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Tax Policy and Abnormal Investment Behavior

Qiping Xu
University of Illinois Urbana Champaign, United States

Eric Zwick
Booth School of Business, University of Chicago, United States

This paper studies tax-minimizing investment, whereby firms tilt capital purchases toward year-end to reduce taxes. We use this pattern to characterize how taxes affect investment behavior. We exploit variation in firm tax positions from administrative data to confirm that tax minimization causes spikes. Spikes increase when firms face financial constraints or higher option values of waiting. Cumulative investment does not completely reverse after spikes. We develop an investment model with tax asymmetries to rationalize these patterns. Both depreciation motives (later investments face lower effective tax rates) and option value motives (tax asymmetry implies time-varying opportunities to minimize taxes) are necessary to fit the data. (*JEL* G31, G38, H25)

This paper was originally accepted for publication in the *Journal of Finance* (*JF*) and subsequently withdrawn prior to publication after *JF* received an unsolicited comment that questioned the relationship between this paper and Kinney and Trezevant (1993). The *JF* decision letter explains that they solicited a revision mainly because of the perceived novelty of the empirical patterns of year-end investment spikes. As a result, our paper might not have received a revision request if we had cited previous literature such as Kinney and Trezevant (1993) in our initial submission. While we referenced this and other relevant studies in the latter-reviewed versions of the paper, including in the version that was accepted prior to the withdrawal, the journal believed a withdrawal was warranted because the initial editorial decision was too favorable. The editors acknowledged that the final version of the paper made a substantial contribution relative to the earlier literature, and did not perceive any barrier for us to submit it to a new journal. Before submitting to the *Review of Financial Studies*, we resolved the issues raised by revising the paper to clarify our contribution. During the review process at the *Review of Financial Studies*, we received valuable feedback from the editor Itay Goldstein, two associate editors, and two anonymous referees. Based on their constructive comments, we made significant revisions that improved the paper prior to its acceptance for publication.

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How do taxes affect business investment? The importance of this question is widely recognized, as policy makers often invoke the contribution of investment to economic growth when proposing tax reforms. Such proposals presume a model of corporate behavior, usually based on the user cost framework of Hall and Jorgenson (1967). Yet recent studies raise questions that the benchmark user cost model of a representative firm struggles to answer. For instance, why do some tax instruments have large effects on investment, while others do not, and what drives the heterogeneity across firms in responsiveness to tax changes? Reconciling these findings and revealing the underlying mechanisms remain goals of ongoing research.

This paper studies tax-minimizing investment, whereby firms tilt capital purchases toward fiscal year-end to reduce taxes. We focus on an understudied measure of investment behavior that is simple, transparent, and orthogonal to low- and medium-frequency policy and firm-by-time shocks. This approach removes time-varying omitted factors that coincide with the identifying variation we exploit, and thus addresses a key concern with existing empirical work. We confirm the importance of taxes for corporate investment behavior and further illustrate that tax asymmetry—in particular, the immediacy of the tax incentive—critically affects how firms respond. We conclude that models most likely to fit the data feature a purchase-year, tax-minimization motive.

The paper begins by revisiting a robust stylized fact about investment behavior among American public companies, a pattern previously studied by Kinney and Trezevant (1993), Callen, Livnat, and Ryan (1996), and Shin and Kim (2002). Firms frequently tilt their investment toward fiscal year-end, leading to quantitatively significant spikes in capital expenditures (CAPEX) in the fourth fiscal quarter (Q4). This pattern is present nearly every year between 1984 and 2016. Over the full sample period, fiscal Q4 CAPEX is on average 36% higher than the average of the first three fiscal quarters. The pattern is robust to non-December fiscal year-end, to changes in fiscal year-end, and to within-year seasonality of sales and cash flows. Moreover, fiscal Q4 investment spikes exist internationally. In data from 24 countries, fiscal Q4 spikes appear nearly universal during the period between 2004 and 2016. Although the magnitude of spikes varies across countries, the general pattern of Q4 spikes is robust.

We interpret Q4 investment spikes as the result of tax-minimizing behavior that consists of two connected motives. First, depreciation allowances are deducted from firms' pretax income and hence reduce their tax bill. Deduction conventions usually allow firms to deduct depreciation for year-end purchases as if the capital had been deployed halfway through the year. This feature creates a "depreciation motive" for firms to increase investment toward the end of the fiscal year (Kinney and Trezevant 1993). Because purchases made later in the year face a lower effective tax rate and deliver a higher rate of return, firms making a fixed amount of investment are better off tilting that investment toward fiscal year-end than uniformly investing throughout the year.

Second, because tax positions can be better estimated close to fiscal year-end when most revenues and expenses for the year have been recorded, investing near the fiscal year-end allows firms to maximize the tax benefit of depreciation. We refer to this feature as the "option value motive" because firms have an incentive to wait and see how their tax position evolves during the fiscal year. This motive is a tax-specific application of the general principle that sequential information arrival affects optimal investment policy (Majd and Pindyck 1987). If the year goes well, firms can increase investment at year-end to minimize their remaining tax burden. If the year goes poorly and the firm's taxable income is already close to zero, they will have less reason to invest in the current fiscal year to reduce taxes. The sharp nature of Q4 spikes allows us to show that these tax motives are driving an important part of this investment behavior. Both motives are necessary to rationalize our findings.

We use a novel empirical strategy to confirm the link between tax minimization and Q4 investment spikes. The strategy exploits the budget kink created by the asymmetry in corporate tax positions: when a firm moves from a positive to negative tax position, the firm must defer the tax benefits of investment from the current year until some future year. To pursue this strategy, we combine Q4 CAPEX spike data from Compustat with tax position data from corporate tax returns for the years 1993 through 2016. Fiscal Q4 investment spikes are substantially higher when firms have an immediate incentive to offset taxable income with new investment rather than having to carry forward tax benefits to future years. Regression estimates show that within firm, a positive-taxable-income fiscal year has a spike between 7% and 12% higher than a negative-taxable-income fiscal year, which is large compared to the sample average of 33%. Additionally, taxable firms with large stocks of net operating loss carryforwards, which serve as an alternative tax shield, show significantly smaller Q4 spikes.

What type of firm is more inclined to employ a tax-minimizing investment strategy? And how does the answer inform models of investment behavior? Firms facing higher option values for waiting until fiscal year-end to make investment decisions—those with positive earnings on average and less downside earnings volatility—show higher investment spikes. We also find that spikes are related to "use it or lose it" budgeting incentives thought to characterize internal capital markets (Callen, Livnat, and Ryan 1996; Shin and Kim 2002). Such incentives, however, cannot explain differential behavior based on tax incentives. Furthermore, the effect of tax position on spikes does not vary across firms with different degrees of budgetary complexity or agency frictions.

Financial constraints alter the effective discount rate firms face and therefore should interact with the depreciation and option value motives. To explore this idea, we study the effects of tax changes on spikes for firms sorted based on different proxies for financial constraints. Regression estimates show that financially constrained firms conduct more tax-minimizing investment and respond more strongly to the 1986 tax reform, which altered the incentive to tilt investment to fiscal year-end. The evidence supports the idea that firms relying heavily on internal funds to finance investment face higher effective discount rates and retime spending more strategically to save taxes and retain cash.

To address whether Q4 spikes have more persistent effects, we study the cumulative impact of investment spikes on the level of investment. Here, we address the question of whether Q4 investment spikes immediately reverse over the next quarter or two, with the higher investment not detectable if aggregated over a slightly longer time frame. To isolate the impact of tax motives from underlying productivity shocks, we compare nontaxable to taxable spikers within a narrow window around the tax position threshold, exploiting the idea that positive-taxable-income firms face stronger tax-minimization motives. We do not find evidence of immediate reversal of investment after spikes. Instead, taxable spikers display a significantly stronger increase in the cumulative investment level relative to nontaxable spikers. Thus, our tax motives operate in addition to potential confounds, such as persistent productivity shocks, which cannot account for differential persistence when comparing nontaxable to taxable spikers. In addition, Q4 spikes are negatively autocorrelated over longer horizons, which further suggests a process with medium-term mean reversion rather than mechanical repetition of spikes each year with only short-term implications.

We confirm several stylized facts on the dynamic and cross-sectional drivers of tax-minimizing investment using the richness of the administrative corporate tax data and an alternative policy that only affects small firms. We examine bunching of eligible equipment investment at the Section 179 depreciation schedule threshold (Zwick and Mahon 2017), and find dynamics that are remarkably consistent with the evidence from Q4 spikes. First, bunching rises with the mean and falls with the variance in within-firm profitability. Second, firms that bunch this year are considerably less likely to bunch in the following several years. Finally, bunching coincides with rising cumulative investment that does not appear to revert in the years immediately after bunching. Given the similar patterns for this distinct tax-minimizing investment measure and using a different sample of firms, our results point toward a general mechanism for modeling firm responses to the asymmetries in the tax code's treatment of investment.

In light of the results on firms' characteristics—namely, higher spikes for firms in a taxable position, for firms with higher profitability and lower downside volatility, and for firms more likely to face high discount rates—the cumulative persistence of investment following spikes likely reflects time-varying opportunities for firms to offset tax bills associated with positive earnings shocks. We examine this conjecture through the lens of a quantitative investment model that embeds a tax-minimization motive. The model clarifies the intuition for the persistence of investment following spikes. Part of the persistence reflects the underlying persistence of productivity shocks. However, productivity cannot account for the stronger persistence in versions with tax asymmetries and the possibility of tax losses. In a version of the model with a depreciation motive but no tax losses, the effective tax rate for new investment falls monotonically over the fiscal year. Even without an option value motive, a firm will invest more when the after-tax price is lower. This behavior will not fully crowd out investment in subsequent quarters, which implies partially persistent investment spikes. In the full model that layers the option value motive on top of the depreciation motive, investment following spikes is even more persistent, because retiming investment is more valuable when firms face a nontrivial risk of tax losses in future years.

We also use the model to conduct a policy experiment in which we reduce the corporate tax rate from 35% to 21%, analogous to the corporate tax rate changes enacted by the Tax Cuts and Jobs Act of 2017. We then study heterogeneous investment responses based on whether a firm's marginal investment decision is likely to influence this year's tax bill. The tax cut leads to a substantial increase in investment rates in the post-reform period. Critically, the model reproduces the stylized fact that the responsiveness of investment to tax policy changes is stronger when firms receive immediate tax benefits (Zwick and Mahon 2017).

In the last part of the paper, we trace the implications of investment spikes for capital goods suppliers and lenders. In Census survey data from domestic manufacturers, spikes in aggregate capital goods shipments coincide with months during which firms commonly have fiscal year-ends. These spikes propagate through production chains by inducing suppliers to accumulate inventories in advance of purchase spikes, a fact we confirm in aggregate data and for suppliers linked to customers in the Compustat Segments Customer database. In small business lending data, December sees significantly higher new business volume than other months, which validates firms' reported fiscal year-end investment spikes from the lending side of the market. In contrast to these strong quantity effects, we find no effects on equipment prices or interest rates.

Our paper contributes to the literature that estimates the effect of taxes on investment.[1] Relative to this literature, which often focuses on

[1] The literature relying on policy-induced variation includes Cummins, Hassett, and Hubbard (1996), Goolsbee (1998), Chirinko, Fazzari, and Meyer (1999), Desai and Goolsbee (2004), House and Shapiro (2008), Edgerton (2010), Becker, Jacob, and Jacob (2013), Yagan (2015), Ljungqvist and Smolyansky (2014), Zwick and Mahon (2017), Ohrn (2018), and Giroud and Rauh (2019). Hassett and Hubbard (2002) survey the early research and offer a perspective that is mostly consistent with subsequent findings, though Chirinko (2008) and Chirinko and Mallick (2017) argue that consensus remains elusive.

measuring policy parameters, our goal is to help understand the underlying mechanism. In addition, because most research relies on quasi-experiments based on nonrandom tax changes, the extent to which estimated tax effects reflect unobservable firm or macroeconomic factors remains unclear. Our approach complements this work by focusing on an understudied measure of investment behavior that is orthogonal to low- and medium-frequency firm-by-time shocks.

Prior research has uncovered several anomalies with respect to the benchmark user cost framework, as studies of different tax instruments yield ostensibly conflicting results.[2] Our findings confirm the importance of immediacy for tax effects and highlight how policy instruments that directly target investment behavior—such as depreciation incentives or investment tax credits—influence corporate decision-making. We propose a simple modification of the workhorse dynamic problem of the firm and show how this model can qualitatively and quantitatively account for the patterns in the data.[3] Promoting intertemporal substitution of investment from future years into the present is a central motivation for many fiscal stimulus policies. Our results help explain why some firms respond more to stimulus and suggest that regimes in which the option value motive is stronger are likely to display greater responsiveness to such policies.

Our paper builds on prior work examining factors driving year-end investment spikes and asset sales, including tax minimization (Kinney and Trezevant 1993), "use it or lose it" budgets (Callen, Livnat, and Ryan 1996), earnings management (Bartov 1993), and agency frictions (Shin and Kim 2002). We contribute to this literature by providing new data to sharpen the identification of tax motives and by broadening the scope of study empirically and through the lens of a dynamic investment model. We use confidential data from administrative tax filings to isolate tax-minimization incentives cleanly and measure their impact.[4] We further exploit this data to develop new tests

2 Yagan (2015) finds that dividend taxes do not affect corporate investment; Suárez Serrato and Zidar (2016), Ohrn (2018), and Giroud and Rauh (2019) find meaningful effects of tax rate changes on firm location, investment, and employment; and House and Shapiro (2008) and Zwick and Mahon (2017) find that "bonus" and Section 179 depreciation incentives significantly affect investment. The response in Zwick and Mahon (2017) is more pronounced for small firms than large firms, with investment decisions showing more sensitivity to immediate tax benefits than the standard model predicts. Edgerton (2010) uses accounting data to study the role of corporate tax asymmetries and finds less evidence that immediacy matters for public firms, but acknowledges that measurement limitations may drive these results because financial accounts do not directly reveal public firms' tax positions.

3 Key studies that propose models of how firms make investment decisions include Summers (1981), Hayashi (1982), Abel and Eberly (1994), Caballero and Engel (1999), Cooper and Haltiwanger (2006), and Winberry (2021). Chen et al. (2023) use a lumpy investment model to study the relative efficacy of policies that target fixed costs, such as investment tax credits, versus those that target marginal costs, such as corporate tax cuts.

4 Kinney and Trezevant (1993) and Callen, Livnat, and Ryan (1996) use alternative proxies for the effective tax rate from financial statements and find partly conflicting evidence on the importance of tax factors. Specifically, Callen, Livnat, and Ryan (1996) document an inverse U-shaped relationship between fourth-quarter investment spikes and average tax rates, which is the primary measure Kinney and Trezevant (1993) use to attribute tax

suggesting agency and budget forces cannot alone account for the facts. Our conceptual contribution is to go beyond explaining the short-term retiming of investment around year-end. We develop and investigate the importance of an option value motive that arises from the interaction between tax asymmetry and time-varying profitability, in addition to the depreciation motive highlighted previously. The option value motive helps explain new evidence we present on the cross-sectional drivers of investment spikes, the dynamic implications of spikes, and the medium-term effects on cumulative investment. We develop a quantitative model to isolate the role of tax factors in spike behavior and to illustrate the importance of the option value motive in accounting for the empirical patterns. The results enhance our understanding of the response to tax incentives, which has implications for policy targeting investment through tax subsidies, such as accelerated depreciation.

1. Policy Background and Data

1.1 Policy background

When making an investment, a firm is permitted a sequence of tax deductions for depreciation over a period of time approximating the investment's useful life. Allowable depreciation deductions offset the firm's taxable income, reducing its tax bill. The current U.S. tax code's schedule of depreciation deductions is specified by the Modified Accelerated Cost Recovery System (MACRS). MACRS assigns a recovery period and depreciation method for each type of property. The recovery period refers to the number of years it takes to completely depreciate the investment, while the depreciation method refers to the speed of depreciation.[5]

Averaging conventions establish when the recovery period begins and ends. The convention determines the number of months for which firms can claim depreciation in the year they place property in service. The most common convention for equipment investment is the half-year convention, where firms treat all property placed in service during a tax year as placed at the midpoint of the year. This means that a half-year's worth of depreciation is allowed for the year in which the property is placed in service.

Because the half-year convention treats investment indiscriminately throughout the fiscal year, the effective tax rate on the return to investment falls over time within the year. In addition, because the half-year convention also applies to investments made at the end of the year, the code creates an

motives to firms. A nonmonotonic relationship is difficult to square with tax minimization but may also reflect measurement or systematic error in this variable. In contrast, our measure has the benefit of using a firm's actual tax position to isolate tax incentives to spike.

5 The common recovery periods for equipment investment are 3, 5, 7, 10, 15, and 20 years. Structures are typically depreciated over 27.5 or 39 years. The most common depreciation methods for equipment are 200% declining balance and 150% declining balance, switching to straight-line. For structures, the depreciation method is straight-line. More details are available in IRS publication 946.

Table 1
Tax benefits of accelerating investment for 5-year items

Year	0	1	2	3	4	5	6	Total
Expenditure in year 1								
Depreciation	0	20	32	19.2	11.5	11.5	5.8	100
Tax savings (τ =35%)	0	7	11.2	6.72	4.03	4.03	2.02	35
NPV of tax savings								29.10
Expenditure accelerated to year 0								
Depreciation	20	32	19.2	11.5	11.5	5.8	0	100
Tax savings (τ =35%)	7	11.2	6.72	4.03	4.03	2.02	0	35
NPV of tax savings								31.14
Benefit to accelerating								2.04

This table displays year-by-year deductions and tax benefits for a $100 investment in computers, a 5-year item, depreciable according to the Modified Accelerated Cost Recovery System (MACRS). This table considers the tax rate prevailing during the period after the Tax Reform Act of 1986, which covers the bulk of our sample. The example compares an investment put in place on December 31st (year 0) to one put in place on January 1st (year 1), and illustrates the incentive to accelerate purchases into the fourth fiscal quarter from subsequent years. NPV calculations apply a 7% discount rate. We choose this for consistency with prior work: Zwick and Mahon (2017) choose this rate because it delivers the most conservative estimated elasticity from the discount rates considered in House and Shapiro (2008). See IRS publication 946 for the recovery periods and schedules applying to other class lives.

incentive for firms to accelerate the timing of investment purchases at the very end of the fiscal year to realize the deductions a year earlier. In other words, the schedule creates a nonlinearity in the marginal incentive to invest near the end of the fiscal year because of discounting applied to the tax savings from future deductions. Our research design exploits this feature and the sharp behavior it induces to separate investment responses driven by the tax code from other confounding factors.

