Tax Policy and Maintenance Behavior

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March 19, 2025

The user cost of capital mediates the transmission of business taxes to capital accumulation, wages, and output. This paper highlights how an overlooked component of user cost—capital maintenance—fundamentally alters the transmission of tax policy to aggregate outcomes in two ways. First, tax-deductibility of maintenance attenuates the tax elasticity of capital to a degree determined by the maintenance share of user cost. Second, tax cuts induce firms to substitute investment for maintenance, which causes depreciation to rise. The substitution between maintenance and investment is second-order for capital and output, but it implies that the tax elasticity of investment is strictly larger than that of capital. Consequently, standard estimates of the tax elasticity of investment are uninformative about aggregate outcomes without knowing maintenance demand. Drawing on unique microdata from Class I freight railroads and an industry-level sample of corporate tax returns, I estimate a price elasticity of maintenance demand of approximately two, with maintenance expenditures rivaling gross investment in magnitude. In a quantitative exercise, I find that the 2017 Tax Cuts and Jobs Act increased corporate capital by 2% after ten years—just 40% of the benchmark neoclassical prediction. That translates into a difference of about $600B worth of corporate capital.

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1 Introduction

Governments often undertake business tax reforms with two main goals: to stimulate short-run economic activity and to promote long-run growth (Romer and Romer 2010). For example, President Kennedy introduced accelerated tax depreciation and an investment tax credit to "stimulate the investment needed for sustained expansion and longer-run growth," a motivation echoed by the architects of the 2017 Tax Cuts and Jobs Act (CEA 2018). These reforms are grounded in workhorse models of investment, in which tax cuts reudce the user cost of capital. This reduction spurs investment, leading to capital deepening and increased output. Despite six decades of declining business tax burdens and extensive empirical evidence indicating strong investment responses to tax cuts (Hassett and Hubbard 2002; Zwick and Mahon 2017; Hartley, Hassett, and Rauh 2025), the evidence for corresponding effects on growth remains mixed.[1] This is difficult to reconcile with benchmark tax policy models, which typically imply that the tax elasticity of investment is equal to the tax elasticity of capital.

This paper links theory and data to show how a distortion in the tax code creates a wedge in the otherwise clear causal chain from tax cut to investment to capital deepening and dampens the effects of tax reforms despite robust investment responses to tax policy. In principle, the capital stock can be altered endogenously by new investment or by the choice to maintain existing capital. Because maintenance is fully tax-deductible whereas investment is not, the choice to maintain or invest in capital is distorted by tax policy, something which most of the public finance literature abstracts from (Hall and Jorgenson 1967; Chodorow-Reich et al. 2023). The result is a distorted cost of capital which responds considerably less to tax policy than workhorse public finance models imply, as well as an endogenous response of depreciation to tax reform. Using new data and a regression disciplined by the model, I find evidence that maintenance—and hence depreciation—is similar in magnitude to gross investment and responds endogenously to tax cuts. As a result, tax reforms like the 2017 Tax Cuts and Jobs Act, which cut corporate tax rates considerably, have a much smaller counterfactual response than predicted by workhorse public finance models.

Model. I begin by extending the standard neoclassical model following McGrattan and Schmitz Jr. (1999) to account for the fact that economic depreciation depends on main-

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1. In a meta-analysis of the effects of corporate taxes on growth, Gechert and Heimberger (2022) find a null effect, something which corresponds with the cross-sectional findings in Gale, Krupkin, and Rueben (2015) and Suárez Serrato and Zidar (2018). On the other hand, SVAR evidence from Mertens and Ravn (2013) points to strong evidence of growth effects.

tenance. In reality, firms invest not only in new capital but also in maintaining existing capital to prolong its useful life. Because maintenance and new investment are taxed differently, this modification leads to two important changes in the model's equilibrium conditions.

First, the user cost of capital now includes an extra term representing maintenance expenses. In practical terms, this means that a firm purchasing a car expects to spend some fraction of the vehicle's value on oil changes, repairs, tire rotations, and so on. However, since the return on capital is taxed net of maintenance, the result is a tax shield effect. The tax elasticity of user cost—and hence of capital and output—is given a haircut by the share of maintenance relative to the rest of user cost. In the limiting case with no depreciation and no discounting, tax policy would have no effect on capital accumulation because the only cost would be tax-exempt maintenance. This implies that, all else equal, longer-lived capital is less responsive to tax changes than short-lived capital. That adds nuance to House ([2014]) and Winberry ([2021]), which both show that long-lived capital should be considerably more price-elastic than short-lived capital.

