibility and operating leverage in the real options framework. Carlson *et al.* (2006) apply the mechanism to study seasoned equity offerings. Cooper (2006) derives the asymmetry mechanism in a different setup with irreversibility and nonconvex adjustment costs. Gu *et al.* (2018) clarify the interaction between costly reversibility and operating leverage when affecting risk and expected returns. All in all, per the Levins-Wimsatt robustness criterion, the asymmetry mechanism resides squarely in the fabric of our reality.

4 Conclusion

The CP article, which concludes "no sign of irreversibility (p. 289)" at the firm level in Compustat, fails to replicate. The sources of the replication failure include (i) a data error from the logic inconsistency between measures of net investment and depreciation rates; (ii) nonstandard sample screens that drop the first 12 quarters for each firm and firm-quarters associated with acquisitions higher than 5% of assets, both curbing the right tail of the investment rate distribution; and (iii) cutting off the right tail at 0.2 when plotting the investment rate distribution. Fixing CP's design issues and discrepancies, our replications show an investment rate skewness between 3.53 to 4.8 and a fraction of negative investment rates between 4.94% to 6.17%. In accordance with the plant-level evidence in Cooper and Haltiwanger (2006), the firm-level gross investment rate distribution in Compustat is heavily asymmetric with a fat right tail.

References

Abel, A. B. 1983. “Optimal Investment under Uncertainty”. *American Economic Review*. 73: 228–233.

Abel, A. B., A. K. Dixit, J. C. Eberly, and R. S. Pindyck. 1996. “Options, the Value of Capital, and Investment”. *Quarterly Journal of Economics*. 111: 753–777.

Abel, A. B. and J. C. Eberly. 1994. “A Unified Model of Investment under Uncertainty”. *American Economic Review*. 84: 1369–1384.

Abel, A. B. and J. C. Eberly. 1996. “Optimal Investment with Costly Reversibility”. *Review of Economic Studies*. 63: 581–593.

Arrow, K. J. 1968. “Optimal Capital Policy with Irreversible Investment”. In: *Value, Capital, and Growth: Papers in Honour of Sir John Hicks*. Ed. by J. N. Wolfe. Edinburgh University Press. 1–19.

Bai, H., K. Hou, H. Kung, E. X. N. Li, and L. Zhang. 2019. “The CAPM Strikes Back? An Equilibrium Model with Disasters”. *Journal of Financial Economics*. 131: 269–298.

Bai, H., E. X. N. Li, C. Xue, and L. Zhang. 2022. “Asymmetric Investment Rates”. NBER Working Paper #29957.

Bernanke, B. S. 1983. “Irreversibility, Uncertainty, and Cyclical Investment”. *Quarterly Journal of Economics*. 98: 85–106.

Bhaskar, R. 1975. *A Realist Theory of Science*. Routledge.

Browning, M., L. P. Hansen, and J. J. Heckman. 1999. “Micro Data and General Equilibrium Models”. In: *Handbook of Macroeconomics*. Ed. by J. B. Taylor and M. Woodford. Vol. 1A. Elsevier B.V. 543–633.

Caballero, R. J. 1999. “Aggregate Investment”. In: *Handbook of Macroeconomics*. Ed. by J. B. Taylor and M. Woodford. Vol. 1B. Elsevier B.V. 813–862.

Caballero, R. J., E. M. R. A. Engel, and J. C. Haltiwanger. 1995. “Plant-level Adjustment and Aggregate Investment Dynamics”. *Brookings Papers on Economic Activity*. 2: 1–39.

Carlson, M., A. Fisher, and R. Giammarino. 2004. “Corporate Investment and Asset Price Dynamics: Implications for the Cross-section of Returns”. *Journal of Finance*. 59: 2577–2603.

Carlson, M., A. Fisher, and R. Giammarino. 2006. “Corporate investment and asset price dynamics: Implications for SEO event studies and long-run performance”. *Journal of Finance*. 61: 1009–1034.

Clemens, M. A. 2017. “The Meaning of Failed Replications: A Review and Proposal”. *Journal of Economic Surveys*. 31: 326–342.

Clementi, G. L. and B. Palazzo. 2019. “Investment and the Cross-section of Equity Returns”. *Journal of Finance*. 74: 281–321.