Table 1 illustrates the tax incentives for a $100 investment in computers, comparing a scenario in which the firm places the investment on the first day of fiscal Q1 versus the last day of the previous fiscal Q4. All calculations assume a 7% discount rate and depreciate investment using the 200% declining balance method and half-year convention. Accelerating the purchase accelerates the depreciation schedule by one year, yielding $2.04 in net present value tax savings; in other words, the firm saves 2% by making the investment 1 day earlier. If firms use higher effective discount rates, the incentive to accelerate investment to fiscal Q4 will be even larger.

1.2 Data

Our primary sample includes Compustat U.S. firms spanning the years from 1984 through 2016.[6] The sample excludes financial firms and utilities, firms with asset amounts less than $10 million, as well as firm-years without

6 We do not include the post-2016 period to avoid the potential confounding impact of the Tax Cuts and Jobs Act of 2017 and to align the Compustat data to our tax data, which end in 2016. Our sample period starts in 1984 because firms' cash flow statements (from which we extract quarterly capital expenditures) were not systematically reported before 1984. In 1984, the Financial Accounting Standards Board (FASB) issued Concepts Statement No. 5, advocating that a statement of cash flows be presented for all reporting periods.

Table 2
Summary statistics

A. U.S. sample (1984-2016)

	N	Mean	Median	SD	P10	P90
Assets (mils)	130,913	3,053.80	238.57	17,139.48	28.17	4,455.25
CAPEX (mils)	130,899	188.59	11.59	1,160.79	0.76	256.11
PPE (mils)	130,846	1,053.67	54.03	6,304.37	3.43	1,463.03
Sales (mils)	130,906	2,536.10	225.41	12,983.06	16.50	4,031.52
M/B	125,622	1.91	1.41	1.77	0.88	3.37
Cash Flow/Assets	127,118	0.03	0.09	0.38	−0.15	0.22
Cash/Assets	130,849	0.17	0.08	0.21	0.01	0.48
EBITDA/Assets	130,671	0.08	0.11	0.19	−0.09	0.23
CAPEX/PPE	129,007	0.41	0.23	0.62	0.07	0.82
CAPEX Q4/Ave(Q1-Q3)%	130,913	135.81	117.99	85.06	47.30	246.55
Sales Q4/Ave(Q1-Q3)%	126,618	111.25	106.78	26.99	84.56	143.24

B. International sample (2004-2016)

	N	Mean	Median	SD	P10	P90
M/B	53,585	2.05	1.35	2.40	0.74	3.73
Cash flow/Assets	84,662	0.03	0.07	0.22	−0.15	0.20
Cash/Assets	85,643	0.18	0.12	0.18	0.02	0.42
EBITDA/Assets	85,182	0.05	0.09	0.22	−0.12	0.23
CAPEX/PPE	84,962	0.48	0.20	1.13	0.04	0.85
CAPEX Q4/Ave(Q1-Q3)%	85,643	135.39	115.68	89.44	41.26	257.76
Sales Q4/Ave(Q1-Q3)%	82,082	114.04	106.33	38.72	79.86	155.19

Panel A presents summary statistics for the sample of U.S. firms. There are 16,202 firms with 130,913 firm-years during the period 1984 to 2016. Panel B presents summary statistics for the sample of international firms from 24 countries during the period 2004 to 2016; 13,969 unique firms and 85,643 firm-years are included in the international sample. *CAPEX 4/3* and *Sales 4/3* are censored at 500%, which excludes approximately 2% of the data. Financial ratios are winsorized at the top and bottom 1% level.

quarterly capital expenditure (CAPEX) information. The full U.S. sample includes 130,913 firm-year observations for 16,202 unique firms. On average, our sample represents 86% of aggregate annual CAPEX of all Compustat firms.

Firms report year-to-date CAPEX in their quarterly 10-Q filings. To produce our primary measure of investment behavior, we first use this year-to-date data to measure CAPEX in each quarter. For example, in fiscal year 2012, U.S. Airways reports quarterly year-to-date CAPEX as Q1 $87 million, Q2 $191 million, Q3 $428 million, and Q4 $775 million. Thus, CAPEX for each quarter is Q1 $87 million, Q2 $104 million, Q3 $237 million, and Q4 $348 million. The year-to-date format makes within-year changes in CAPEX less salient, although this example indicates strong bunching of investment in the last quarter of the year. We use the *Q4 spike* as our key measure of tax-driven investment behavior, defined as the ratio of Q4 CAPEX to the average of Q1 through Q3, which equals 243% in this case.

Table 2 presents summary statistics for the sample of U.S. and international firms (see Internet Appendix Table IA.1 for definitions). For the U.S. sample, the average firm-year has $3.05 billion in assets and $188.6 million in CAPEX. The average Q4 spike is 136% (median 118%), which indicates that Q4 CAPEX is 36% higher than the average CAPEX over the first three fiscal quarters.[7] Sales also display some Q4 periodicity due perhaps to the holiday season, with a Q4 sales spike yielding a mean value of 111%. In Section 2.1, we demonstrate the robustness of the Q4 CAPEX spike to this seasonality as well as other potential confounds. Similar summary statistics are shown for international firms.

For some analyses, we supplement the Compustat U.S. data with corporate tax returns from the Statistics of Income (SOI) division of the IRS Research, Analysis, and Statistics unit. Each year the SOI produces a stratified sample of approximately 100,000 unaudited corporate tax returns that includes all of the largest U.S. firms. We link these data using the EIN reported in Compustat, and design sharp tests of whether the Q4 CAPEX spike depends on a firm's tax position measured in tax accounting data. These data also contain detailed information on investment for small private firms, which we exploit to study dynamic tax-minimizing investment behavior for firms that bunch at depreciation schedule kink points.

Our focus is primarily on tax policy that affects the incentive for large U.S. firms to invest, but we also study investment behavior for firms in developed and developing countries. We draw international evidence of Q4 CAPEX spikes from the Compustat Global database. From 2004, Compustat Global collects quarterly CAPEX data systematically. We use countries with at least 11 years of data during the period 2004 to 2016. Our international sample includes 13,969 firms and 85,643 firm-year observations from 24 countries (excluding the United States) (see Table 2, panel B).

We also draw from Compustat Segment data, which provide detailed information on the financial characteristics of a firm's various business lines. We use these data to measure firms' corporate or budgetary complexity.[8] Additional proxies for the importance of budget cycles come from Orbis and ExecuComp. We use Compustat Customer Segments data to identify corporate supplier and customer links for U.S. firms.

Finally, we draw data on equipment lending from the Equipment Leasing and Finance Association's (ELFA) Monthly Leasing and Finance Index (MLFI-25), aggregate investment from Manufacturers' Shipments, Inventories, and Orders (M3) survey data from the Census Bureau, the Producer Price Index (PPI) from the Bureau of Labor Statistics, and interest rate data from RateWatch (part of S&P Global Market Intelligence).[9]

[7] To ensure outliers do not drive our results, we censor spikes at the top at 500% (roughly the top 3%) and censor the bottom 3% of spikes for symmetry. In addition, our graphical analysis focuses on medians to demonstrate representativeness and robustness of spike patterns.

[8] Following convention in the literature, we only keep segment information for firms whose segment data add to more than 80% of the sales and CAPEX at the consolidated level.

[9] The MLFI-25 measures monthly commercial equipment lease and loan activity reported by participating ELFA member companies, which represents a cross-section of the equipment finance sector. The M3 survey provides monthly statistical data on economic conditions in the domestic manufacturing sector. The PPI program measures the average change over time in the selling prices received by domestic producers for their output. The

2. Investment Spikes and Tax Minimization

2.1 Investment spikes in fiscal Q4

Figure 1, panel A, presents the time series of fiscal Q4 investment spikes for U.S. firms in Compustat between 1984 and 2016. We plot the median ratio of quarterly CAPEX to the average CAPEX within a firm's fiscal year. The fourth quarters, represented by red dots, consistently display higher CAPEX compared to the first three quarters. The fiscal Q4 spikes are relatively lower during the 2001 and 2008 recession periods but remain above 100%.[10]

We conduct several robustness checks to confirm that this behavior is both present and real. First, we show that steady growth cannot mechanically explain the magnitude of Q4 spikes. To account for the average fiscal Q4 spike of 136%, investment would have to grow 17.1% per quarter on average, implying a counterfactual amount of annual growth in investment. Figure 1, panel B, plots the quarterly median CAPEX level instead of the ratio and reveals a clear spike pattern that is inconsistent with a steady growth explanation.[11]

Second, fiscal year-end investment spikes are not driven by calendar-year seasonality and are still present for firms that do not display seasonality in cash flows or sales. In the U.S. sample, 64.1% of firms have fiscal year-ends in December, 7.1% in June, 6.2% in September, and 5.6% in March, with the remaining 17% distributed across the other 8 months. Figure 1, panel C, plots the time series of Q4 CAPEX spikes for firm-years with non-December fiscal year-ends. Fiscal Q4 CAPEX spikes still hold for the non-December subsample, alleviating the concern that calendar-time patterns drive year-end spikes. Figure 1, panel D, plots Q4 CAPEX spikes for firm-years with smooth cash flows, defined as fiscal Q4 cash flows lower than the average of the first three fiscal quarters. Though partly attenuated, fiscal Q4 investment spikes continue to hold after controlling for seasonality in cash flows.[12]

RateWatch database provides detailed interest rate information for commercial equipment loans, commercial real estate loans, and personal loans. Financial institutions use these data to track regional and national pricing trends.

[10] Figure 1, panel A, and other time-series figures use the average within a firm's fiscal year as the denominator to demonstrate the robustness of this pattern at the aggregate level. In subsequent analysis, we will use the average of the first three quarters as the denominator to permit an easier interpretation of investment effects, such as the effect of taxes on Q4 CAPEX spikes.

[11] In Internet Appendix Figure IA.1, panel A, we use the average of lagged two-period to forward two-period quarterly CAPEX as the denominator to calculate the spike ratio. This method is immune to discrete jumps in the denominator when moving across years. Fiscal Q4 spikes remain clear and large. Internet Appendix Figure IA.1, panel B, plots spikes with the average of Q4 and the next fiscal Q1 in the numerator of the spike measure. The graph reveals that, on average, the drop in fiscal Q1 investment only partially offsets the prior Q4 spike. We further explore the relationship between spikes and the level of investment in Section 3.3. We thank Mitchell Petersen for comments on how to address this concern.

[12] Kinney and Trezevant (1993) also find that calendar-year seasonality does not drive spikes by computing placebo spikes for noncalendar firms. Internet Appendix Figure IA.1, panel C, shows that the spike pattern holds for firms with smooth sales. Internet Appendix Figure IA.1, panel D, shows higher book depreciation in the fourth quarter, indicating that these patterns reflect real investment expenditures from the perspective of the firm's financial accounts. Financial accounting applies economic depreciation for new investment, rather than the

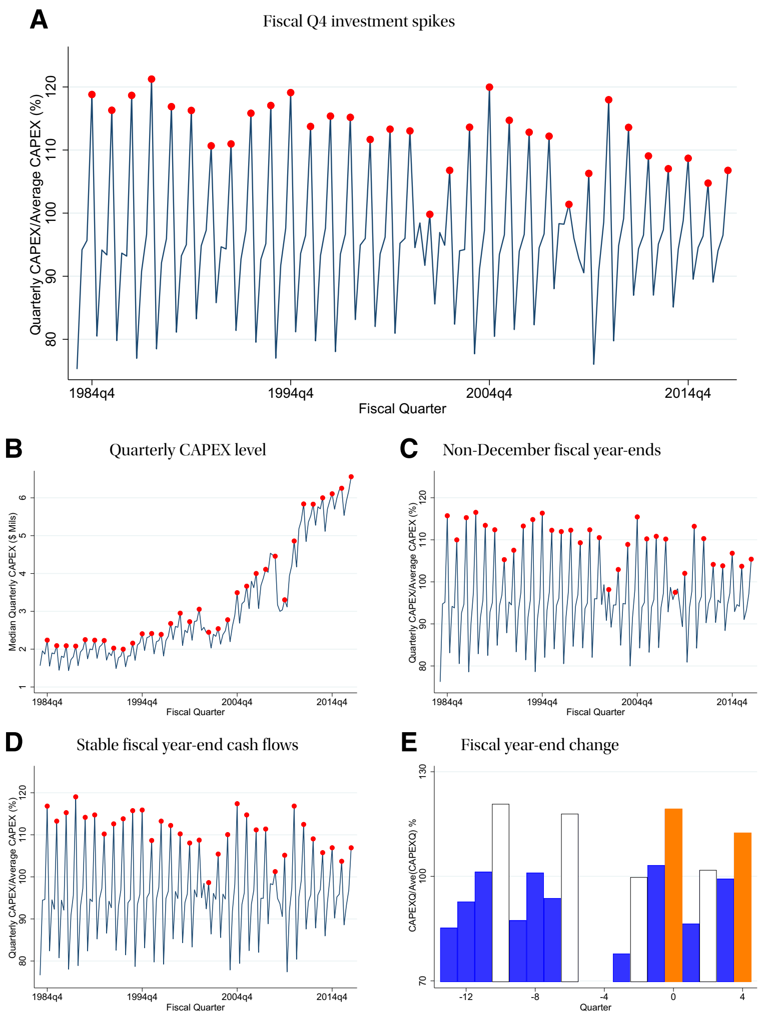

Figure 1
Time series of fiscal Q4 investment spikes (1984–2016)
This figure documents fiscal fourth-quarter (Q4) capital expenditure (CAPEX) spikes for U.S. firms in Compustat. Panel A plots the median ratio of quarterly CAPEX to the average CAPEX within a firm's fiscal year. Red dots represent Q4. Panel B plots the median quarterly CAPEX level ($M). Panel C plots the time-series pattern of Q4 CAPEX spikes for firms with non-December fiscal year-ends. Panel D plots the time series of Q4 CAPEX spikes for firms with stable fiscal year-end cash flows, defined as firm-years for which fiscal Q4 cash flows are lower than the average of the first three fiscal quarters. Panel E plots the time series of CAPEX for 81 sample firms that switched their fiscal year-ends to 6 months later. White bars represent the old regime, and orange bars represent the new regime.

Third, Figure 1, panel E, isolates firms that move their fiscal year-end to 6 months later. The *y*-axis measures the ratio of quarterly CAPEX to average CAPEX in a firm-year. White bars represent the fiscal year-end quarter according to the old regime, and orange bars represent the fiscal year-end quarter after switching. CAPEX spikes transition to the new fiscal Q4 after the switch. The consistency of this pattern before and after the fiscal year-end change clearly demonstrates that CAPEX spikes are indeed related to the fiscal year-end.

Investment expenditures are not the only cost that firms can manage near fiscal year-end for tax purposes. The IRS allows firms to deduct R&D expenditures in the tax year when incurred. Firms may also claim the R&D credit against taxes for certain qualified R&D expenditures and combine the credit as one component of the general business credit. Internet Appendix Figure IA.2 presents the time series of fiscal Q4 R&D spikes for U.S. firms in Compustat between 1989 and 2016. The fourth quarters consistently display higher R&D compared to the first three quarters, and the first fiscal quarter displays the lowest R&D within a year.[13]

Finally, we consider an international sample to show that fiscal Q4 CAPEX spikes occur nearly universally. For the period from 2004 to 2016, Figure 2 plots the time series of fiscal Q4 investment spikes. In each plot, fiscal Q4s are represented by red dots. We sort countries according to their average corporate income tax rate during the period—Switzerland has the lowest average corporate income tax rate (about 8%), while Pakistan has the highest (about 35%).

Across the 24 countries in Figure 2, we see fiscal Q4 CAPEX spikes throughout. Indonesia, China, and Mexico, among other countries, show the highest spikes, while the United Kingdom, Australia, New Zealand, and France show much lower spikes than average. Australia, New Zealand, and France use the effective life to calculate property depreciation. For example, for property placed in service in the last month of a fiscal year, a firm only gets to depreciate one-twelfth of the first year's depreciation amount for the current tax year. The effective life method significantly reduces the tax savings from fiscal year-end investment. In general, the evidence from the international data is remarkably consistent with the pattern that obtains in U.S. data. This suggests that factors more general than the specific U.S. institutional setting are responsible for Q4 CAPEX spikes.

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half-year convention that applies for tax depreciation. Spikes in book depreciation therefore indicate that spike expenditures are not just made on the last day of the fiscal year.

13 R&D is net of R&D-related salary and benefit expenses, which is calculated at the industry average according to the Business Research and Development and Innovation Survey (BRDIS), conducted by the National Science Foundation. We assume that salary and benefit expenses are flat over the four quarters in the same fiscal year. Fiscal Q4 R&D spikes are robust to including salary and benefit expenses. R&D spikes are smaller after 2001. We have confirmed that this change in R&D spikes is not due to adjustment of salary and benefit expenses in the R&D calculation, reporting frequency, or outsourcing and firms' foreign sales. We leave further investigation of R&D spikes to future research.