The second change is an additional equilibrium condition relating the marginal benefit of maintenance—marginally less depreciation—to its marginal cost, which is a foregone unit of new investment. Policy creates a tax wedge in the decision to maintain or invest at the margin, which induces firms to overmaintain capital to a degree determined by the depreciation technology. Since maintenance is inextricable from depreciation, tax cuts result in higher depreciation as maintenance declines. I show that the input substitution effect, which is emphasized by McGrattan and Schmitz Jr. ([1999]), is second-order for capital accumulation and output. That follows from the fact that both maintenance and depreciation rates are components of the cost of capital and tax cuts induce them to move against each other.[2]

Despite being second order for output, the substitution effect has first-order implications for investment. In the standard model, the tax elasticity of investment is equal to the tax elasticity of capital. That remains true in my model as long as the demand for maintenance is inelastic. However, if maintenance demand has any curvature, then the tax elasticity of investment is equal to the sum of the elasticities of capital and depreciation. That creates a problem for standard empirical and quantitative analyses of tax

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2. Some papers model depreciation as a function of capacity utilization in addition to maintenance (Kabir, Tan, and Vardishvili [2024]; Boucekkine, Fabbri, and Gozzi [2010]; Albonico, Kalyvitis, and Pappa [2014]). If there is a non-zero cross-elasticity between maintenance and utilization, then tax cuts directly affect depreciation through maintenance and indirectly through the cross-partial between maintenance and investment. In other contexts, that cross-partial is important. However, since the input substitution effect is second-order for the aggregate effects of tax policy, I ignore utilization because it would require modeling and estimating indirect effects of indirect effects on capital accumulation.

reforms. Typically, we only observe investment and infer capital from that, which is the determinant of how output and wages respond to tax cuts. As a result, often infer the macroeconomic consequences of tax reforms by relating investment to a model-based measure of investment demand (Summers 1981; Zwick and Mahon 2017; Chodorow-Reich et al. 2023). Theory implies that this procedure is problematic for two reasons. First, investment elasticities are biased downward by a failure to account for maintenance. Second, because maintenance demand is elastic, there not a one-to-one correspondence between investment and capital, so we cannot make a conclusion about the effects of the reform on macroeconomic variables based solely on the investment elasticity unless we know the demand for maintenance as well.

Empirical Analysis. With a constant elasticity depreciation technology, the model implies a simple regression of the log maintenance rate on the log relative price of maintenance to investment. If we know the demand elasticity, then we can fully assess the effects of tax reforms on capital. Nevertheless, there is little evidence on maintenance demand functions at all, let alone for the United States.[3] Some studies of maintenance rely on data from India (Kabir, Tan, and Vardishvili 2024; Kabir and Tan 2024) or Canada (Albonico, Kalyvitis, and Pappa 2014; Angelopoulou and Kalyvitis 2012), but none, to my knowledge, estimate a maintenance demand function. However, there is some indirect evidence. We know from Goolsbee (1998b) that airlines retire their airplanes more quickly when tax policy makes it favorable to buy new ones. Similarly, Goolsbee (2004) shows that firms buy capital with lower maintenance requirements following tax cuts, where quality is proxied with the price, which is in line with the tax shield effect emphasized in this paper. Moreover, casual evidence from firms (Pfeifer 2023) and households (Pinsker 2024) suggest that agents do adjust their maintenance behavior when the price of maintenance changes. But we lack direct evidence on maintenance because, like intangible expenditures, maintenance is often a hidden expenditure that goes under broader categories like costs of goods sold. Toward shedding light on maintenance demand in the United States, I bring together two datasets.

First, I construct a novel dataset on the maintenance and investment activities of Class I freight railroads using their R-1 financial filings. Large railroads are required to file heavily audited financial statements with the Surface Transportation Board, all of which include the most detailed data available on maintenance in the United States. I digitize

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3. A famous counterexample is Rust (1987), which studies Harold Zurcher's decisions to replace bus engines. In a similar vein, Harris and Yellen (2023) study the implementation of advanced maintenance technologies for a large trucking company. The model could be extended to contain productivity shocks to maintenance or investment, but those would simply be reflected in relative prices.

and put together a panel of maintenance, investment, capital, and relative prices from 1999-2023 using those filings, which are akin to 10-Ks filed with the SEC by corporations, but they are more detailed and hence provide a unique window into the firm.[4] For example, I observe maintenance broken down by capital type and the extent of maintenance done internally versus purchased externally and the cost shares of both labor and materials for internal maintenance. Using that information, I construct an after-tax relative price of maintenance to investment specific to every firm and capital type. I leverage variation in cost shares of maintenance inputs across capital types and firms to get variation in exposure to aggregate materials and labor prices. With that Bartik-style instrument, I show that the elasticity of demand for maintenance is statistically significant around four. The approach stands up to scrutiny from a number of robustness checks, including a unique measure of a *physical* maintenance rate.