Cooper, I. 2006. “Asset Pricing Implications of Nonconvex Adjustment Costs and Irreversibility of Investment”. *Journal of Finance*. 61: 139–170.

Cooper, R. W. and J. C. Haltiwanger. 2006. “On the Nature of Capital Adjustment Costs”. *Review of Economic Studies*. 73: 611–633.

Cooper, R. W., J. C. Haltiwanger, and L. Power. 1995. “Machine Replacement and the Business Cycle: Lumps and Bumps”. *American Economic Review*. 89: 921–946.

Dixit, A. K. and R. S. Pindyck. 1994. *Investment Under Uncertainty*. Princeton University Press.

Doms, M. and T. Dunne. 1998. “Capital Adjustment Patterns in Manufacturing Plants”. *Review of Economic Dynamics*. 1: 409–429.

Fraumeni, B. M. 1997. “The Measurement of Depreciation in the U.S. National Income and Product Accounts”. *Survey of Current Business*. July: 7–23.

Gu, L., D. Hackbarth, and T. Johnson. 2018. “Inflexibility and Stock Returns”. *Review of Financial Studies*. 31: 278–321.

Hamermesh, D. S. 2007. “Viewpoint: Replication in Economics”. *Canadian Journal of Economics*. 40: 715–733.

Herskovic, B., T. Kind, and H. Kung. 2023. “Micro Uncertainty and Asset Prices”. *Journal of Financial Economics*. 149: 27–51.

Hulten, C. R. and F. C. Wykoff. 1981. “The Estimation of Economic Depreciation Using Vintage Asset Prices”. *Journal of Econometrics*. 15: 367–396.

Kuehn, L.-A. and L. Schmid. 2014. “Investment-based Corporate Bond Pricing”. *Journal of Finance*. 69: 2741–2776.

Laudan, L. 1971. “William Whewell on the Consilience of Inductions”. *The Monist*. 55: 368–391.

Levins, R. 1966. “The Strategy of Model Building in Population Biology”. *American Scientist*. 54: 421–431.

Lin, X. and L. Zhang. 2013. “The Investment Manifesto”. *Journal of Monetary Economics*. 60: 351–366.

Lucas, R. E. 1980. “Methods and Problems in Business Cycle Theory”. *Journal of Money, Credit, and Banking*. 12: 696–715.

Lyandres, E., L. Sun, and L. Zhang. 2008. "The New Issues Puzzle: Testing the Investment-based Explanation". *Review of Financial Studies*. 21: 2825–2855.

Mäki, U. 2004. "Some Truths about Truth for Economists and Their Critics and Clients". In: *Economic Policy-making under Uncertainty: The Role of Truth and Accountability in Policy Advice*. Ed. by P. Mooslechner, H. Schuberth, and M. Schürz. Edward Elgar. 9–39.

Mäki, U. 2005. "Models are Experiments, Experiments are Models". *Journal of Economic Methodology*. 12: 303–315.

McDonald, R. L. and D. Siegel. 1986. "The Value of Waiting to Investment". *Quarterly Journal of Economics*. 101: 707–728.

Nilsen, Ø. A. and F. Schiantarelli. 2003. "Zeros and Lumps in Investment: Empirical Evidence on Irreversibilities and Nonconvexities". *Review of Economics and Statistics*. 85: 1021–1037.

Tuzel, S. 2010. "Corporate Real Estate Holdings and the Cross Section of Stock Returns". *Review of Financial Studies*. 23: 2268–2302.

Wahlen, J. M., S. P. Baginski, and M. T. Bradshaw. 2018. *Financial Reporting, Financial Statement Analysis, and Valuation: A Strategic Perspective*. Cengage Learning.

Weisberg, M. 2013. *Simulation and Similarity: Using Models to Understand the World*. Oxford University Press.

Whited, T. M. 1992. "Debt, Liquidity Constraints, and Corporate Investment: Evidence from Panel Data". *Journal of Finance*. 47: 1425–1460.

Wimsatt, W. C. 2007. *Re-engineering Philosophy for Limited Beings: Piecewise Approximations to Reality*. Harvard University Press.

Zhang, L. 2005. "The Value Premium". *Journal of Finance*. 60: 67–103.