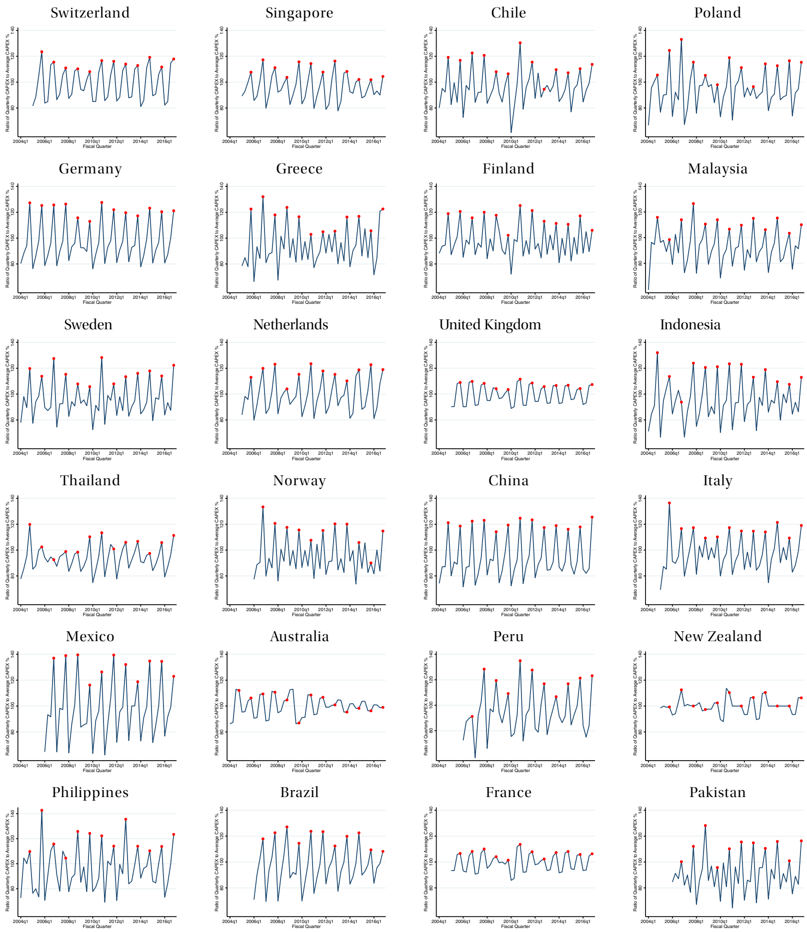

Figure 2
International evidence of fiscal Q4 spikes (2004-2016)
This figure shows fourth-quarter CAPEX spikes across country. Countries are sorted according to their average corporate income tax rate during the sample period: Switzerland has the lowest average corporate income tax rate (≈8%) while Pakistan has the highest (≈35%).

2.2 Investment spikes and tax position

To establish the causal link between tax minimization and Q4 investment spikes, we combine Q4 CAPEX spike data from Compustat with tax position data from corporate tax returns for the years 1993 through 2016. We follow Zwick and Mahon (2017) and define *D(taxable)* as an indicator for whether a firm has positive income before depreciation expense and thus an immediate incentive to offset taxable income with additional investment.

Figure 3, panel A, plots the relationship between Q4 spikes and a firm's tax position. We divide firm-years into $1,000 bins based on their taxable income before depreciation expense and plot the median Q4 CAPEX spike for each bin.

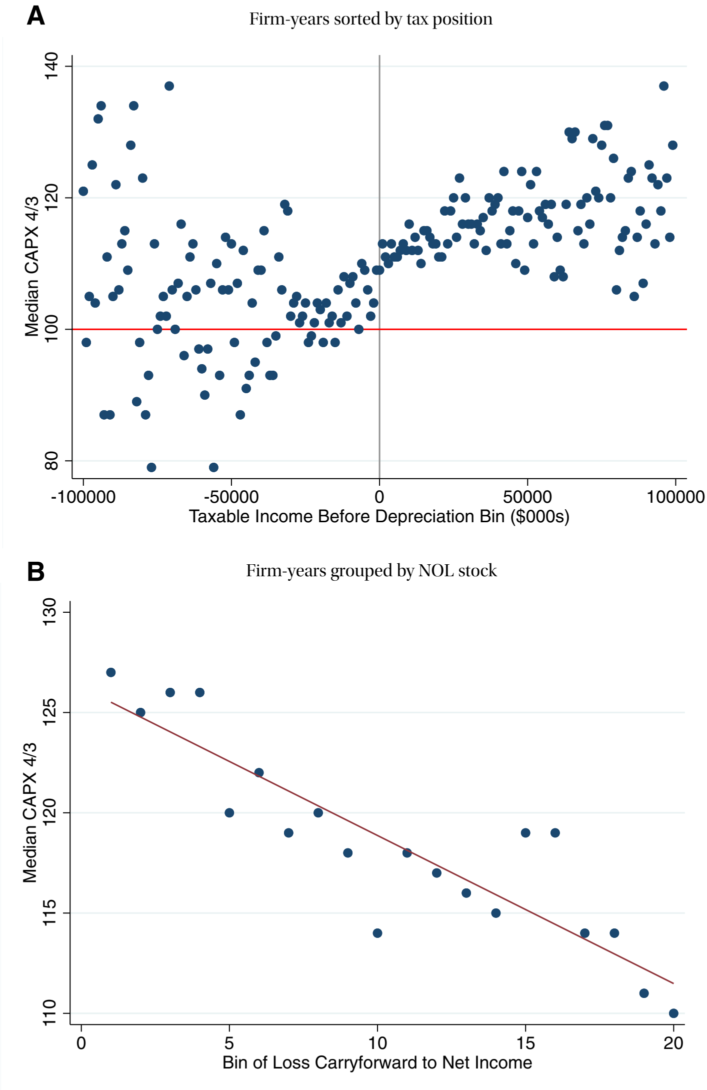

Figure 3
Fiscal Q4 spikes and tax incentives
This figure shows the relationship between fourth-quarter capital expenditure (CAPEX) spikes and firm-level incentives to use investment as a tax shield. Both figures identify a firm's tax position by combining CAPEX spike data from Compustat with tax position data from corporate tax returns for the years 1993 through 2016. In panel A, we divide firms into $1,000 bins based on their taxable income before depreciation expense is taken into account and plot for each bin the median ratio of fourth-fiscal-quarter CAPEX to the average CAPEX of the first three fiscal quarters. In panel B, we focus on firms with a positive tax position and group firms by the ratio of the stock of NOL carryforwards to net income before depreciation.

Table 3
Fiscal Q4 CAPEX spikes and tax status

A. Fiscal Q4 CAPEX spikes and tax status

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
D(taxable)	7.9***	6.9***	4.0***	12.4***	7.9***	7.0***	6.6***
	(1.1)	(1.1)	(1.2)	(2.8)	(2.8)	(1.3)	(1.4)
CAPEX/PPE		4.3***	4.1***		3.4*		5.2***
		(1.0)	(1.0)		(1.8)		(1.3)
EBITDA/Assets			28.2***				
			(4.1)				
Observations	69,779	67,259	67,185	22,597	21,742	47,182	45,517
R^2	.0901	.107	.109	.106	.131	.102	.113
Controls	No	1	2	No	1	No	1
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Period				Pre-2000	Pre-2000	Post-2000	Post-2000

B. Robustness

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
D(Taxable)	7.9***	7.4***	6.9***	7.5***	8.2***	8.3***	7.9***
	(1.1)	(1.1)	(1.1)	(1.5)	(1.4)	(1.4)	(1.7)
Sales 4/3			0.4***				0.4***
			(0.00)				(0.0)
Earnings surprise				4.7**			−1.7
				(2.3)			(2.6)
Lagged sales growth					−6.5***		2.3
					(1.8)		(2.2)
Lagged CAPEX growth						−11.7***	−12.7***
						(0.8)	(1.1)
Observations	69,779	68,054	67,259	40,790	45,237	45,456	27,856
R^2	.0901	.0987	.1074	.1163	.1095	.1177	.1438
Controls	No	3	3	3	3	3	3
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

This table presents regression estimates of firm Q4 CAPEX spikes on firm tax position by combining CAPEX spike data from Compustat with tax position data from corporate tax returns for the years 1993 through 2016. We follow Zwick and Mahon (2017) and define *D*(*taxable*) as an indicator for whether a firm has positive income before depreciation expense and thus an immediate incentive to offset taxable income with additional investment. All columns include firm and year fixed effects. Panel A, columns 2, 3, 5, and 7, includes the following controls: *ln*(*assets*), *Market-to-Book*, *Cash/Assets*, *CAPEX/PPE*, and *Sales 4/3*. Column 3 adds *EBITDA/Assets* as an additional control. Columns 4 and 5 are run using just the years 1993 through 2000, and columns 6 and 7 use the years from 2001 to 2016. Panel B examines the robustness of tax factors by adding alternative contributors to Q4 CAPEX spike step-by-step. The control variables in panel B include *ln*(*assets*), *Market-to-Book*, *Cash/Assets*, and *CAPEX/PPE*. Standard errors are clustered at the firm level. *$p<.1$; **$p<.05$; ***$p<.01$.

The results starkly confirm that a firm's immediate tax position is a first-order driver of Q4 spikes. To the right of zero, the median Q4 spike is approximately 120% and considerably above 100% for all bins. To the left of zero, the median spikes are centered around 100% with no clear pattern above or below.[14]

Table 3 presents regressions designed to capture the size and robustness of the tax position result. All regressions include firm and year fixed effects and

[14] The density of firm-year observations is relatively thin at levels below -\$50M, which accounts for the wider variance in within-bin medians. In addition, the density exhibits bunching around \$0, which precludes regression discontinuity analysis at this point.

thus measure spike responsiveness while only exploiting variation in a firm's tax position over time. Analyses of tax regimes and investment often suffer endogeneity issues, as variation in tax position often follows macroeconomic factors that could also affect investment. However, these endogeneity issues are more likely to affect investment levels. Since we focus on the timing of investment within a fiscal year, rather than investment levels, it is unlikely that shocks or growth opportunities that affect the level of investment would also systematically shift investment to one part of the fiscal year.

Table 3, column 1, shows that a positive tax position leads firms to spikes that are 7.9% higher than for nontaxable firms, which equals 24% of the within-sample spike of 32.6% (relative to 100%, or no Q4 spike). Column 2 adds the following controls: *ln*(*assets*), *Market-to-Book*, *Cash/Assets*, *CAPEX/PPE*, and *Sales 4/3*. Even controlling for the level of investment does not materially affect the tax position coefficient. Columns 4 through 7 show similar results in the pre-2000 and post-2000 samples.[15] Column 3 adds a measure of cash flow (*EBITDA/Assets*), which reduces the coefficient to 4.0%. As cash flows may reflect the intensity of a firm's tax position, this regression likely "overcontrols" for confounding factors, causing a downward bias in the tax position coefficient. The regression suggests an alternative interpretation of the sensitivity between investment and cash flows, which has been used in many studies going back to Fazzari, Hubbard, and Petersen (1988) to measure financial constraints. Such sensitivity may instead reflect tax minimization (see Appendix B).

Relative to prior work, we find somewhat stronger evidence on the impact of taxes on Q4 spikes. Callen, Livnat, and Ryan (1996) find a nonmonotonic relationship between spikes and effective tax rates, which is the primary measure Kinney and Trezevant (1993) use to attribute tax motives to firms. A nonmonotonic relationship is difficult to square with tax minimization but may also reflect measurement or systematic error in this variable, as both papers use financial statements to develop proxies for effective tax rates and NOL stocks. Our administrative data on firms' tax position help remove measurement error that might confound these analyses, leading to sharper results and additional tests presented in the next section.

In panel B of Table 3, we examine the robustness of our tax position results against several alternative factors that might also contribute to fiscal Q4 CAPEX spikes, including Q4 sales spikes, earnings management, and the growth paths of sales and CAPEX. We begin by showing the coefficient estimate on positive tax position indicators in column 1, and then add the following firm-level control variables: *ln*(*assets*), *Market-to-Book*, *Cash/Assets*, and *CAPEX/PPE* in column 2. In column 3, we separately add Q4 sales spikes, a pronounced feature of fiscal year-end seasonality. Controlling

[15] Internet Appendix Table IA.2 presents regression estimates with alternative Q4 spike measures and different censoring thresholds and delivers similar results.

for Q4 sales spikes only marginally decreases the estimate of the tax position. This is consistent with evidence presented in Section 2.1, where we show that Q4 investment spikes are still present for firms that do not display seasonality in sales (or cash flows).

Next, in column 4, we examine the connection between tax minimization and earnings management considerations. Given that expensing and depreciation affect book earnings, the effect of Q4 spikes on book earnings could provide incentives or disincentives for corporate investment, depending on a firm's book earnings position.[16] Nonetheless, controlling for earnings surprises does not change the effect coming from tax positions. Similar results are presented in columns 5 and 6 with the additional control of lagged sales and CAPEX growth. In column 7, we pool all measures and the coefficient estimates on tax position remain exactly the same as in column 1. The evidence presented in panel B demonstrates that while factors such as sales seasonality and earnings management might also contribute to Q4 investment spikes, they do not confound the tax effects identified in panel A.[17] We further examine budget cycles as an alternative driver of Q4 CAPEX spikes in Section 3.5.

When filing tax returns, firms can deduct net operating loss (NOL) carryforwards if they enter the tax year with past losses (see IRS publication 536). Because loss carryforwards serve as an alternative tax shield, a firm with a large stock of carryforwards has a weaker incentive to accelerate investment for a tax reduction. We examine this prediction in Figure 3, panel B. We focus on firms with a positive tax position and plot median Q4 CAPEX spikes for groups of firms sorted according to the ratio of lagged loss carryforward stock to current-year net income before depreciation. The figure shows a strong negative relationship between the presence of this alternative tax shield and the size of Q4 spikes.[18]

Internet Appendix Table IA.3 presents regression estimates and additional robustness checks for the relationship between NOL and Q4 CAPEX spikes. Firms are sorted into quintiles based on the ratio of lagged loss carryforward stock to current-year net income before depreciation. In these tests, we do not include firm fixed effects as NOL is a stock variable and highly persistent within our firm panel. Columns 1 and 2 show that quintile 1 (lowest NOL stock) has significantly higher Q4 CAPEX spikes than higher quintiles, consistent

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[16] Internet Appendix Figure IA.3 shows that firms meeting or beating their analyst forecasts have higher Q4 spikes on average, suggesting that earnings management and tax planning decisions are connected decisions.

[17] In subsequent tests, we have retained the control in column 3 but do not include the additional variables in columns 4–6. Because these variables do not appear to interact with the tax effects, the cost of limiting the sample appears to outweigh the benefit from including them.

[18] Note that firms with loss carryforwards may still have an incentive to accelerate investment and thereby save carryforwards for the future. Our point is that this incentive is weaker for these firms than for firms for which accelerating investment affects current taxes as well. Empirically, firms in all groups in Figure 3, panel B, have observed net operating loss (NOL) deductions below their potential deductions, leaving positive taxable income to be offset by depreciation deductions. Thus, most of these firms are likely in the position to trade off the tax consequences of additional investment against taking larger NOL deductions.

with firms in quintile 1 having limited NOLs to shield taxable income and hence a stronger incentive to accelerate investment. In columns 3 through 8, we add variables capturing potential alternatives that might contribute to fiscal year-end CAPEX spikes, including Q4 sales spikes, earnings management, and growth trajectories and additional firm charactersitic controls. These additional variables do not attenuate the effect of NOL stocks on Q4 CAPEX spikes.

3. Cross-Sectional and Dynamic Drivers of Investment Spikes

This section explores how different factors influence the magnitude of fiscal year-end investment spikes across and within firms over time. We focus on factors likely to influence intertemporal decision-making via the discount rate firms use to evaluate investment decisions. We investigate whether investment spikes only reflect high-frequency retiming of investment across fiscal quarters, as emphasized in Kinney and Trezevant (1993), or instead combine high-frequency and lower-frequency adjustments in the capital stock. We also explore the interaction between tax-minimizing investment and other patterns of corporate behavior, asking what role capital budgeting plays in determining Q4 spikes.

3.1 Earnings volatility

This section considers dynamic factors that influence a firm's decision to accelerate investment. We study firm characteristics that tend to increase the option value associated with retiming investment to minimize taxes and ask whether these factors do indeed contribute to higher Q4 spikes on average.

The option value motive suggests that investment spikes cluster in fiscal Q4 because tax positions can be better estimated close to fiscal year-end when most revenues and expenses for the year have been recorded. Figure 4, panels A and B, present binned scatterplots for firms sorted by the mean and volatility of earnings, measured by the within-firm mean and standard deviation of *EBITDA/Assets*. We also plot the share of observations with negative EBITDA and the share of EBITDA variance coming from negative EBITDA.

Firms with higher average profitability display higher Q4 spikes because they are less likely to enter a negative tax position. The relationship between spikes and profitability is positive over the first three deciles of within-firm profitability, which corresponds to the range over which firms often face losses, and then flattens. Interestingly, firms with higher volatility show lower Q4 spikes. This pattern can be reconciled by the fact that earnings variance comes disproportionately from large negative shocks to earnings. Tax code asymmetries imply that only positive surprises should be correlated with investment spikes.