However, the representative firm model misses an important aspect of reality. As Feldstein and Rothschild (1974) and Cooley, Greenwood, and Yorukoglu (1997) show, firms may respond to tax cuts by selling capital to other firms. In an extension to the model, I show that since the purchasers of used capital presumably have lower relative prices of maintenance to investment than sellers of capital, reallocation dampens the aggregate maintenance elasticity in general equilibrium. To illustrate that, I leverage a representative sample of corporate tax returns from the Internal Revenue Service's Statistics of Income (SOI) Division. Because the SOI data are aggregated at the roughly three-digit NAICs industry level, the resulting maintenance elasticity should capture general equilibrium effects as long as capital is sufficiently industry-specific. Using variation in exposure to exogenous tax policy changes as an instrument to identify the coefficient in a regression of the log maintenance rate on the tax term, I estimate a demand elasticity around two. The identification strategy, which has its roots in the investment literature (Garrett, Ohrn, and Suárez Serrato 2020; Zwick and Mahon 2017) relies on the fact that industries vary in their capital composition and because capital is differentially taxed, industries are differentially exposed to tax policy. I validate the approach by breaking the SOI down into a sample of taxable and non-taxable firms. Consistent with theory, the taxable firm response is the same as in the R-1 data, but the non-taxable firms weakly increase maintenance in response to tax cuts.

Each dataset has its own advantages and disadvantages, but together they tell a unified story. In both the SOI and the R-1 data, maintenance is about as large as gross investment in physical capital. Moreover, both yield a demand elasticity between two and

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4. Bitros (1976) uses an early version of this data to analyze the determinants of maintenance expenditures, but does not estimate a maintenance demand function or analyze its price elasticity.

four. Together, these observations roundly contradict the null hypothesis of inelastically zero maintenance demand in workhorse models. This accords with analyses of housing maintenance, which consistently show that households spend significant resources maintaining houses (Knight and Sirmans 1996; Harding, Rosenthal, and Sirmans 2007; Hernandez and Trupkin 2021).[5]

Quantification. I wrap up by quantifying the relevance of elastically positive capital maintenance demand in the context of the 2017 Tax Cuts and Jobs Act (TCJA).[6] The objective is not only to quantify TCJA, but to understand the importance of building in maintenance to quantitative tax policy models. Researchers may choose to alter the benchmark Hall and Jorgenson (1967) model with a variety of complications such as explicit demographics (PWBM 2019), heterogeneous capital (Barro and Furman 2018), heterogeneous firms (Sedlacek and Sterk 2019; Zeida 2022), lumpy adjustment (Winberry 2021), or global tax considerations (Chodorow-Reich et al. 2023). At the heart of every tax model, however, is capital accumulation, and the essential question is the extent to which explicitly modeling capital maintenance adds value quantitatively.

My starting point is the domestic block of the workhorse neoclassical growth model (NGM) from Chodorow-Reich et al. (2023), which is the seminal assessment of the general equilibrium effects of TCJA. I build in a maintenance demand function using a conservative estimate from the Statistics of Income. This model, which I call the NGMM, features a tax elasticity of capital which limits to the NGM as maintenance demand goes to zero. In partial equilibrium, domestic corporate capital rises by about 10.9% in the NGM and by 6.9% in the NGMM. The NGM estimate compares favorably with similar partial equilibrium estimates in Chodorow-Reich et al. (2023) and Barro and Furman (2018). To get general equilibrium estimates, I assume that labor supply is perfectly inelastic and rationed across a corporate and a non-corporate sector. Additionally, using an external calibration of the interest elasticity of deficit financing from Laubach (2009), I calibrate some degree of crowding out.

In the short-run, capital adjustment costs cause an even bigger distinction between the NGMM and the NGM in general equilibrium. Since having two inputs to produce

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5. The investment-maintenance distortion goes the other way in the housing tax code. Whereas improvements are deductible from the capital gains tax basis, maintenance is not, which creates a distortion in favor of the former. There is no direct evidence of the importance of that margin, but Cunningham and Engelhardt (2008) and Shan (2011) show that the 1997 Taxpayer Relief Act, which lowered the capital gains tax, increased housing mobility, which is akin to increasing the renewal rate of housing.