Figure 4, panel C, provides evidence supporting the idea that spikes represent a firm's decision to realize a tax-minimizing option in response to a temporary positive earnings shock. We estimate local projections at the firm-year level,

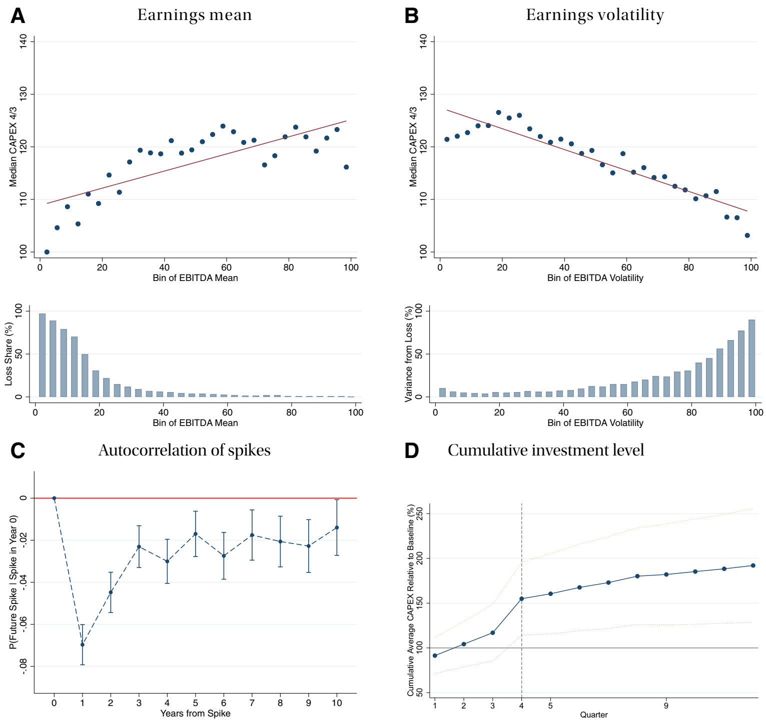

Figure 4
Cross-sectional and dynamic determinants of and cumulative investment after Q4 spikes
This figure documents the cross-sectional relationship between Q4 CAPEX spikes and earnings moments, measures the average autocorrelation of spikes, and explore whether Q4 spikes lead to short-term reversal of investment. Panels A and B plot median Q4 spikes against the mean and variance of *EBITDA/Assets*, respectively. We also plot the share of observations with negative EBITDA in panel A and the share of variance coming from negative EBITDA in panel B. In panel C, we estimate local projections at the firm-year level, regressing an indicator for a Q4 spike in a future year on an indicator for a Q4 spike in the current year. We include firm and year fixed effects to estimate the autocorrelation of spikes within firm over time. Panel D presents the cumulative level of investment after large Q4 spikes, defined as *CAPEX Q4/Ave(Q1-Q4)* exceeding 112.91% (the sample median). The baseline (denominator) is average quarterly CAPEX in the year before spikes (t from -3 to 0). Starting from quarter 1 of the spiking year ($t=1$), the numerator is calculated as the average quarterly CAPEX: CAPEX Q1 for quarter 1 ($t=1$), CAPEX $\frac{Q1+Q2}{2}$ for quarter 2 ($t=2$), CAPEX $\frac{Q1+Q2+Q3}{3}$ for quarter 3 ($t=3$), and so on. The dotted lines represent two standard deviations above and below the estimates.

regressing an indicator for a Q4 spike in a future year on an indicator for a Q4 spike in the current year. We include firm and year fixed effects to estimate the autocorrelation of spikes within-firm over time. The plot presents coefficients and standard errors from regressions for leads between 1 and 10 years. In the year following a spike, the probability of spiking falls by 7 percentage points, which corresponds to a 20% reduction in the probability that a firm spikes in the next year. This decline weakens to approximately zero over time but remains low for several additional years. This fact suggests that spikes do not reflect a fully planned, repetitive budgeting process, but instead a process with mean reversion and time variation in the value of spiking.

3.2 Investment spikes and financial constraints

Firms that face costly external finance should place a higher value on the tax savings associated with retiming investment, as they apply higher effective discount rates when trading off taxes paid this year versus in the future (Zwick and Mahon 2017). However, financial constraints limit the amount of extra investment firms are able to conduct near fiscal year-end, especially when financing is required to fund new investment. Thus, it is theoretically unclear how financial constraints affect the tax sensitivity of firms' investment spikes in fiscal Q4.[19]

To empirically test the impact of financial constraints on firms' Q4 investment spikes, we follow past literature and test this prediction by studying how tax-induced Q4 spikes vary among firms sorted according to five proxies for financial constraints: (1) *ln*(*assets*), where small firms are more constrained; (2) a nondividend payer dummy; and (3) a speculative-grade bond rating dummy. Following Faulkender and Petersen (2012), we also include (4) a dummy variable indicating CAPEX exceeding internal cash flow and (5) a dummy variable indicating CAPEX exceeding internal cash flow and not having an S&P rating.

Rather than studying the direct correlation between financial constraint measures and fiscal Q4 CAPEX spikes, which might be confounded by omitted factors, we interact the financial constraint measures with the time-series variation in Q4 spike incentives induced by the Tax Reform Act of 1986 (TRA86).[20] The high discount rate prediction suggests that the decrease in Q4 spikes following the tax change should be larger for financially constrained firms, whereas limited investment due to costly external financing suggests a smaller decrease for these firms. Table 4, columns 1 through 5, supports the former prediction: firms that are more constrained experience a larger drop in their Q4 spikes after 1987. The estimate in column 1 implies that firms in the top quartile of *ln*(*assets*) reduced Q4 spikes by 0.7 percentage points, whereas firms in the bottom quartile reduced Q4 spikes by 8.5 percentage points.[21] In columns 2 through 5, the effects are consistently at least 50% larger for firms more likely to face financial constraints based on alternative proxies, consistent with the discount rate effect.[22]

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19 This ambiguity is analogous to the result in Kaplan and Zingales (1997) that the cross-partial for investment-cash flow sensitivities with respect to changes in financial constraints cannot be signed without further assumptions (see equation (6) in their paper).

20 Appendix A provides the policy background and formally tests that TRA86 decreases Q4 spikes.

21 The top and bottom quartiles have mean *ln*(*assets*) equal to 8.39 and 3.45, respectively. Implied effects equal $13.96-1.58\times 8.39=0.70$ and $13.96-1.58\times 3.45=8.51$, respectively.

22 One implication of the tax-minimization incentive of firms' CAPEX spending for the study of financial constraints concerns the investment-cash flow sensitivity. We show in Appendix B that, in a decomposition

Table 4
Investment spikes and financial constraints

	(1)	(2)	(3)	(4)	(5)
D(84-87)	13.96***	3.67***	−1.38	3.61**	4.03***
	(3.80)	(1.39)	(2.12)	(1.59)	(1.41)
D(1984-1987)*ln(assets)	−1.58***				
	(0.61)				
D(1984-1987)*D(nondividend payer)		5.08**			
		(2.51)			
D(1984-1987)*D(speculative grade)			8.58**		
			(4.15)		
D(1984-1987)*Faulkender-Petersen I				4.84**	
				(2.18)	
D(1984-1987)*Faulkender-Petersen II					5.05**
					(2.32)
Observations	118,303	118,303	30,739	116,933	116,933
Adjusted R^2	.08	.08	.16	.08	.08
Controls	Yes	Yes	Yes	Yes	Yes
Year FE	No	No	No	No	No
Firm FE	Yes	Yes	Yes	Yes	Yes

This table presents regression estimates relating the magnitude of firm Q4 investment spikes to various proxies for financial constraints used in prior work: *ln*(*assets*), where small firms are more constrained, a nondividend payer dummy, a speculative-grade dummy, a dummy variable indicating CAPEX exceeding internal cash flow, and a dummy variable indicating CAPEX exceeding internal cash flow and not having an S&P rating (Faulkender and Petersen 2012). Columns 1 through 5 interact financial constraint proxies with tax policy changes around the Tax Reform Act of 1986. Control variables include *ln*(*assets*), *Market-to-Book*, *Cash/Assets*, *CAPEX/PPE*, and *Sales 4/3*. Firm fixed effects are included. Standard errors are clustered at the firm level. * $p<.1$; ** $p<.05$; *** $p<.01$.

3.3 The cumulative effect of investment spikes

To what extent do spikes reflect only high-frequency retiming of investment versus a longer-lasting cumulative change in the level of investment? Answering this question serves two purposes. The first is to address whether year-end spikes have longer-term implications beyond the quarter after a spike occurs. The second is to provide more evidence that spikes reflect time-varying opportunities for firms to offset tax bills associated with positive earnings shocks.

To answer the first question, Figure 4, panel D, plots the ratio of average quarterly CAPEX from the beginning of the spike year to the current quarter relative to a baseline in event time. The baseline is the average quarterly CAPEX in the year before the spike year. The sample includes firms with large spikes in fiscal Q4, defined as *CAPEX Q/Ave*(*Q1–Q4*) exceeding 113%, the sample median Q4 spike level. We follow average quarterly CAPEX relative to baseline up to 2 years after the spike year. Q4 spikers show a persistent and statistically significant increase in investment after the spike quarter, with the average investment level remaining at approximately 200% relative to the

across fiscal quarters, the fourth fiscal quarter displays sensitivities about twice as large as that of the first three quarters. This finding suggests that tax-minimization motives provide an alternative factor behind investment-cash flow sensitivity, since financial constraints alone cannot easily account for higher sensitivity in the fourth quarter.

baseline by the end of the post-period. The persistence suggests that high-frequency intertemporal shifting—for instance, if firms are just moving the timing of purchases a few weeks to receive tax benefits—cannot fully account for the higher level of investment in end-of-year CAPEX spikes.

Given we are now looking at the level of investment, we again explore firms' tax position to address the concern that omitted variables affecting the firm's investment opportunity set might confound interpretation. We use firms' tax position as a proxy for spike incentives and compare cumulative investment patterns for taxable versus nontaxable late-year spikers, restricting the sample to a narrow bandwidth around the tax-position threshold. Firms with positive tax positions face stronger tax-minimization motives relative to nontaxable firms, while confounds are likely more evenly distributed around this threshold. The goal is to measure how much cumulative investment occurs because firms face stronger tax motives, relative to the impact of other shocks to investment demand. If tax motives matter little for cumulative investment, then we should see no meaningful difference across firms in these tests.

We examine the CAPEX level from one year before to 3 years after large Q4 spikes, normalized by total capital (*PPENT*) in the year before spikes. All regressions include event and year fixed effects. Thus, the regressions compare within-event investment levels around large spikes, with the year before large spikes serving as the omitted benchmark. To isolate the role of tax factors, we interact the tests of cumulative investment levels around spikes with an indicator for whether a firm has positive income before depreciation. The sample only includes observations within $10 million of the tax position threshold.

Table 5 presents firm-level regression estimates to measure the increase in investment level for all Q4 spikers (columns 1 and 2), for nontaxable (columns 3 and 4) and taxable Q4 spikers (columns 5 and 6), and the differential responses between these two subgroups in a pooled regression (columns 7 and 8). Columns 2, 4, 6, and 8 add *Market-to-Book*, *Cash/Assets*, and *EBITDA/Assets* as additional controls to absorb the impact of time-varying firm characteristics and investment-opportunity shocks on investment levels. Both nontaxable spikers (columns 3 and 4) and taxable spikers (columns 5 and 6) display persistently higher investment levels compared with the prespike year. However, the increase in investment level is much stronger for taxable spikers, as demonstrated by the formal tests of the differential responses across these two subgroups in columns 7 and 8.[23] The results provide direct evidence that tax motives account for a quantitatively important share of the cumulative investment effects of spikes: the interaction coefficient indicates that immediate

[23] Internet Appendix Figure IA.5 presents estimates for the interaction term *D(Forward 3Y)*Taxable Spiker* in column 8 of Table 5 in samples with bandwidths ranging from zero to $50 million in $1 million increments. The estimated coefficients remain statistically positive and stable throughout.

Table 5
Investment after Q4 CAPEX spikes

	All		Nontaxable spikers		Taxable spikers		All	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
D(Spike Y)	0.062***	0.058***	0.045***	0.043***	0.071***	0.066***	0.046***	0.044***
	(0.005)	(0.005)	(0.008)	(0.008)	(0.006)	(0.006)	(0.008)	(0.008)
D(Forward 1Y)	0.140***	0.135***	0.111***	0.105***	0.154***	0.150***	0.114***	0.108***
	(0.008)	(0.007)	(0.013)	(0.013)	(0.009)	(0.009)	(0.012)	(0.012)
D(Forward 2Y)	0.169***	0.165***	0.130***	0.120***	0.188***	0.186***	0.137***	0.127***
	(0.010)	(0.010)	(0.017)	(0.016)	(0.012)	(0.012)	(0.015)	(0.014)
D(Forward 3Y)	0.206***	0.201***	0.169***	0.159***	0.222***	0.220***	0.179***	0.169***
	(0.012)	(0.012)	(0.019)	(0.019)	(0.016)	(0.015)	(0.018)	(0.018)
D(Spike Y)*							0.025***	0.022**
Taxable spiker							(0.009)	(0.009)
D(Forward 1Y)*							0.038***	0.041***
Taxable spiker							(0.014)	(0.013)
D(Forward 2Y)*							0.049***	0.056***
Taxable spiker							(0.016)	(0.016)
D(Forward 3Y)*							0.039*	0.047**
Taxable spiker							(0.020)	(0.020)
Observations	26,144	25,837	8,487	8,383	17,657	17,454	26,144	25,837
Adjusted R^2	.529	.541	.528	.549	.530	.539	.529	.542
Event FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls	No	Yes	No	Yes	No	Yes	No	Yes

This table examines the investment level around firm-years with large CAPEX spikes. The dependent variable is CAPEX divided by total capital level (*PPENT*) in the year before spikes. Dummy variables indicate the time period from the spiking year to 3 years after large spikes. The omitted benchmark year is the year before spikes. Columns 1 and 2 present pooled regressions. Columns 3-6 present results for spikers that differ in current-year tax incentives, by separating the spikers in the matched Compustat-tax data based on whether a firm has positive income before depreciation expense. Columns 7 and 8 present pooled regressions that compare taxable spikers to nontaxable spikers. We only include observations within $10M of the tax position threshold (Internet Appendix Figure IA.5 shows estimates are stable for different bandwidth choices). Spike event fixed effects and year fixed effects are included. Control variables include *Market-to-Book*, *Cash/Assets*, and *EBITDA/Assets*. Standard errors are clustered at the firm level. $^{*}p<.1$; $^{**}p<.05$; $^{***}p<.01$.

tax incentives increase investment level effects by 40% on average over the 3 post-spike years.

The analysis in Table 5 isolates a change in tax-minimization motives and demonstrates that firms with stronger tax motives display higher cumulative investment levels after spikes. This effect operates in addition to factors such as persistent productivity shocks that can account for the positive persistence of investment for nontaxable spikers, but not for the differential persistence when comparing taxable to nontaxable spikers. Nontax factors, such as use-it-or-lose-it budgets or earnings management, do not correlate with the effect of tax position on spike magnitudes (Table 3, panel B), which suggests these factors also cannot explain higher persistence for taxable spikers. We return to the role of tax factors for cumulative investment in the model, which allows us to more cleanly isolate how tax motives affect persistence after spikes.

We interpret these results as reflecting both the depreciation and option value motives. Firms that face a temporary opportunity to invest and reduce their tax burden will increase investment this year. Because investment is a long-lived asset, they may substitute investment from several years in the future, which results in persistent investment levels when cumulated over subsequent years. House and Shapiro (2008) apply this logic to understanding the response of long-lived investment to temporary investment incentives.[24] In our setting, it helps us understand why corporate investment appears to respond to time-varying tax incentives arising from the interaction of the low after-tax price and time-varying firm profitability. We explore this logic further in the context of the model in Section 4.

3.4 Evidence from bunching at depreciation kink points

In this section, we use the richness of the SOI corporate tax data to study the dynamic drivers of tax-minimizing investment behavior by small firms. Following Zwick and Mahon (2017), we examine bunching of eligible equipment investment at the Section 179 depreciation schedule threshold. This threshold, which rises gradually from \$17,500 in 1993 to \$500,000 in 2016, induces a kink in the after-tax price of investment. Consistent with tax-minimizing behavior, Zwick and Mahon (2017) document an excess mass of firms locating at the threshold, and they find bunching only occurs when firms receive the tax benefit immediately. We build on these findings by asking whether the dynamic and cross-sectional patterns that characterize Q4 CAPEX spikes also appear in a sample of bunchers.

The data set includes 2,091,829 observations, extending the analysis sample in Zwick and Mahon (2017) through 2016. We confirm that the bunching patterns observed in Zwick and Mahon (2017)—defined as having eligible investment within \$250 of the statutory threshold—arise in the extended data, including the asymmetry when firms are separated by tax position. We divide the sample into an *early* epoch and a *late* epoch because the statutory thresholds move over time and thus apply to firms of different sizes in each epoch.[25]

Figure 5, panels A and B, asks how bunching varies with firm-level profitability moments, which provides evidence analogous to the Q4 spike analysis in Figure 4. We plot the probability of bunching versus bins of the within-firm mean and variance of EBITDA/Assets, respectively. To make magnitudes comparable across early and late epochs, we scale all levels in percentage terms relative to the lowest bin. We also plot the share of observations with EBITDA losses and the share of EBITDA variance coming from losses.

The evidence from bunchers nicely mimics the pattern we observe for Q4 spikes. Bunchers in both the early and late epochs are more likely to have higher

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24 Regarding cumulative impacts, they write that "The fundamental value of the good…is unchanged by the transitory policy and, thus, investment returns to normal in the absence of the subsidy. This implication runs counter to the intuition that investment would be abnormally low immediately following expiration of the subsidy. While it is true that subsidized investment effectively substitutes for future investment, the reduction in future investment is spread out over a long period of time" (p.742).

25 During the early period (1993–2002), the threshold varied between \$17,500 and \$24,000. During the late period (2003–2016), the threshold varied between \$100,000 and \$500,000.