6. TCJA is the largest tax reform since the 1980s, spurring a large quantity of research using various methods. The UNC Tax Center maintains a list of dozens of papers on the effects of TCJA on numerous outcomes, while the Journal of Economic Perspectives has a symposium on the effects of TCA featuring papers from Gale, Hoopes, and Pomerleau (2024) and Clausing (2024), among others.

capital makes investment significantly more elastic, we need much stronger adjustment costs than typical applications to make estimated investment elasticities accord with the model. Following Chodorow-Reich et al. (2023), I calibrate capital adjustment costs by relying on a short-run estimate of the tax elasticity of investment. My maintenance demand function suggests that the tax elasticity of investment from user cost regressions should be increased by a factor of 1.5. This implies that, for example, the Hassett and Hubbard (2002) consensus range of 0.5-1.0 should be increased to 0.75-1.5. Adjusting up the Chodorow-Reich et al. (2023) estimate of the tax elasticity by that factor results in an increase in the domestic corporate capital of 2% after ten years, which is one-third as much as the NGM predicts. Given an initial level of corporate physical capital of $17T, that amounts to a difference in corporate capital of about $650B. In the long run, corporate capital rises in the NGM by 6.4%, consistent with leading general equilibrium estimates (Chodorow-Reich et al. 2023; Sedlacek and Sterk 2019; Zeida 2022), and in the NGMM by 3.4%. Thus, the tax elasticity of capital is about fifty percent as large in the NGMM as the NGM in steady state.

There are two useful ways to contextualize the finding. First, the neoclassical model with Cobb-Douglas production predicts a tax elasticity of capital given by $-1/(1-\alpha)$, where α is the profit elasticity. The NGMM tax elasticity of capital is therefore equivalent to an NGM with a profit elasticity α reduced from a standard value of 0.67 to 0.45, or cutting the profit elasticity by one third. Second, the *general equilibrium* tax elasticity of capital in the NGM is equivalent to the *partial equilibrium* tax elasticity of capital in the NGMM. Therefore, if reducing the capital share by one third or accounting for general equilibrium effects is considered critical in tax policy analysis, then accounting for maintenance should be regarded as equally important.

2   Capital Maintenance in Policy and in Practice

In this section, I discuss the legal and practical distinctions between capital investment and capital maintenance. Later in the section, I use new data from two sources to describe maintenance practices.

2.1   The Legal Distinction Between Maintenance and Investment

Capital maintenance is any activity that maintains the productivity of an existing asset, while investment improves the productivity of an existing asset or creates a new one altogether. For example, a ground shipping company may make its vehicle fleet live longer

through diligent attention to routine maintenance like oil changes or proactively changing the tires early to avoid worse damage through a highway tire blowout. By contrast, investment would be purchasing an entirely new fleet of vehicles or replacing the engine in an existing vehicle. Thus, the key distinction between investment and maintenance is that the former adds new capital to the stock, while the latter simply keeps old capital around for longer in its existing quality.

Although the distinction between improvement and maintaining productivity may seem like an irrelevant fiction to economists because both, in practical terms, make the asset live longer, it is nevertheless critical for tax accounting. Under the "betterment test," expenditures are evaluated based on whether they merely restore an asset to its original condition or whether they provide a "betterment" improving its productivity or inherent quality beyond the original state. If the work performed simply returns the asset to its prior operating condition without adding lasting value, it qualifies as a repair expense under IRC §162 and can be deducted in full in the year incurred. Conversely, if the expenditure results in a permanent improvement that exceeds the original state of the asset, it is considered a capital improvement under IRC §263 and must be capitalized.

Because maintenance can be expensed immediately whereas investment in an equivalent asset cannot, the subsidy on investment is effectively smaller than on investment, something first pointed out by McGrattan and Schmitz Jr. (1999). The government categorizes assets under the Modified Accelerated Cost Recovery System (MACRS) according to their different useful lives. For example, a locomotive is a fifteen-year asset, while a car is a five-year asset. For example, Table 1 illustrates the tax consequences for Hertz in the decision between investing in a new car (top panel) and maintaining an existing one. Whereas maintaining the car can be deducted immediately, investing in the new car requires it to be depreciated over time. As a result, as long as Hertz discounts the future positively, the net present value of its depreciation allowances will be smaller investing in the new car than maintaining the existing one. In this example, a 7% discount rate implies that the present value of tax deductions are only 89% as large for buying a new car as compared to maintaining the old one. The distinction is even larger for longer-lived assets like locomotives and freight cars; Table B.7 shows that the net present value of deductions is only 69% as large.