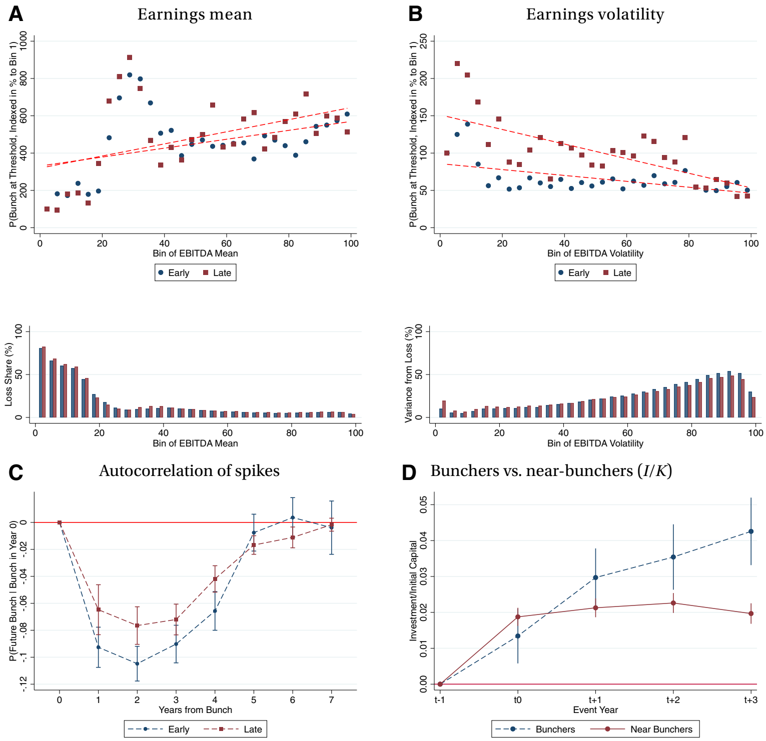

Figure 5

Cross-sectional and dynamic determinants of and cumulative investment after Section 179 bunching

This figure documents the cross-sectional relationship between investment bunching and earnings moments, measures the average autocorrelation of bunching, and explores whether bunching results in short-run reversal of investment. For this analysis, we use the SOI sample of private firms and examine bunching at the Section 179 depreciation schedule kink (following Zwick and Mahon (2017) with updated data through 2016). Above the kink, firms can no longer expense eligible investment and instead must follow the MACRS schedule for deductions. *Early* refers to the pre-2003 period when the bunch threshold varied between \$17,500 and \$24,000, and *Late* refers to the post-2003 period when the threshold varied between \$100,000 and \$500,000. Panels A and B plot the probability of bunching versus the within-firm mean and variance of *EBITDA/Assets*, respectively, scaled to 100 in the lowest bin. We also plot the share of observations with negative EBITDA and the share of variance coming from negative EBITDA. In panel C, we estimate local projections at the firm-year level, regressing an indicator for bunching in a future year on an indicator for bunching in the current year. We include firm and year fixed effects to estimate the autocorrelation within firm over time. Panel D presents investment level regressions for bunchers versus near-bunchers (defined as nonbunchers within $\pm\$2,500$ for the early period and within $\pm\$25,000$ for the later period) by plotting coefficient estimates and 95% confidence intervals based on analogous event-time regressions to those in columns 4 and 6 of Table 5.

profitability on average and less likely to have higher variance. As with the Q4 spike sample, low EBITDA firms in the bunching sample tend to be in loss most of the time, and high variance in EBITDA is driven by losses.[26]

[26] The bunching graph in panel A displays a nonmonotonicity between the 20th and 40th percentiles of mean profitability. This pattern reflects the excess mass of firms that consistently report zero taxable income, which has

Figure 5, panel C, explores the intertemporal nature of bunching behavior following the autocorrelation analysis of spikes in Figure 4, panel C. We estimate local projections at the firm-year level, regressing an indicator for bunching in a future year on an indicator for bunching in the current year. We include firm and year fixed effects to estimate the autocorrelation within firm over time. Bunchers exhibit a strikingly similar dynamic pattern to that of investment spikers. In the 3 years immediately following a bunching observation, the expected probability of bunching falls by 10 percentage points. The probability then gradually reverts to the mean by year five. We find similar patterns for both early-epoch and late-epoch bunchers. This result suggests that, as with Q4 investment spikes, the choice to bunch investment likely reflects an intertemporal trade-off margin operating with a frequency of several years.

As a final test, we return to the question of cumulative impacts after tax-minimizing investment behavior. Following the approach in Section 3.3, we compare bunching firms to a group of "near-bunchers" that invest in the neighborhood of the bunching threshold. If bunching behavior is followed by a substantial decrease in investment, this pattern would imply that bunching only reflects short-term retiming of investment. Alternatively, if investment levels in the year after bunching do not revert sharply, then the results point toward a mechanism with longer-term implications about how firms respond to taxes.

Figure 5, panel D, plots coefficient estimates and 95% confidence intervals for bunchers versus near-bunchers, defined as nonbunchers within $\pm\$2,500$ for the early epoch and within $\pm\$25,000$ for the later epoch. We obtain the estimates from analogous event-time regressions to those in columns 4 and 6 of Table 5. The results from the cumulative regressions suggest that investment rates do not reverse in the years immediately following a bunching observation. Instead, investment rates appear to continue growing in the following years and more strongly for the bunchers relative to the near-bunchers.

Taken together, the dynamic bunching evidence is remarkably consistent with what we see for Q4 spikes. While we focus the paper primarily on Q4 spikes, it is worth emphasizing that here we document similar patterns for a distinct tax-minimizing investment measure and using a different sample of firms. This fact points toward a general mechanism for modeling firm responses to the asymmetries in the tax code's treatment of investment.

3.5 Investment spikes and internal capital markets

An alternative explanation for the Q4 CAPEX spikes is related to firm budget cycles. Some firms have budgets that expire at the end of fiscal years and the accounts will be set lower if budgets are not spent. Those firms face a "use it or lose it" dilemma and are motivated to bring expenditures from the

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been documented previously. See, for example, Devereux, Liu, and Loretz (2014) and Coles et al. (2022). That the observed bunching behavior correlates with bunching at zero taxable income points to the role of investment decisions as part of a broader tax-minimization strategy.

following budget period to the present to prevent unspent funds from being lost (Callen, Livnat, and Ryan 1996; Libby and Lindsay 2010). Moreover, in some firms, evaluation of employee or manager performance might also be linked to budget spending, where more spending can be interpreted as better performance. These factors could create an incentive for firms to rush to spend budgets near the fiscal year-end.[27]

Because we cannot access firms' budget data, we focus on different measures of budgetary complexity and agency costs. If the rush in fiscal year-end CAPEX spending is true, then we would expect it to be more pronounced in firms with more complex budgetary structures where budgets across different divisions cannot be uniformly managed. Similarly, firms with lower executive ownership, which proxies for larger potential agency frictions, are expected to conduct more wasteful year-end spending driven by budget cycles.

We use three different measures to capture the complexity of a firm's budgetary structure: the number of segments, the number of two-digit SIC codes in the corporate segment, and the number of subsidiary layers. As a proxy for agency costs, we include the percentage of stock owned by top executives. Because complexity tends to increase with firm size and executive stock ownership tends to decrease with firm size, we condition on size to measure the impact of these factors within firm-size groups. The variation in these measures is mainly cross-sectional, so we average them across firm-years and then standardize the averages to aid interpretation.

Table 6 shows that firms with more complex budgetary structures do indeed display higher Q4 spikes: a one-standard-deviation increase in the complexity measures leads to a 1.4% to 3.7% increase in fiscal Q4 CAPEX spikes. In contrast, firms with higher share ownership among top executives display lower Q4 CAPEX spikes: a one-standard-deviation increase in top executive ownership results in a 2.7% drop in fiscal Q4 spikes.

The economic magnitudes of the effects in Table 6 are somewhat smaller than our estimated tax effects, but this finding may reflect our inability to measure budget and managerial incentives directly. We therefore interpret this result as suggesting that "use it or lose it" incentives likely contribute to spikes. To see whether such incentives can explain the responsiveness of spikes to tax changes, we investigate whether the tax sensitivity of spikes depends on "use it or lose it" motives. We estimate regressions as in Table 3 in subsamples with different levels of budgetary complexity and managerial incentives and present results in Internet Appendix Table IA.8. For each measure related to the budget hypothesis, high and low subgroups are defined as the top and bottom

27 Oyer (1998) connects seasonal sales patterns to year-end incentive contracts among salespeople and executives. Shin and Kim (2002) show that large, cash-rich, and diversified firms spend more CAPEX in Q4, suggesting agency costs in investment decisions. Similar year-end "rush to spend" behavior has been observed in other organizations. Liebman and Mahoney (2017) study spikes in year-end procurement spending for the U.S. federal government and show that expiring budgets lead to wasteful year-end spending, while an agency that has the ability to roll over the unfinished budget does not exhibit year-end spending spikes.

Table 6
Investment spikes and complicated firms: Use it or lose it?

	(1)	(2)	(3)	(4)
# Segments	2.3***			
	(0.3)			
# SIC2		1.5***		
		(0.3)		
# Layers			3.7***	
			(0.7)	
Exec own %				−2.7***
				(0.5)
Observations	102,256	102,239	23,215	34,941
Adjusted R^2	.02	.02	.02	.03
Controls	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

This table presents regression estimates relating firm Q4 investment spikes to measures of corporate budgetary complexity and managerial incentives. These measures include: (1) the number of segments; (2) the number of two-digit SIC codes in the corporate segments; (3) the number of subsidiary layers; and (4) the percentage of shares owned by top executives. Control variables include *ln*(*assets*), *Market-to-Book*, *Cash/Assets*, *CAPEX/PPE*, and *Sales 4/3*. The right-hand-side variables are standardized for ease of interpretation. Year fixed effects are included. Standard errors are clustered at the firm level. *$p < .1$; **$p < .05$; ***$p < .01$.

30% of the sample. The equality tests show that we do not find tax effects that differ meaningfully between the high and low groups. Overall, the evidence is consistent with the idea that strong tax incentives operate in addition to internal budget cycles.

We note a few additional reasons to be skeptical that internal budget cycles can explain our findings. Survey evidence on the importance of such cycles is mixed, with the majority of firms reporting that managers do not face hard constraints on investment spending (Burns and Walker 2009). In the absence of capital-rationing motives, most firms report that internal budgets are not hard constraints and that budgets are often adjusted to accommodate new projects. Managers apply to adjust their budgets and submit projects to traditional capital budgeting criteria, such as interest rate of return or net present value tests. If these tests model the tax consequences of investment decisions, they will tend to favor late-year purchases due to the depreciation motive we highlight. For some firms, internal budgets arise because of capital constraints at the firm level (Mukherjee and Hingorani 1999). However, we find that Q4 spikes coincide with increased borrowing (Internet Appendix Table IA.9), inconsistent with a capital-rationing story that would give rise to hard internal budgets.

The budget story also does not naturally explain our findings on the relation between spikes and earnings moments. If budgets bind tightly, then investment will not respond to unexpected shocks occurring after plans are set. A similar argument would imply that investment spikes should be unresponsive to shocks in the presence of tight internal budgets. Consistent with a role for flexible budgets, Lamont (2000) finds that, while investment plans are predictive for aggregate investment, unexpected investment contributes substantially to aggregate fluctuations and also responds strongly to unexpected profit shocks.

4. A Dynamic Model of Tax-Minimizing Investment

This section develops a dynamic model of investment in the presence of a tax motivation to accelerate investment. We examine how different factors influence the magnitude of fiscal year-end investment spikes, use counterfactuals to understand the role of taxes in post-spike cumulative investment persistence, and study the effect of tax policy shocks.

Beginning with a discrete-time neoclassical investment model with adjustment costs (Abel 1982; Hayashi 1982; Winberry 2021), we introduce predictable time variation in the value of the investment tax shield. We calibrate the model to match partial equilibrium investment moments quantitatively. We then apply the model to answer three questions. First, can a standard calibration deliver investment spikes like those observed in the data? Second, what is the relative importance of the depreciation motive and option value motive in accounting for the evidence, such as the correlation between spikes and earnings moments or the persistence of investment following spikes? Finally, can the model help us understand the responses of investment to tax policy changes?

4.1 Model

The model follows Winberry (2021), modified to include tax asymmetry, the half-year convention for depreciating current year investment, and four subperiods within a fiscal year.

4.1.1 Variables and parameters. Firms choose labor n and capital k to maximize profits. ε determines productivity, θ and ν are the output elasticity of capital and labor, and w is the wage. Investment i yields capital k, where δ is the rate of economic depreciation. Adjustment costs are convex with adjustment cost shifter ϕ.

Productivity shocks ξ have variance σ_ε^2 and productivity persistence is ρ. Profitability depends on productivity and an additional random term, ω, which has arrival probability λ and scale $\bar{\omega}$. The flow of gross operating surplus before depreciation is denoted GOS and its accumulated stock is denoted g. β is the quarterly discount factor.

The firm's tax bill depends on a linear tax rate τ. $\hat{\delta}$ is the tax depreciation rate; p is the constant market price of investment; $\hat{k}$ is the current depreciation stock; and $\bar{k}$ is the start-of-year depreciation stock carried over from last fiscal year. We use TI to denote taxable income.

4.1.2 Model setup. The labor choice is static, given by:

$$n(k,\varepsilon)=\underset{n}{\operatorname{argmax}}\left\{e^{\varepsilon}k^{\theta}n^{\nu}-wn\right\}=\left(\frac{\nu e^{\varepsilon}k^{\theta}}{w}\right)^{\frac{1}{1-\nu}}, \quad \theta+\nu<1.$$

Productivity evolves according to the AR(1) process:

$$\varepsilon = \rho\varepsilon_{-1} + \xi,$$

where the productivity shock is distributed $\xi \sim \mathcal{N}(0, \sigma_\varepsilon^2)$ and $|\rho| < 1$.

Capital evolves according to the law of motion $k' = (1-\delta)k + i$. Adjustment costs take the form $-\frac{\phi}{2}\left(\frac{i}{k}\right)^2 k$. The model abstracts from fixed costs to focus on the dynamics from a richer tax environment.

The profitability shifter ω provides a simple way to generate both a left-skewed distribution of profitability to fit the Compustat data and a significant mass of firms in a tax loss position to fit the tax data. This variable can be thought of as a random overhead fixed cost or an accounting adjustment, which creates the possibility that the firm experiences operating losses. Define the firm's gross operating surplus prior to depreciation deductions as:

$$GOS(k, \varepsilon, \omega) = e^{\varepsilon} k^{\theta} n(k, \varepsilon)^{\nu} - wn(k, \varepsilon) + \omega.$$

The firm's tax bill equals τ times taxable income, defined as g plus current GOS less depreciation deductions if taxable income is positive and zero otherwise: $TB = \tau \max\{TI, 0\}$. Tax asymmetries interact with the left-skewed profitability process, jointly determined by ε and ω, to generate rich investment dynamics both across and within firms over time.

Each fiscal year has four quarters: Q1, Q2, Q3, and Q4. For tax purposes, the firm accumulates quarterly realizations of GOS and investment expenditures, which jointly determine the firm's end-of-year tax position and reset after Q4. g evolves according to $g' = g + GOS(k, \varepsilon, \omega)$ in Q1 through Q3 and $g' = 0$ in Q4.

In the first three quarters, the firm faces no tax obligations, so its choice of investment only affects deductions made at the end of the year. Taxable income in all quarters is given by:

$$\text{(Q1–Q3)} \quad TI \equiv 0 \qquad\qquad \text{(Q4)} \quad TI \equiv (g + GOS) - 4\hat{\delta}\bar{k} - 2\hat{\delta}\left(\hat{k} - \bar{k} + pi\right).$$

Both depreciation stock variables are necessary because of the half-year convention, which treats depreciation stocks accumulated in the current year differently from those carried over from past years. The depreciation stock evolves based on the rules for deductibility during the fiscal year:[28]

$$\text{(Q1–Q3)} \quad \hat{k}' = \hat{k} + pi \qquad\qquad \text{(Q4)} \quad \hat{k}' = (1 - 4\hat{\delta})\bar{k} + (1 - 2\hat{\delta})(\hat{k} - \bar{k} + pi).$$

We can now write the recursive firm problem for each quarter. The firm's state variables are k, $\bar{k}$, $\hat{k}$, ε, ω, and g. The value functions in Q1-Q3 are defined

[28] For tractability, we do not model tax loss carryforwards or carrybacks across fiscal years, so deductions unused in a particular year are lost. As long as loss offsets are partial or occur with a delay, the incentive to use investment to reduce taxes will be stronger if the firm is currently taxable.

by the Bellman equation:

$$
\begin{aligned}
V^N(k,\hat{k},\bar{k},g,\varepsilon,\omega) = {} & GOS(k,\varepsilon,\omega) \\
& + \max_i \left\{ -pi - \frac{\phi}{2}\left(\frac{i}{k}\right)^2 k + \beta \mathbb{E}_{\varepsilon'|\varepsilon,\omega'} V^C(k',\hat{k}',\bar{k}',g',\varepsilon',\omega') \right\} \\
\text{s.t.} \quad & \hat{k}' = \hat{k} + pi \qquad k' = (1-\delta)k + i \qquad \bar{k}' = \bar{k} \\
& g' = g + GOS(k,\varepsilon,\omega) \qquad i \geq 0,
\end{aligned} \tag{1}
$$

where $V^C(\cdot) = V^N(\cdot)$ for Q1 and Q2 and $V^C(\cdot) = V^T(\cdot)$ for Q3, marking the transition to when taxes are determined and paid. The superscripts N and T, respectively, denote quarters without and with current tax payments. The value function in Q4 is defined by the Bellman equation:

$$
\begin{aligned}
V^T(k',\hat{k}',\bar{k}',g',\varepsilon',\omega') = {} & GOS(k',\varepsilon',\omega') \\
& + \max_{i'} \Big\{ -\tau \max\Big\{ g' + GOS(k',\varepsilon',\omega') - 4\hat{\delta}\bar{k}' \\
& -2\hat{\delta}\left(\hat{k}' - \bar{k}' + pi'\right), 0 \Big\} - pi' - \frac{\phi}{2}\left(\frac{i'}{k'}\right)^2 k' \\
& + \beta \mathbb{E}_{\varepsilon''|\varepsilon',\omega''} V^N(k'',\hat{k}'',\bar{k}'',g'',\varepsilon'',\omega'') \Big\} \\
\text{s.t.} \quad & \hat{k}'' = (1-4\hat{\delta})\bar{k}' + (1-2\hat{\delta})(\hat{k}' - \bar{k}' + pi') \\
& k'' = (1-\delta)k' + i' \qquad \bar{k}'' = \hat{k}'' \qquad g'' = 0 \qquad i' \geq 0.
\end{aligned} \tag{2}
$$

We note two differences between the Q1-to-Q3 value functions (1) and the Q4 value function (2). First, the investment decision affects current taxes in (2), but only affects future taxes in (1). As a result, the after-tax price of investment is effectively higher in (1). Second, the continuation values deterministically alternate between (1) in Q3 and (2) in Q4, such that firms know which problem they face in the next period and thus how uncertainty over their profitability will be resolved. These features combine to create an incentive to tilt investment toward the end of the fiscal year and especially into the last quarter.

We compare this full model to a baseline model in which depreciation deductions start whenever the investment is made, and in which even firms with losses receive tax credits for depreciation. In this case the firm's problem is identical each quarter and defined by the Bellman equation

$$\begin{aligned} V(k,\hat{k},\varepsilon,\omega) = &GOS(k,\varepsilon,\omega) \\ &+\max_i \Big\{ -\tau\Big[GOS(k,\varepsilon,\omega)-\hat{\delta}(\hat{k}+pi)\Big]-pi \\ &-\frac{\phi}{2}\left(\frac{i}{k}\right)^2 k+\beta\mathbb{E}_{\varepsilon'|\varepsilon,\omega'}V(k',\hat{k}',\varepsilon',\omega')\Big\} \\ \text{s.t.}\quad &\hat{k}'=(1-\hat{\delta})(\hat{k}+pi) \qquad k'=(1-\delta)k+i \qquad i\geq 0. \end{aligned} \tag{3}$$

The baseline model removes all "depreciation motives" driving spike behavior, including the tax asymmetry, the half-year convention, and the disconnect between when taxes net of depreciation deductions are due and when investment expenditures occur.

The value functions for the full model show how the incentive to use investment to minimize taxes is stronger at year-end because there is no uncertainty about the firm's tax position as a function of investment. We refer to this feature as the "option value" motive because firms have an incentive to wait and see how their tax position evolves during the fiscal year. If the year goes well, they can increase investment at year-end to minimize their remaining tax burden. If the year goes poorly and the firm's taxable income is already close to zero, they will have less reason to increase investment in the current fiscal year to reduce taxes.

The option value motive is not relevant when firms are always taxable. In this case, they face a similar problem every year. In the model with $\omega=0$ and under the standard calibration, firms rarely find themselves in a tax loss position. We therefore use an $\omega=0$ version to measure the relative importance of the option value motive versus the depreciation motive for spike levels and persistence.

Because the model abstracts from nontax drivers of investment spikes, such as use-it-or-lose-it budget constraints, the interpretation of our model's comparative statics does not depend on these potential alternative drivers of Q4 investment spikes. This abstraction allows us to focus on the importance of tax motives. However, we acknowledge this clarity comes at the expense of our quantitative estimates not being directly comparable to all aspects of the data.

4.2 Solution and calibration

We solve the model by value function iteration and then simulate investment and capital paths for 10,000 firms with different productivity shock paths over $T=500$ (see Appendix C for computational details). We choose the following parameters based on Winberry (2021): output elasticities $\nu=0.64$ and $\theta=0.21$, productivity persistence $\rho=0.9$, the standard deviation of productivity $\sigma_\varepsilon=0.08$, and convex adjustment costs $\phi=2.95$. We parametrize ω as a scaled Bernoulli variable with arrival probability of $\lambda=0.17$ and scale upon arrival of $\bar{\omega}=-0.5$, jointly chosen to match (1) the share of firms with negative gross operating surplus to the distribution of profitability in our Compustat data and (2) the share of firms with negative taxable income in Q4 to the distribution of tax losses in our tax data. In the Compustat data, the coefficient of variation for this variable is 1.8, while its simulated analogue (*GOS/Assets*) has coefficient of variation of 1.7. The simulation generates a nontaxable share of 30%, compared to 31% for our matched analysis sample.[29] When we simulate the model with $\omega=0$, the nontaxable share is approximately zero. Thus, our calibrated productivity process matches the underlying variance of earnings and taxable income better than the standard model in the literature.

We also follow Winberry (2021) and set economic depreciation $\delta=0.025$ per quarter and tax depreciation $\hat{\hat{\delta}}=0.119$ to match a 10% aggregate *CAPEX/Assets* ratio in the data and the statutory depreciation schedule, respectively. The standard deviation of annual investment relative to assets is 0.06 in the simulation compared to 0.13 in the data, likely reflecting the fact that the model does not feature the mix of long- and short-duration investment present in the data. The tax rate is $\tau=0.35$, the top statutory rate at the end of our sample.

Our choice of quarterly discount factor $\beta=0.975$ implies an annual discount factor of 0.904. The implied discount rate is reasonable from a weighted-average cost-of-capital perspective.[30] Given the centrality of this parameter for the response of firms to depreciation deductions (Summers 1987; House and Shapiro 2008; Zwick and Mahon 2017), we explore the sensitivity of spikes to changes in the discount rate. We also consider extensions that apply either a lower discount rate for depreciation deductions because of their lower perceived risk or a higher effective discount rate because inflation erodes their real value.[31]

4.3 Results

Figure 6, panel A, plots the ratio of average investment in each quarter to average investment in the whole year, indicating that the model is able to match the data's quantitatively large spikes at the end of the fiscal year. We plot results for three versions of the model following the parameterization above: a "Baseline" version without depreciation motives (as in (3)), a "Depreciation" version that adds depreciation motives but removes the profitability shifter from the model, and a "Full" version that reintroduces the profitability shifter and thereby the option value motive for spikes.

29 Relative to the 36% net operating loss share in Zwick (2021), the empirical nontaxable share is lower here because (1) it is computed before depreciation deductions and (2) it only includes public companies.

30 Gormsen and Huber (2023) report a mean perceived cost of capital among public firms based on conference call transcripts of 9% and a P5-P95 range of 5% to 12%.

31 One reason it may not make sense to apply the riskless rate to depreciation tax shields is that, given the possibility of tax losses, firms cannot rely on these deductions in all states of the world. Because they are more likely to have enough income to deduct depreciation in good times than bad times, a discount rate that retains some weight on the equity risk premium can make sense.

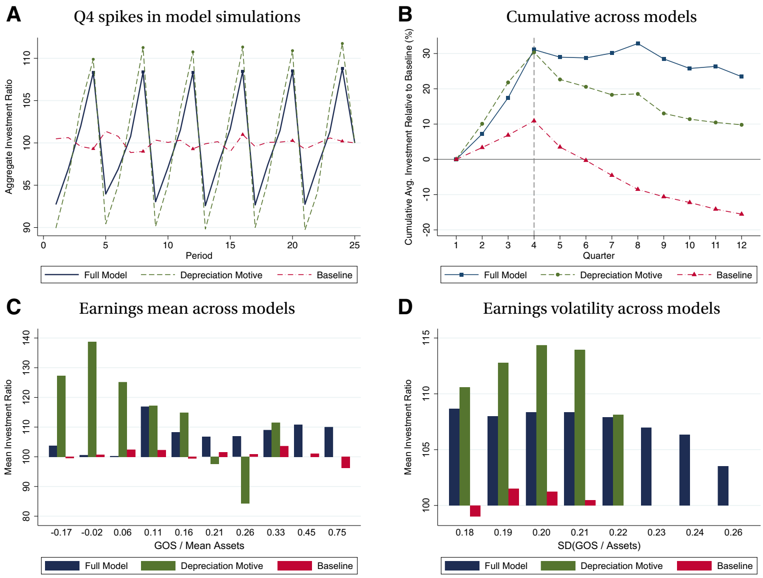

Figure 6
Depreciation versus option value motives in model simulations
This figure presents analysis of simulated data based on the model in Section 4. Panel A plots the ratio of average investment across all simulated firms in a given quarter to average investment across firms in the fiscal year. For the Depreciation Motive version of the model, we set the profitability shifter to zero. We compare the Full and Depreciation Motive models to a Baseline model in which depreciation deductions start whenever the investment is made and in which even firms with losses receive tax credits for depreciation. Panel B evaluates the cumulative investment effect following spikes while controlling for underlying productivity persistence. For each model version, we first sample 10 spike events for a representative simulated firm sequence and then order the data in event time relative to the spike. Spikes are defined as investment ratios (Q4 investment divided by Q1–Q4 average) greater than the sample median. For each event, we compute cumulative average investment beginning in Q1 of the spike year and scale this cumulative series by the average investment rate across all simulated quarters, which serves as a measure of benchmark investment within the model. We then regress scaled cumulative investment on event time dummies and plot the dummies, while controlling for productivity and the initial spike size (to account for differences in spike means across models). Panels C and D plot model analogues to Figure 4, panels A and B. For each model version, we sort firm-quarters using either *GOS/Mean Assets* or *SD*(*GOS/Assets*). We then calculate the deciles of *GOS/Mean Assets* and *SD*(*GOS/Assets*) for the Full version, and plot the mean investment ratio of firm-years within these deciles against average values of these GOS variables within the deciles.

The Depreciation model yields larger spikes than the Full model because of differences across the model in simulated tax positions. In particular, when $\omega=0$, firms almost never experience tax losses, as they are able to adjust variable inputs to offset the effect of negative productivity shocks. In contrast, approximately 30% of Full model firm-years experience tax losses, which attenuate the tax-minimization motive. Consistent with tax-policy-induced spikes, the Baseline model shows no systematic spike patterns.

We compute tax-policy-relevant comparative statics using model simulations after solving the model for different parameter values (Internet Appendix Table IA.10). The results confirm the basic intuition that spikes depend on the value of investment as a tax shield. This intuition emerges clearly upon comparing the firm problems between the first three quarters (1) and the last quarter (2). As the tax rate approaches zero, the decision problems converge. Thus, spikes are increasing in the tax rate and approach zero when the tax rate is low. Investment spikes are also increasing in the speed of tax depreciation for investment purchases. Investment spikes are larger in a version of the model that adds a nonrefundable 10% investment tax credit on top of accelerated depreciation.

Internet Appendix Figure IA.6 shows how aggregate spikes change when we only vary the discount rate for depreciation deductions.[32] When firms use lower discount rates to value depreciation deductions, their value as a tax shield increases and spikes become larger. Conversely, when inflation erodes the nominal value of deductions over time, spikes become smaller. In contrast to these results, the magnitude of investment spikes is increasing in the firm's overall discount rate (i.e., decreasing in β), shown in Internet Appendix Table IA.10. A higher discount rate reduces the net present value (NPV) of depreciation deductions but raises the option value of accelerating deductions from the future, while at the same time lowering the average level of investment through the standard user-cost channel. The net effect of these forces is an overall increase in Q4 spikes. This result confirms the empirical relationship between spikes and discount rates using different proxies for high discount rates (Table 4).

Figure 6, panel B, uses the three versions of the model to decompose the persistence of investment spikes into contributions from the depreciation versus option value motives. For each model version, we first sample 10 spike events for a representative simulated firm sequence and then order the data in event time relative to the spike. Spikes are defined as investment ratios (Q4 investment divided by Q1–Q4 average) greater than the sample median. For each event, we compute cumulative average investment beginning in Q1 of the spike year and scale this cumulative series by the average investment rate across all simulated quarters in that event's respective model version, which serves as a measure of benchmark investment within the model. We then regress scaled cumulative investment on event time dummies and control for productivity with indicators for each level of productivity. These controls remove the effect of productivity persistence from the model simulations. We also control for the size of the initial spike interacted with event time dummies to control for different mean spikes across model versions. The coefficient estimates in panel B capture the changes in investment level relative to Q1 within each model version.

Figure 6, panel B, plots the coefficients from these regressions for the Baseline, Depreciation, and Full models for the simulated firm events. For the

[32] To implement this comparative static, we add a drift term to the law of motion for depreciation deductions. This drift term adds 1.3% per quarter for the low discount rate scenario, chosen to implement an annual discount rate of 5%, and subtracts 2.5% for the inflation scenario, chosen to implement an inflation rate of 10%.

Depreciation and Full models, coefficients remain above zero and only partly reverse after the spike quarter. For the Baseline model, the coefficients decline quickly after the spike event and indicate short-run mean reversion. This pattern reflects the fact that spikes in the Baseline model, while rare, occur when the firm experiences a string of positive and increasing productivity shocks, which tend to reverse in subsequent periods. On average, both diminishing productivity following the shocks and the high level of investment from the spikes reduce investment in the subsequent quarters to below the Q1 level. In contrast to this pattern, both model versions with tax motives display cumulative investment effects in excess of that predicted by the underlying productivity process.

The Full model displays larger persistence of spike-year investment with a coefficient in period 12 of 23% compared to 10% for the Depreciation model and −16% for the Baseline model. The graph displays these results for one particular sample of firm events, so to demonstrate their robustness, we generate a distribution of cumulative effects by bootstrapping these coefficients over 1,000 iterations. The mean period-12 effect in the Full model is 29.4% (s.d.=4.1), which considerably exceeds the effects in the Depreciation model of 4.9% (s.d.=3.4) and in the Baseline model of −14.7% (s.d.=2.3). The Depreciation model delivers persistence of spike-level investment approximately halfway between the Baseline and Full models. The model therefore implies that the depreciation and option value motives each account for half of the post-spike persistence in investment in excess of that accounted for by underlying productivity persistence.

The model helps clarify the intuition for the persistence of investment following spikes. Part of the persistence reflects the underlying persistence of productivity shocks. However, productivity cannot account for the stronger persistence in the Full model versus the Baseline and Depreciation models. This fact reflects the increased option value of retiming investment when firms face a nontrivial risk of tax losses in future years. Baseline and Depreciation model firms do not face this risk, so investment spikes only reflect productivity shocks in the Baseline model and how productivity interacts with the time-varying, after-tax price of investment in the Depreciation model.

Table 7 uses a simple numerical example to illustrate how the tax structure affects the after-tax price of investment in the Depreciation model versus the Baseline model. We perform a discounted cash flow analysis at the quarterly frequency of a $100 investment using the parameterization in our model and choosing a gross return that delivers a 7% IRR in the Baseline model. We compare the returns to investments made in each fiscal quarter of the first year and model cash flows for 20 years. The table reports the NPV of profits from the investment, taxes paid on those profits, economic depreciation, and net income, and how these flows map into effective tax rates and IRRs.

In the Baseline model, investment timing does not influence the after-tax price of investment (proxied here by the effective tax rate on economic income),

Table 7
Effective tax rates by fiscal quarter (baseline vs. depreciation)

	Baseline				Depreciation			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Net present values for $100 investment								
a. Taxes	85.06	83.50	81.96	80.45	72.68	70.85	68.97	67.04
b. Profits	299.38	293.89	288.48	283.15	299.38	293.89	288.48	283.15
c. Economic depreciation	56.37	55.33	54.31	53.31	56.37	55.33	54.31	53.31
d. Net income (b-c)	243.02	238.56	234.17	229.84	243.02	238.56	234.17	229.84
Tax rate and internal rate of return								
e. Effective tax rate (%; a/d)	35.0	35.0	35.0	35.0	29.9	29.7	29.5	29.2
f. IRR (%)	7.0	7.0	7.0	7.0	8.6	8.8	9.1	9.4

This table uses a numerical calibration to demonstrate how the tax structure in the Depreciation model affects the after-tax price of investment relative to the Baseline model. We perform a discounted cash flow (DCF) analysis at the quarterly frequency of a $100 investment using the parameterization in our model and choosing a gross return that delivers a 7% internal rate of return (IRR) in the Baseline model. We compare the returns to investments made in each fiscal quarter of the first year and model cash flows for 20 years. The top panel reports the net present values (NPV) of profits from the investment, taxes paid on those profits, economic depreciation, and net income. The bottom panel reports effective tax rates, equal to the NPV of taxes divided by the NPV of gross profits less economic depreciation, and the IRR. In the Baseline model, investment timing does not influence the after-tax price of investment. In the Depreciation model, the effective tax rate falls and the IRR rises through the fiscal year, peaking in fiscal Q4. This comparison illustrates the incentive to tilt investment toward the later part of the year, as well as why increased investment levels in Q4 do not completely revert in Q1. See the replication package for the full DCF spreadsheet.

which is constant across quarters. In the Depreciation model, the effective tax rate falls monotonically through the fiscal year from 29.9% in Q1 to 29.2% in Q4 and the IRR rises from 8.6% to 9.4%.[33] This comparison illustrates the incentive to tilt investment toward the later part of the year, as well as why increased investment levels from Q4 spikes do not completely revert in the subsequent Q1. Even without the option value motive, a firm will invest more when the after-tax price is lower. This behavior will not fully crowd out investment in the subsequent quarters, which implies a partially persistent effect of investment spikes. The Full model layers the option value motive on top of this depreciation motive, because the higher return to investment depends on the firm's time-varying tax position. This force also contributes to the persistence of investment by inducing firms to retime investment from further in the future, such that cumulative investment declines more gradually relative to the Depreciation model. Overall, investment spikes persist because the fiscal year-end is a "good time" to invest when the returns to investment are high—in the Depreciation model, it is a good time because the price is low; in the Full model, it is a good time because the price is low *and* there is a nontrivial chance the price will be higher in the coming years.

Figure 6, panels C and D, compares the three models in terms of the mean and variance of profitability. The Full model successfully matches the relationship in the data for the within-firm earnings mean and variance. In the Depreciation model, these relationships are weaker or absent in the

33 Note the overall IRR is higher in the Depreciation model than in the Baseline model because tax depreciation is faster than economic depreciation. As a result, the optimal capital stock is higher in the Depreciation model.