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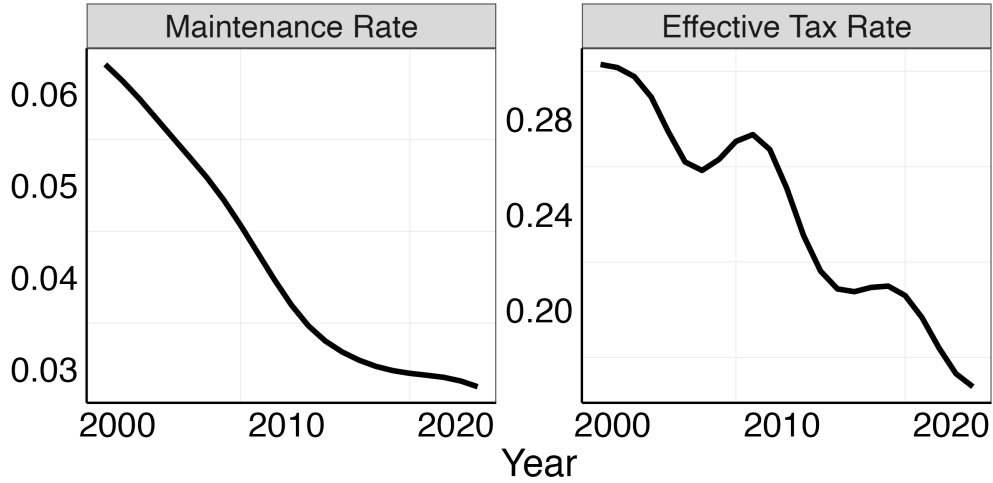Table 1: The Tax Treatment of Investment and Maintenance

Year:	0	1	2	3	4	5	Total	z
Investment								
Deductions (000s)	200	320	192	115	115	58	1,000	
Tax benefit ($\tau = 35\%$)	70	112	67.2	40.3	40.3	20.2	350	0.89
Tax Benefit (Present Value)	70	104.7	58.7	32.9	30.7	14.4	311.4	
Maintenance								
Deductions (000s)	1000	0	0	0	0	0	1,000	
Tax benefit ($\tau = 35\%$)	350	0	0	0	0	0	350	1.00
Tax Benefit (Present Value)	350	0	0	0	0	0	350	

Notes: This table repurposes Table 1 from Zwick and Mahon (2017) to show the difference in tax depreciation between investing in a new five-year asset and in maintaining an existing one, while also adding an extra row to display present values. The table shows year-by-year deductions, tax benefits, and the present value of tax benefits for a five-year asset according to MACRS. The z columns shows the present value of one dollar of tax deductions.

As the tax rate τ decreases, the tax benefit of maintaining existing capital over investing in new capital declines. One would expect that as long as maintenance and investment are substitutable, then if τ declines, we should observe a corresponding decline in the maintenance rate. Casual observation suggests that is indeed the case. Figure 1 plots one measure of the maintenance rate together with the effective corporate tax rate since 1997. The maintenance rate is the ratio of gross output in the equipment maintenance and repair sector to the current cost of private equipment capital. While the relationship is by no means causal, it is nevertheless suggestive that we see a strong long-run comovement between tax rates and maintenance rates.

One may worry about firms gaming the maintenance-investment distinction to avoid capitalizing assets. In practice, however, this is generally not an issue because maintenance expenditures are smaller and more frequent. For example, an oil change is $100 while a new car may be $20,000. Under tax law, there is a *de minimis* safe harbor which allows businesses to expense small expenditures immediately, thereby limiting the opportunity to reclassify costs in a way that might the system. These rules and safe harbors, together with established case law, help ensure that the betterment test is applied consistently for tax purposes.

Figure 1: Trends in Maintenance and Corporate Tax Rates

Notes: The maintenance rate is constructed as gross output in NAICS 811 excluding home repair as a share of current cost private equipment capital. The effective tax rate is the ratio of domestic corporate taxes paid to pre-tax profits from BEA Tables 6.16D and 6.17D. The cyclical component of each series has been removed with a Hodrick-Prescott filter.

2.2 Observations On Maintenance in Practice

The central challenge of empirical maintenance analysis is a paucity of data in the United States. For example, the Bureau of Economic Analysis does not publish estimates of capital maintenance at the aggregate level and neither does Compustat at the firm level. The empirical analysis in this paper expands on the existing empirical investment literature with two new data sources. First, I construct a novel dataset on the maintenance behavior of locomotives and freight cars by Class I freight railroads. Second, I rely on corporate tax data at the industry level from the Statistics of Income (SOI) published by the Internal Revenue Service. While these data are not new and have been used to analyze investment (*e.g.*, Zwick and Mahon (2017)), it is the first time the SOI has been used to analyze maintenance. These two data sources are complementary. The R-1 data are a unique window into the detailed micro behavior of the firm, while the industry data ensure external validity at the national level and allow us to later test general equilibrium effects. The remainder of this section describes some of the basic features of maintenance data.

R-1 Data. I construct a novel and considerably more granular dataset of maintenance in the freight rail industry. Class I freight railroads—defined as having revenue greater than $500m—carry about 40% of all freight in the United States, with the rest largely taken by trucks. Although the industry used to be highly fragmented, it has consolidated considerably since deregulation in the early 1980s and has been in a stable competitive equi-

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librium of around seven large firms since the late 1990s, which is when my data begin. Seven companies carry most of the freight traffic: CSX Industries, Burlington Northern & Santa Fe, Union Pacific, Norfolk Southern, Kansas City Southern, Soo Line, and Grand Trunk, which is operated by the Canadian National Railway. The railroads are geographically dispersed but have one or two large local competitors along with smaller Class II and Class III competitors. Burlington Northern and Union Pacific dominate the western United States, CSX and Norfolk Southern the eastern seaboard, while the Soo, Kansas City Southern, and Grand Trunk operate more in the midwest. All of these railroads own their tracks and equipment and have faced relatively little financial trouble over the past 25 years. Railroads extensively maintain their own capital with either internal unionized labor or with externally purchased maintenance services.

By regulation, any freight railroad with sufficiently high revenue must file an annual R-1 report with the Surface Transportation Board (STB). The R-1 report can be thought of as a much more granular version of a 10-K filed by a publicly traded corporation. However, the accounting standards meaningfully differ from GAAP standards in important ways. For example, railroads often depreciate assets using composite rates, which must be approved *ex ante* by the STB. All reports are independently audited by firms like KPMG and PwC and then once more by the government. The main reason for the R-1 reporting requirement is that the predecessor to the STB, the Interstate Commerce Commission, extensively used the R-1 report to regulate rate setting prior to the 1990s. To some extent, the STB still plays that regulatory role, but rate setting disputes are far less common now.

Each R-1 report contains about twenty different "schedules" which correspond to different information about the railroad. For example, Schedule 410 has several hundred line items on different operating expenses which break down the extent to which expenditures are attributable to internal labor and materials costs or to external costs. Thus, we can observe each firm and capital type's maintenance input cost shares and map them to associated prices. Various schedules detail the size and composition of firms' capital in value and quantities, its trackage by state, taxes paid, capital expenditures, and detailed data on maintenance expenditures by capital type. This level of granularity and precision is a unique and unparalleled window into the physical capital structure of the firm. The data run from 1999-2023.

For this paper, I maintain a narrow focus on freight cars and locomotives because the maintenance activities and associated prices can be straightforwardly identified in the data, whereas maintenance and the price thereof is not for other types of capital. Additionally, track maintenance is strictly regulated by the Federal Railroad Administration, while regulation of locomotives and freight cars is considerably less intense. That allows
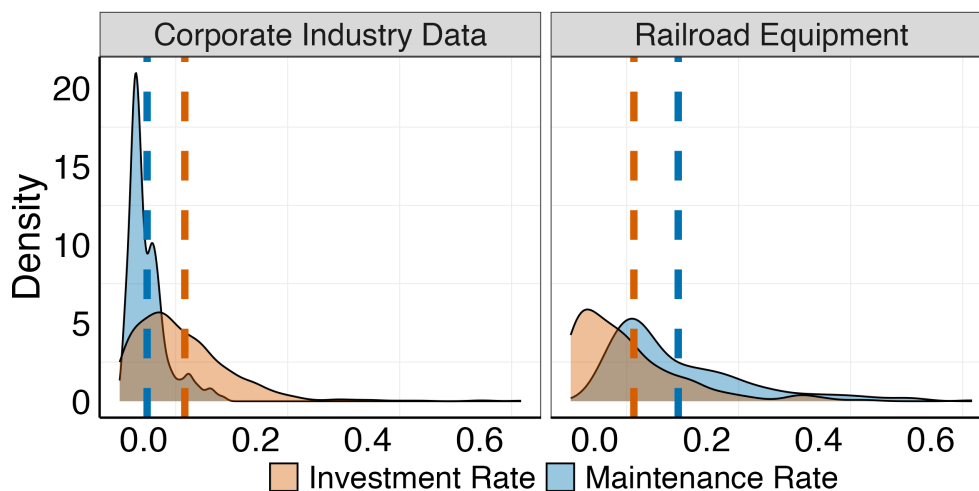
firms some leeway in how intensely they maintain their equipment subject to inspection and safety protocols. Of course, that decision is intertwined with how intensely the firms invest in new capital, which is unregulated and determines how much they need to spend on maintaining and repairing existing capital.