Table 8
The effect of a corporate tax cut on investment in model simulations

A. Taxable model-simulated observations

	I/K pre (%)	I/K post (%)	Diff
No tax change	11.34	11.32	−0.02
Tax rate cut	11.11	11.68	0.57
Diff	−0.23	0.36	0.60
Semi-elasticity (% of I/K pre)			5.370
Tax term coefficient			−0.184

B. Nontaxable model-simulated observations

	I/K pre (%)	I/K post (%)	Diff
No tax change	7.79	7.56	−0.23
Tax rate cut	7.81	7.80	−0.01
Diff	0.02	0.24	0.22
Semi-elasticity (% of I/K pre)			2.818
Tax term coefficient			−0.068

This table presents simple difference-in-difference (DD) calculations from simulated data based on the model in Section 4. We produce a panel with 10,000 firms and 150 years of data. For the first 75 years, all firms are subject to a 35% corporate income tax rate; after that, half of the firms are subject to a 21% rate. We compare mean investment rates (I/K), defined as annual investment divided by pre-reform capital, in the 2 years before and 2 years after the tax change for these "Tax rate cut" firms versus the "No tax change" firms that do not receive the rate cut. We focus on the short-run response of investment rates to the tax change because investment rates in the model converge to the rate of economic depreciation in the longer run. We further divide firm-year observations based on whether their marginal investment decisions are likely to influence this year's tax bill. Taxable (nontaxable) firm-years are those with positive (weakly negative) total gross operating surplus after deducting tax depreciation for beginning-of-year capital. The tables also report a semi-elasticity—which rescales the DD estimate by the mean level of preshock investment rates for "Tax Rate Cut" firms—and a tax term elasticity—which rescales the DD estimate by the change in the tax term (i.e., $(1-\tau z)/(1-\tau)$ with $z=0.88$).

case of earnings volatility and of the wrong sign in the case of earnings means. Importantly, the Baseline model cannot match these relationships, which underscores the likely importance of tax asymmetries and immediate tax benefits in generating the empirical patterns we observe.

Table 8 uses the model to conduct a policy experiment in which we reduce the corporate tax rate from 35% to 21%, analogous to the corporate tax rate changes enacted by the Tax Cuts and Jobs Act of 2017. We produce a panel with 10,000 firms and 150 years of data. For the first 75 years, all firms are subject to a 35% corporate income tax rate; after that, half of the firms are subject to a 21% rate. We compare mean investment rates (I/K), defined as annual investment divided by pre-reform capital, in the 2 years before and 2 years after the tax change for these Tax Rate Cut firms versus the No Tax Change firms. We further divide firm-year observations based on whether their marginal investment decisions are likely to influence this year's tax bill.[34]

[34] We focus on the short-run response of investment rates to the tax change because investment rates in the model converge to the rate of economic depreciation in the longer run. Taxable (nontaxable) firm-years are those with positive (weakly negative) total gross operating surplus after deducting tax depreciation for beginning-of-year capital.

The tax cut leads to a substantial increase in investment rates in the post-reform period. Critically, the model reproduces the stylized fact that the responsiveness of investment to tax policy changes is stronger for firms that receive immediate tax benefits (Zwick and Mahon 2017). The semi-elasticity of investment rates with respect to the tax change is 5.37% for taxable firms versus 2.82% for nontaxable firms. The implied tax term elasticity, which scales the difference-in-differences estimate by the change in the tax term, is 63% ($=(0.184-0.068)/0.184$) smaller for the firm-years in loss position.

A strength of the model is that there are no other motives to spike at play (e.g., earnings management or use-it-or-lose-it budgets), which allows us to more cleanly isolate and explore how tax motives affect spike behavior. The comparison between our Baseline and Full model shows that observed spiking behavior is fully attributable to the tax motives in the model. Qualitative differences between the model and our empirical findings, for example, in the precise dynamics of cumulative investment effects, could reflect the impact on these patterns from nontax motives or modeling simplifications, such as abstracting from loss carryforwards or from more complex profitability shocks.

5. Implications of Tax-Minimizing Investment Behavior

5.1 Supply effects via inventories and capital goods prices

We now study the within-year spiking patterns for aggregate capital goods shipments, total inventories, and prices. The data come from the Manufacturers' Shipments, Inventories, and Orders (M3) survey from the Census Bureau (1958 to 2016) and the Producer Price Index (PPI) from the Bureau of Labor Statistics (1998 to 2016). Figure 7, panel A, presents the comparisons between nondefense capital goods shipments and consumer goods shipments. For nondefense capital goods, the month of January consistently has the lowest shipment value, approximately 85% of the level for the year on average. March, June, September, and December, commonly used as fiscal year-ends, display significantly higher shipment values compared to other months. The largest spikes occur in December at 112% and June at 110%, which correspond to the most common fiscal year-ends among firms in Compustat. Importantly, we do not observe similar patterns for consumer goods, where tax incentives do not play a role.

In Figure 7, panel B, we examine whether capital goods suppliers build up inventories in anticipation of higher demand in Q4 by tracing the co-movement between shipments and total inventories. The plot shows modest evidence of inventory buildup leading shipment spikes by approximately 1 month. Taking Q4 as an example, total inventories start to increase in October and peak in November in anticipation of the December shipment spike, then return to the average level in December. Overall, within-year variation of inventories is smaller than that for shipments, with the largest spikes shown in November

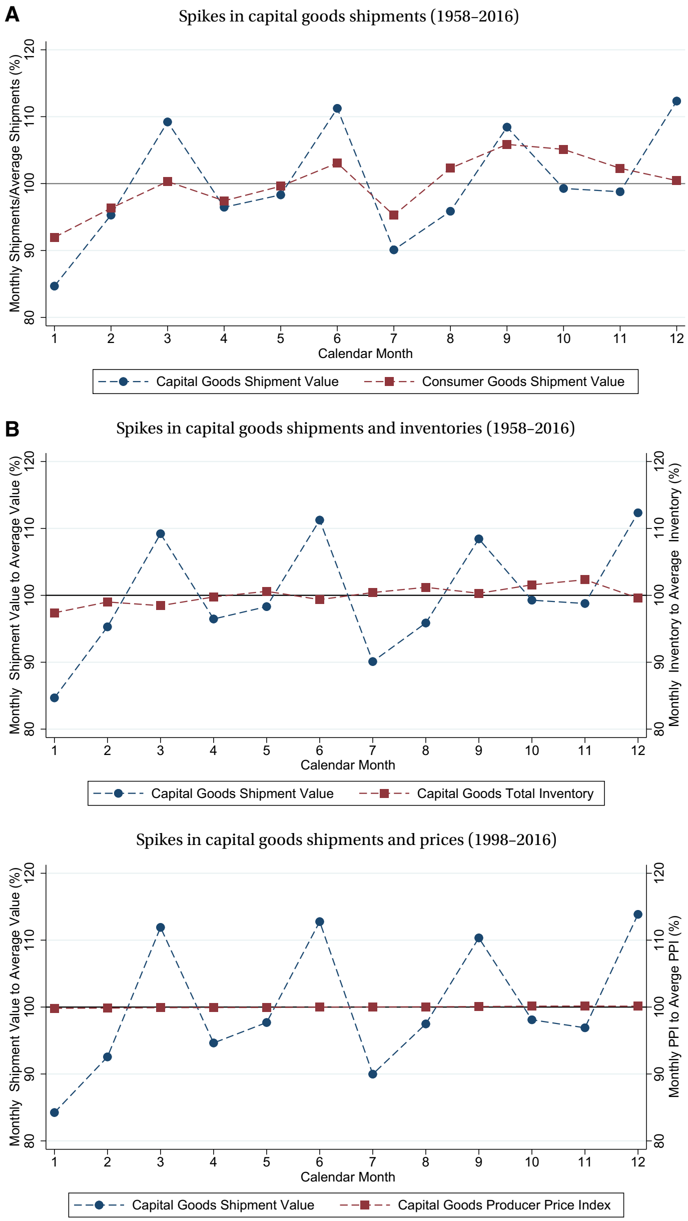

Figure 7
Spikes in capital goods shipments, inventories, and prices
This figure presents within-year seasonality of aggregate nondefense capital goods shipments, total inventories, and prices. Shipment and inventory data come from the Census Bureau's Manufacturers' Shipments, Inventories, and Orders (M3) survey of the domestic manufacturing sector. Capital goods price is measured by the Producer Price Index (PPI) provided by the Bureau of Labor Statistics, which records the selling prices received by domestic producers for their output at the NAICS6 level. PPI is linked to M3 using M3/NAICS-6 industry composition from the Census. Panel A presents shipments of nondefense capital goods and consumer goods. Panel B presents shipments and total inventories, and panel C presents shipments and prices for nondefense capital goods. For each variable, we compute the ratio of monthly value to the average monthly value within that month's calendar year.

Table 9
Spikes in capital goods shipments, inventories, and prices

	Shipment (%)		Lagged inventory (%)		PPI (%)		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Month 3/6/9/12	22.15***		2.38***		−0.02		
	(5.37)		(0.49)		(0.10)		
March		24.25***		2.29***		0.06	
		(4.57)		(0.73)		(0.24)	
June		22.63***		2.45***		0.05	
		(5.51)		(0.63)		(0.03)	
September		20.10***		2.37***		−0.11	
		(5.28)		(0.72)		(0.26)	
December		21.59***		2.41***		−0.08	
		(6.61)		(0.43)		(0.41)	
Shipments (%)							−0.00
							(0.00)
Observations	3,348	3,348	3,333	3,333	3,348	3,348	3,348
R^2	.36	.36	.07	.07	.01	.01	.01

This table presents regression estimates of the within-industry-year seasonality of capital goods shipments, inventories, and prices. The unit of observation is at the Industry-month level. For each variable, we compute the ratio of monthly value to the average monthly value within that month's calendar year. Standard errors are clustered at the industry level. $^{*}p<.1$; $^{**}p<.05$; $^{***}p<.01$.

at 102.3%. As for shipments, inventories are also lower in Q1, with January consistently displaying the lowest inventory value at 97.4%.

Figure 7, panel C, presents the within-year seasonality of shipments and capital goods prices measured by the PPI. The PPI records the selling prices received by domestic producers for their output and is linked to M3 using M3/NAICS-6 industry composition from the U.S. Census.[35] We aggregate PPI ratios across all 15 M3 categories weighted by the shipment value of each category. While shipments spike in March, June, September, and December, price indexes remain stable throughout the year. Thus, the spikes in sales and shipments are not associated with price fluctuations for capital goods.

Table 9 presents formal tests of the within-year seasonality captured in Figure 7 and the relation between capital goods shipments and prices. For each variable, we compute the ratio of the monthly value to the average monthly value within that month's calendar year to focus on within-year variation. In columns 1 and 2, the coefficient estimates on quarter-end months are above 20%, consistent with the large spikes in March, June, September, and December from Figure 7, panel A. Inventories show spikes 1 month earlier with smaller magnitudes (around 2%) in columns 3 and 4. In contrast, in columns 5 and 6 quarter-end months do not show significantly different price index levels. In column 7, we directly relate prices to shipment value and do not find shipment spikes to be associated with major price movements. Overall, the regression estimate from column 7 confirms the lack of correlation between

35 M3 nondefense capital goods include 27 categories, 15 of which can be matched to the PPI. This match corresponds to 40 NAICS-6 industries in total. PPI is set to be 100% in January 1998 as the baseline for each industry.

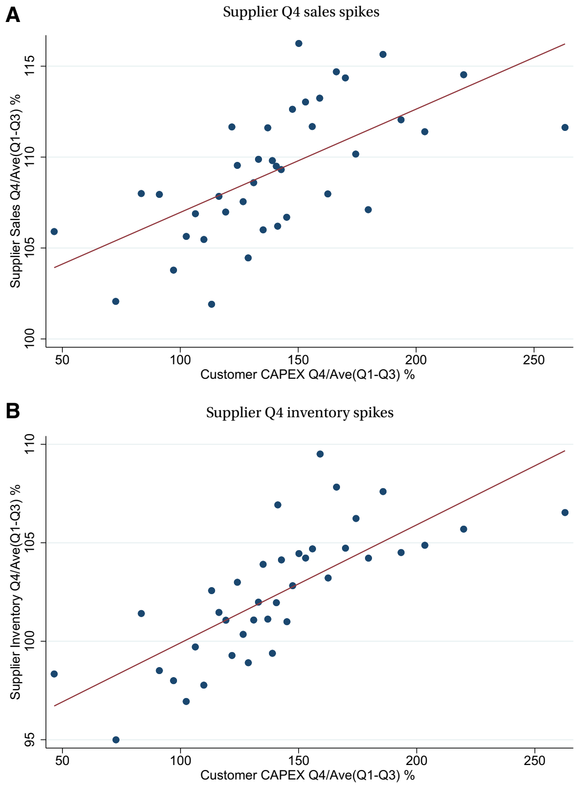

Figure 8
Supplier Q4 inventory and sales spikes
This figure shows the relationship between corporate customer Q4 CAPEX spikes and supplier Q4 sales and inventory spikes. Corporate customer information comes from the Compustat Segments Customer database, which records all customers that represent 10% or more of a firm's total sales with the names of the customers and their sales figures. We only use suppliers in manufacturing and business equipment industries in this figure.

aggregate shipments and prices in Figure 7. The result is also consistent with previous findings, such as in House and Shapiro (2008), that tax-induced capital investment does not change market prices (cf. Goolsbee 1998).

We develop complementary evidence from firm-level data that suppliers build up inventories in anticipation of Q4 sales spikes. The Compustat Customer Segments database records all customers that represent 10% or more of a supplier's total sales with the names of the customers and sales figures on a quarterly basis. To focus on depreciation-related capital investment, we narrow the suppliers to be within the manufacturing and business equipment industries (based on the Fama-French 12-industry classification).

Figure 8 plots corporate customer Q4 CAPEX spikes against supplier Q4 sales and inventory spikes. Customer Q4 CAPEX spikes are positively associated with supplier Q4 sales spikes in panel A, validating the major customer and supplier links. In panel B, we relate customer Q4 CAPEX spikes to supplier inventory movement. Suppliers that witness Q4 sales spikes increase inventory stocks in fiscal Q4 correspondingly. The documented firm-level pattern provides micro-level support for the macro-level correlation in Figure 7 and Table 9, where inventories anticipate shipment spikes.

Note that Q4 investment spikes might cause greater tax liabilities for suppliers, where the incremental taxable income is approximately the profit margin applied to the accelerated sales amount. On the other hand, the purchasing firms gain by accelerating depreciation deductions for the full sales amount. Therefore, the increase in suppliers' tax liability is likely smaller than the tax savings of purchasing firms, resulting in an overall reduction in tax payments when pooling suppliers and buyers (Kinney and Trezevant 1993). In addition, the lack of response in capital good prices (Figure 7; Table 9) suggests that price adjustments are unlikely to affect the total tax payments.

5.2 Supply effects via corporate borrowing

To further trace the impact of investment spikes in adjacent markets and confirm that investment spikes reflect real activity, we explore implications of Q4 spikes for lending and borrowing behavior. Figure 9, panel A, plots monthly overall new business volume based on the Equipment Leasing and Financing Association's Monthly Leasing and Finance Index (MLFI-25). This business primarily covers loans and leases to small businesses, which typically have fiscal year-ends in December. Each year, the month of December experiences significantly higher new business volume than previous months. For example, in 2018 new business volume ranges from $7 billion to $9 billion per month before December, and in December 2018 it increases sharply to around $13 billion. Similar December spikes can be seen throughout the entire decade of the sample.[36]

One might be concerned that lending-side unobservables are driving December spikes in new business volume. If for some reason lenders offer cheaper loans in December, then December lending spikes may not be surprising. To address this concern, we acquire RateWatch data, which tracks branch-level rates on a monthly basis for over 100,000 bank-branch locations representing banks with more than $100 million in assets. We focus on commercial equipment loans (below $250,000) and also include commercial real estate (at $1 million) and personal loans for comparison. For each loan type, the most populated maturity is used: 36 months for commercial equipment loans, 60 months for commercial real estate loans, and 36 months for personal loans.

Figure 9, panel B, presents within-year movements of loan interest rates (net of Treasury yields of like maturity) for commercial equipment, commercial

[36] Internet Appendix Table IA.9 confirms, as in Kinney and Trezevant (1993), that Q4 investment spikes coincide with new debt issuance in our sample.

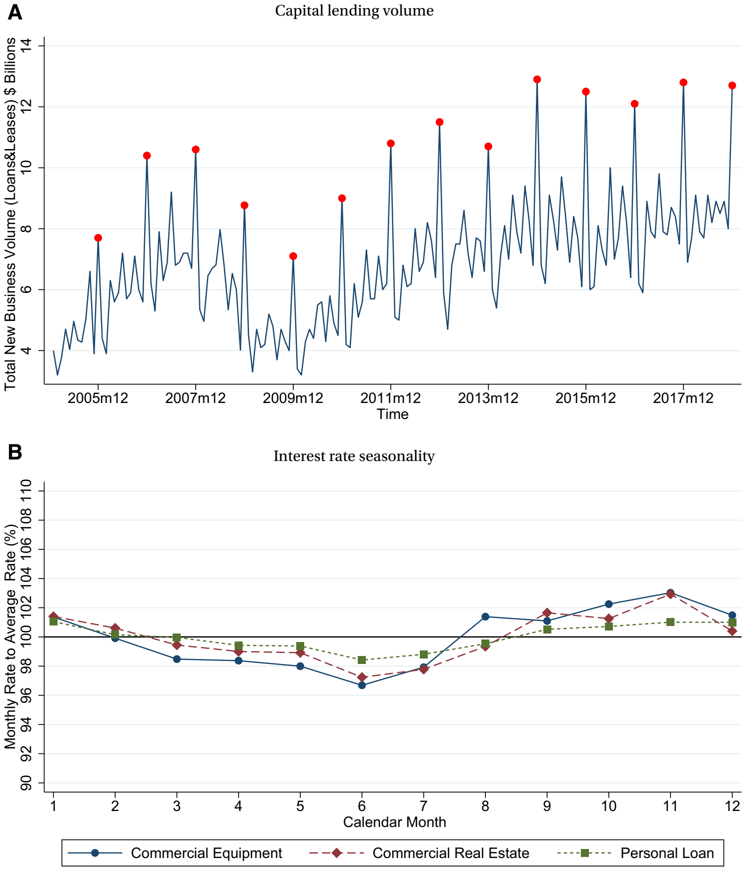

Figure 9
Capital lending volume and interest rate (2005–2018)
This figure presents within-year seasonality of capital financing volume and rates. Panel A plots monthly overall new business volume from the Equipment Leasing and Finance Association's (ELFA) Monthly Leasing and Finance Index (MLFI-25, available at http://www.elfaonline.org/data/MLFI). The MLFI-25 measures monthly commercial equipment lease and loan activity reported by participating ELFA member companies, which represent a cross section of the equipment finance sector. Red dots represent the month of December. Panel B presents the within-year seasonality of interest rates for commercial equipment (60 months), commercial real estate (60 months), and personal loans (36 months), respectively. The data come from RateWatch (part of S&P Global Market Intelligence) and track branch-level rates for over 75% of banks and credit unions in the United States. For each category, the interest rate is net of the Treasury rate of the same maturity. For each month, we take the median rate across all lenders and then compute the ratio of monthly rate to the average monthly rate within that month's calendar year.

real estate, and personal loans. Across these three different loan types, late spring and early summer (June and July) show the lowest interest rates within a year, whereas November and December show higher interest rates. On average, within-year movement is relatively modest: both the low and high ends are approximately half a standard deviation of the corresponding series (7.7%

for commercial equipment, 7.9% for commercial real estate, and 3.5% for personal loans).[37]

5.3 Interactions with fiscal stimulus policy

Promoting intertemporal substitution of investment from future years into the present is a central motivation for many fiscal stimulus policies. Our results suggest that regimes in which the option value motive is stronger are likely to display greater responsiveness to such policies. Such a mechanism can help us understand the observed responses to fiscal stimulus documented in House and Shapiro (2008) and Zwick and Mahon (2017), who study a temporary switch from a slower depreciation baseline to more accelerated expensing of investment purchases. In addition, the option value motive can help account for the higher responses both for firms likely to face liquidity constraints and for firms with sufficient taxable income to immediately draw deductions.