SOI. Corporations report a large number of operating expenses and balance sheet items as line items on their tax forms to the IRS, including maintenance expenditures and book capital. The Statistics of Income (SOI) aggregates the returns into a stratified industry-level sample at a roughly three-digit NAICS level. This is the only economy-wide collection of maintenance data at an annual frequency in the United States. I take maintenance, investment, and book capital stock data from the SOI corporate reports from 1999-2019. This excludes filings made with Forms 1120S, 1120-REIT, and 1120-RIC.

Observation 1: Maintenance is Large Relative to Investment

While the numerical magnitudes and properties of investment are well-known, we know considerably less about maintenance. The investment rate gives a notion of how intensely firms replace their capital, while maintenance rates tell us, similarly, how intensely firms maintain their existing capital. Figure 2 plots the density of overall maintenance rates and gross investment rates for both the corporate industry-level data and the granular freight rail data. There is a large discrepancy between the two. While the maintenance rate for railroad equipment is twice that of the investment rate, it is only half as large in the national data. In either case, however, maintenance is a large expenditure.

Figure 2: Density plots for maintenance and gross investment rates

Note: Each density plot is constructed with beginning of period book capital in the denominator. The dashed lines are mean maintenance and investment rates. In the corporate data, the mean maintenance rate is 5%, while it is 20% for freight railroads. The mean investment rate is 11% across both sources.
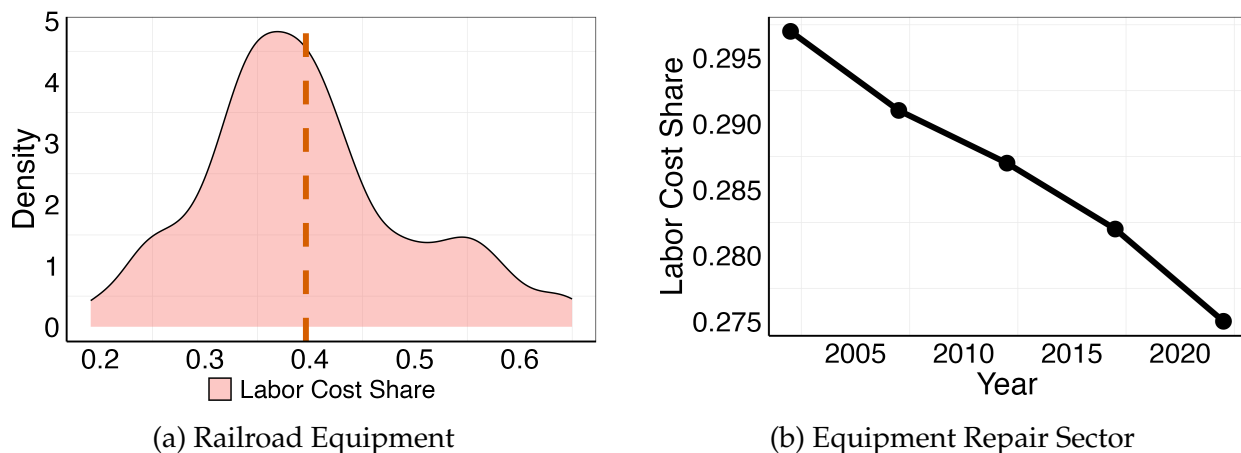
What accounts for the discrepancy? First, locomotives and freight cars, like airplanes, typically lives for 15-20 years before it is sensible to replace them. Because of that, firms intensively maintain them to make sure they last long enough. Second, the government imposes minimum—but often not binding—maintenance standards on railroad equipment. That yields a baseline maintenance rate that would be higher than on, for example, a standard office computer. Third, the maintenance rate is biased downward by a peculiar feature of the IRS data. Maintenance expenditures are composed of three parts: external maintenance, materials expenditures for internal maintenance, and labor expenditures for internal maintenance. In tax return data, all labor costs get allocated to the wage bill to avoid double-counting, resulting in downward-biased maintenance rates in the SOI.

Observation 2: 30-40% of Maintenance Costs are for Labor.