Our results have implications for the design of temporary fiscal stimulus policies. First, policy stimulus usually comes in weak economic times when firms may have insufficient taxable income or sufficient alternative tax shields in the form of NOL deductions. In the 2001 recession, policy makers introduced temporary bonus depreciation, which allowed firms to take additional deductions for eligible investment from 2001 to 2004. In our sample at the time, only 60% of firms had sufficient taxable income to benefit immediately from the policy change.[38] Thus, to the extent such stimulus policies do not provide purchase-year benefits, their impact will be mitigated by the tax-minimization motives we document.

Second, firms subject to the bonus depreciation policy in the early 2000s accumulated large NOL stocks to be used in future years. Thus, by the time the policy was reintroduced in 2008 to combat the next recession, nearly 50% of firms had sufficient NOLs to zero out their taxable income before taking depreciation into account. Policy makers therefore face trade-offs when deploying temporary investment incentives to target corporate investment. Such incentives may face "crowding out" by the impact of similar policies implemented in the past.

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[37] Although Ratewatch provides comprehensive coverage for U.S. lenders, one drawback is the lack of loan- and borrower-specific characteristics. In a related study of the seasonal variation of syndicated loans, Murfin and Petersen (2016) show late spring and fall to be the "sales" seasons for these loans after controlling for firm and loan characteristics. Firms borrowing during sales season issue at 19-basis-points cheaper than winter and summer borrowers (January/February and August). In particular, November and December do not belong to either sales season. In summary, both the survey evidence provided by the RateWatch data and the contract-level characteristics from Murfin and Petersen (2016) rule out lower interest rates attracting higher lending volume near the year end.

[38] Internet Appendix Figure IA.7 plots the share of firms in our matched Compustat-SOI sample who have potential to immediately benefit from depreciation deductions, given their net income and stock of NOL deductions.

6. Conclusion

This paper uses tax-minimizing investment behavior to study how taxes affect corporate investment more broadly. First, firms face a depreciation motive because purchases made later in the year face a lower effective after-tax price—firms making a fixed amount of investment are better off tilting that investment toward fiscal year-end than uniformly investing throughout the year. Second, firms face an option value motive—because tax positions can be better estimated close to fiscal year-end, investing near the fiscal year-end allows firms to maximize the tax benefit of depreciation. Tax-minimizing investment leads to robust and large spikes in fiscal Q4 CAPEX. Similar behavior occurs in many countries.

The analysis in this paper offers a rich portrait of the mechanism underlying tax-minimizing investment behavior. It is true that any model with an oscillating after-tax price of investment will produce investment spikes. However, the model we have presented further accounts for the additional cross-sectional and dynamic features of the data, and points to a specific way in which volatility matters for corporate investment. Tax asymmetry, time-varying shocks, and the structure of depreciation deductions jointly contribute to produce investment spikes that are larger for financially constrained firms and for firms more likely to find themselves in a taxable position. Our analysis suggests that financially constrained firms and those that value immediate liquidity may be particularly sensitive to tax policy changes. The results are consistent with models in which firms use high effective discount rates to evaluate investment decisions, in particular the after-tax costs of those investments. Models of corporate behavior without a first-year tax-minimization motive are unlikely to fit the patterns revealed in the data.

Tax asymmetry can also help account for the fact that the additional investment does not merely substitute for investment the firm would have made in the next period, but represents a cumulative increase in investment persisting for several periods. This persistence weakens considerably in a model in which firms are always taxable, even though productivity shocks are autocorrelated. The option to reduce the firm's tax bill in good times through intertemporal substitution thus improves the loss offset feature of the tax code, enabling the firm to use potential losses incurred from future investments to reduce current tax liabilities. At the same time, such a mechanism may induce procyclical investment behavior, as tax positions are strongly correlated with the macroeconomy.

Our findings show that tax incentives that directly target investment expenditures have pronounced effects on investment planning decisions for even the largest firms in the economy. These effects are particularly driven by how the code treats expenditures in the year of purchase. Policy makers may want to consider these factors as they debate the relative merits of proposals that lower corporate tax rates while slowing depreciation deductions versus proposals that accelerate depreciation deductions, such as in the cash-flow tax proposal of Auerbach (2010).[39] The model could be used to think about the relative importance of the half-year convention versus loss asymmetry for the implied investment distortions of the corporate income tax versus a cash-flow tax. Such an exercise would likely require engaging with how firms finance investment, given the different treatment of interest deductions in that proposal.

While this paper proposes a modification that improves the explanatory power of the benchmark microeconomic model of firm behavior, we address the macroeconomic effects of tax-minimizing investment only briefly. Perhaps such behavior can provide a concrete microfoundation for the accelerator model of aggregate investment. Another natural question is whether fiscal Q4 spikes help account for the patterns of lumpy investment highlighted by Caballero and Engel (1999) and Cooper and Haltiwanger (2006). We hope to explore these ideas in future work.

Code Availability: The replication code and data are available in the Harvard Dataverse at https://doi.org/10.7910/DVN/VTKPL8.

Appendix A. Tax Reform Act of 1986 and Q4 Investment Spikes

In this section, we study the effect of tax policy changes on investment spikes using TRA86, as in Kinney and Trezevant (1993). The United States passed TRA86, enacted October 22, 1986, to simplify the income tax code and broaden the corporate tax base. Three key changes affected corporate incentives regarding CAPEX spending.

First, TRA86 abolished the Investment Tax Credit (ITC).[40] The ITC generates reductions in tax liability as a percentage of the purchase price of investments and reduces tax liabilities dollar-for-dollar. The ITC is not refundable, and thus is valuable for a firm only if there is a tax liability.[41] Between 1979 and 1985, the ITC was set at 10% for spending on business capital equipment and special purpose structures, which was considerably more generous than first-year deductions for most investments. By targeting investment directly, the ITC creates a strong incentive for firms to retime investment as a tax planning strategy. Thus, removal of the ITC reduced the incentive to wait to fiscal year-end to make tax-minimizing investments.

Second, the corporate income tax rate for the top bracket decreased significantly after 1987: the top rate dropped from 46% over the 1984 to 1986 period to 40% in 1987 and 34% over the 1988 to 1992 period, then remained at 35% over 1993 to 2016.[42] The decrease in the corporate income tax rate further reduced the tax-minimization incentive of CAPEX spending, because for a given amount of CAPEX, the reduction in tax liability is lower when the tax rate is lower.

Third, the depreciation system switched from the Accelerated Cost Recovery System (ACRS) to the Modified Accelerated Cost Recovery System (MACRS) after 1987. In general, MACRS lengthens the recovery periods for property. For example, automobiles and trucks had a

[39] Batchelder (2017) discusses in detail how behavioral factors and financial frictions should enter into cost-benefit analysis of tax reform proposals.

[40] Starting with the Revenue Act of 1962, the ITC went through many rounds of major changes, including being suspended, reinstated, and eventually repealed in 1986.

[41] The safe-harbor leasing provision in the Economic Recovery Tax Act of 1981 allowed the sale of unused tax credits to firms with current tax liabilities, but it was eliminated at the end of 1983.

[42] Internet Appendix Table IA.4 provides details on corporate income tax changes from 1984 to 2016.

depreciation schedule of 3 years under ACRS but 5 years under MACRS; nontechnical office equipment had a depreciation schedule of 5 years under ACRS but 7 years under MACRS.[43] In addition, MACRS requires that firms use the mid-quarter convention if the total depreciable bases of MACRS property placed in service during the last 3 months of the tax year are more than 40% of the total MACRS property during the entire year.[44] For property placed in service during Q4, only 1.5 months of depreciation is allowed under the mid-quarter convention instead of 6 months of depreciation under the half-year convention.[45] The lengthening of depreciation periods and the mid-quarter convention requirement further reduced the incentive for tax-minimizing investment, as the same amount of investment leads to a smaller first-year depreciation deduction and lower initial tax savings after TRA86.

In sum, TRA86 repealed the ITC, decreased the top corporate income tax rate, and introduced the less generous MACRS for depreciation deductions. Each of these changes reduces the taxes saved given an amount of investment. The tax-minimization hypothesis thus predicts a weaker incentive to tilt investment toward the fiscal year-end and as a result smaller spikes. We illustrate the intuition by recalculating the tax benefit for the example in Table 1 under the effective tax rates and Investment Tax Credit regime before TRA 86. The comparison is presented in Internet Appendix Table IA.5. The higher tax rate and shortened recovery periods in the pre-TRA86 period raise the tax benefit by 38%, from \$2.04 to \$2.82. The investment tax credit has a larger effect, raising the benefit by an additional \$0.66 to \$3.48. Thus, the overall benefit to accelerating the investment increases by 70% with pre-TRA86 parameters.[46]

We formally test this prediction in regression form and present estimates in Internet Appendix Table IA.6. The coefficients of interest are on the dummy variable *D*(*1984-1987*), which indicates the corresponding years for the pre-TRA86 period in our sample and the phase-in year for the rate changes and ITC phase-out. Firm fixed effects are included to control for time-invariant firm characteristics. We also include firm financial characteristics, such as the level of *CAPEX/PPE*, *Sales 4/3*, *ln*(*assets*), *Market-to-Book*, and *Cash/Assets*, to control for the effect of contemporaneous nontax shocks.

Here, the identifying assumption is that in the absence of a change in tax motives to retime investment, we would not observe a difference before and after TRA86 in the share of investment taking place in fiscal Q4. This assumption is weaker than a common trends assumption, as it permits firm-by-time shocks that do not consistently coincide with the firm's fiscal year. Moreover, as shown in Section 2, two of the most likely alternative explanations—seasonality of cash flows and relabeling of investment purchases—cannot account for observed spike behavior.

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43 See IRS publication 534. ACRS set up a series of useful lives based on 3 years for technical equipment, 5 years for nontechnical office equipment, 10 years for industrial equipment, and 15 years for real property. MACRS lengthens the lives of property further for taxpayers covered by the alternative minimum tax (AMT).

44 This rule excludes nonresidential real property, residential rental property, any railroad grading or tunnel bore, property placed in service and disposed of in the same year, and property that is being depreciated under a method other than MACRS. In our data, 16% of firm-years have Q4 CAPEX in excess of 40% of total annual CAPEX.

45 A few factors make this 40% threshold less salient in the data. First, the threshold does not apply to structures or other property that is depreciated under a non-MACRS method, all of which are included in the CAPEX numbers in the financial statement. Second, the threshold does not apply to investments made by incorporated foreign subsidiaries, if the depreciation is instead taken overseas. The consolidated CAPEX in financial accounts includes both categories and may therefore overstate the investment spike relevant for domestic tax purposes. Third, the 40% threshold does not restrict "bonus" depreciation allowed under IRC Section 168(k), which will offset the lost depreciation from switching to mid-quarter for the residual, nonbonus investment basis.

46 Other tax policy parameters can also interact with investment to affect firms' tax liabilities. For example, during the past two recessions, U.S. policy makers introduced additional first-year (or "bonus") depreciation to stimulate investment and expanded the Section 179 provision, which allows small and medium-sized businesses to fully deduct the cost of eligible purchases during the year of purchase. The 2% effective subsidy across quarters in Table 1 is similar in magnitude to the subsidy from 50% bonus depreciation. Relative to the pre-TRA86 versus post-TRA86 comparison in Table 1, bonus depreciation only modestly inccreases the incentive to accelerate investment into fiscal Q4.

We run regressions for different time periods for robustness. Columns 1 and 2 show regression estimates for the period 1984 to 1992, as the corporate income tax rates after 1992 are slightly higher. Columns 3 and 4 show regression estimates for the period 1984 to 2000. Columns 5 and 6 present regression estimates for the full 1984 to 2016 period. In all six specifications, *D*(*1984-1987*) shows significantly higher fiscal Q4 spikes. On average, Q4 spikes drop by between 4.6 and 10.8 percentage points after TRA86, a large change relative to the mean Q4 spike of 36%. Columns 7 and 8 present regression estimates with the left-hand-side variable being a dummy variable indicating whether Q4 CAPEX is over the 40% threshold, which may trigger the mid-quarter convention requirement. The probability of firms passing the 40% threshold drops by between 1.6 and 4.4 percentage points, a modest but meaningful decrease relative to the 20.7% average before 1987.

Internet Appendix Figure IA.4 presents the dynamic response of Q4 spikes around TRA86 for the period 1984 to 2000. We estimate regressions using the same sample and controls as in Table IA.6, column 4, and plot the year effects and confidence bands. The year 2000 is omitted as the benchmark year. The plot reveals a sharp decrease in average Q4 spikes beginning in 1987, and Q4 spikes continue to fall through the transition period in 1988 and 1989.[47] In the decade following the transition, within-firm Q4 spikes are consistently lower than prior to TRA86. Compared to Kinney and Trezevant (1993), we have more post-TRA86 years to study, which reveal that the response of spikes to the reform did not converge until after the transition phase in the late 1980s.

Appendix B. Tax Minimization and Investment-Cash Flow Sensitivities

One implication of the tax-minimization incentive of firms' CAPEX spending for the study of financial constraints concerns the investment-cash flow sensitivity. A large literature in macroeconomics and finance examines how firm investment responds to changes in cash flow. The idea is that if firms rely more on internal funding for investment and hence are more financially constrained, their investment should display larger sensitivities to cash flow. Our paper provides an alternative explanation for investment-cash flow sensitivities—firms experiencing higher cash flows, which tend to correspond to higher taxable incomes, might invest more due to tax minimization. This argument resonates especially in the case of one-time or low-persistence shocks to cash flows and would hold even if cash flow shocks were uncorrelated with other drivers of investment, as long as those shocks come in pretax dollars.

To explore this idea, we decompose the conventional investment-cash flow sensitivity into different fiscal quarters and present the results in Internet Appendix Table IA.7. To facilitate comparison with past work, in column 1 we replicate the annual investment-cash flow sensitivity analysis by showing that a firm's CAPEX is positively related to its cash flow after controlling for Tobin's q. As is standard, both firm and year fixed effects are included to isolate the within-firm sensitivity. In columns 2 and 3, we decompose annual CAPEX into four quarters and run the same regressions but with cash flow interacted with dummy variables indicating different fiscal quarters. Column 2 interacts a fiscal Q4 dummy with *Cash Flow/Assets*. Column 3 interacts dummies for each fiscal quarter with *Cash Flow/Assets*. While the investment-cash flow sensitivity remains positive with a smaller magnitude, the fourth fiscal quarter displays sensitivities about twice as large as that of the first three quarters. A financial constraint hypothesis alone cannot account for the sudden spike in sensitivity—is the fourth quarter more financially constrained than the first three?—but the tax-minimization hypothesis offers a natural explanation.

47 During the transition, the corporate tax rate was higher for some firms with fiscal years ending in 1988 and the ITC was still available for some asset classes through 1989. In addition, Maydew (1997) documents income shifting immediately following TRA86 for public firms seeking to maximize NOL carrybacks, which may produce some post-TRA86 investment spikes. See also Kinney and Trezevant (1993) and Beatty, Riffe, and Welch (1997) for evidence on investment timing responses to TRA86.

Appendix C. Computational Details

We discretize the six state variables of the model with 94 grid points for k, 56 for $\hat{k}$, 56 for $\bar{k}$, 90 for g, 7 for ε, and 2 for ω, which results in 371 million grid points.

We center the grid near the steady-state level of capital implied by the model k_{ss} and set a minimum k at 0.9 $\times k_{ss}$ and a maximum at 3.3 $\times k_{ss}$. Grid points are evenly spaced between these points. Faster tax depreciation means that we can use a smaller grid for $\hat{k}$ and $\bar{k}$. Here, the maximum and minimum are set at 0 and 1.8, respectively. These scalings guarantee that the capital choice never hits the grid's limits, and the results are not sensitive to extending the grid above or below these points.

The AR(1) productivity grid is matched via Tauchen's method and the Bernoulli profitability grid is calibrated to match empirical tax loss moments, as described in the text.

The Full model in the paper uses substantial computational resources. On the university's high performance computing cluster, we solve the parallelized model across 120 cores with 15 gigabytes of memory per core, and it takes approximately 5 days to converge.

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