Accounting for labor costs pushes up the average maintenance rate in the SOI. Figure B.4 shows that the labor cost share—defined as the ratio of labor cost to total maintenance cost—is consistent between freight railroads and the equipment maintenance sector (NAICS 811). NAICS 811 is composed of computer repair shops, auto repair shops, as well as larger operations like Delta TechOps, which maintains a large share of airplanes in the United States. The left panel shows the density of labor cost shares for freight cars and locomotives within the freight rail sector. Although the distribution is wide, the mean labor cost share is around 40%. The right panel plots the ratio of labor costs to gross output

in the equipment maintenance sector as a whole; typically it is around 30%. Given the rough agreement between the railroad data and the equipment repair sector, we could reasonably boost the typical SOI maintenance rate to between 7% and 8%, or about 2/3 as large as the usual investment rate.

Figure 3: Labor Cost Share by Sector

(a) Railroad Equipment

(b) Equipment Repair Sector

Note: Figure 3a is the winsorized density of labor cost shares for locomotives and freight cars from R-1 reports. The share is computed by dividing labor costs by total internal maintenance costs. Figure 3b plots the ratio of labor costs to total receipts for NAICS code 811, which is the maintenance and repair sector, from 2002-2022. Each data point comes from the Economic Census.

Observation 3: In-House Maintenance is Typically Larger than External Maintenance
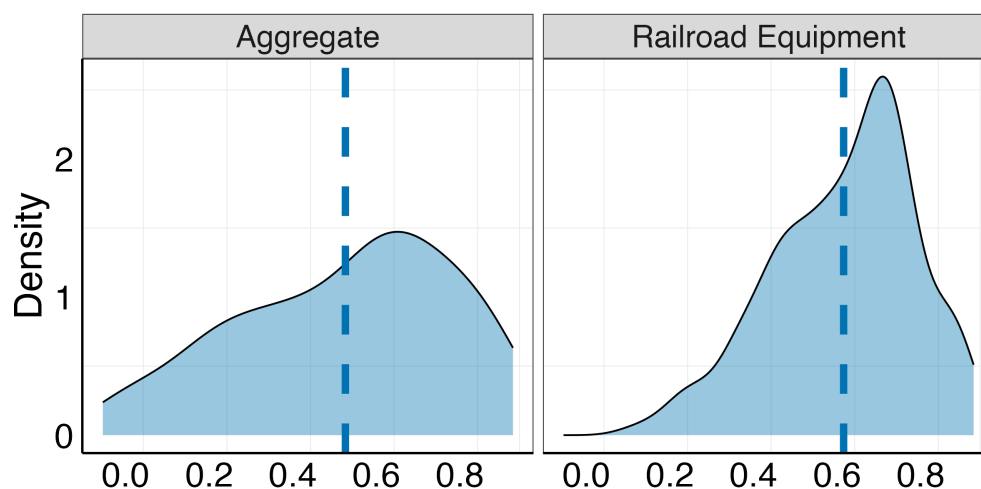
We can think of maintenance as taking two forms. Either firms can outsource their maintenance to other firms or they can do it themselves. By analogy, we can choose to change the oil in our car engines at home in the garage or we can bring it to a mechanic. It is likely that such decisions depend considerably on the complexity of the maintenance required as well as the extent of in-house expertise. As a result, it is likely that the degree to which firms maintain internally likely varies considerably across and within industries. For example, many airlines rely on Delta's in-house maintenance arm, Delta TechOps, to carry out routine maintenance and repairs, but even Delta relies on suppliers for more complex repair operations. However, we lack cross-industry data on how reliant firms are on outside maintenance services.

I provide new evidence on in-house maintenance in two ways. First, I construct a rough measure of how reliant industries are on external maintenance by putting together the BEA's input-output table and reported maintenance from the SOI's sample of all firms in the economy, regardless of legal type. By subtracting payments to the external main-

tenance sector (NAICS 811) from total maintenance expenditures, we get a rough idea at the aggregate level of how much firms spend in-house. I try to account for missing wage payments in the SOI by dividing total maintenance expenditures by 0.7. I do this exercise for 2007, 2012, and 2017, which are the years in which the BEA has input-output data and overlap with the SOI sample. Second, the R-1 data provides a uniquely precise measure of in-house versus external maintenance; it is a line-item in their operating expenses.

Figure 4 plots the density of the ratio of internal maintenance to total maintenance expenditures at both the aggregate level and for railroad equipment. Both exceed 50% on average and display a left skew, although the industry-level data is more uniformly distributed. This implies that the actual size of the maintenance sector is more than twice as large as implied by Figure 1, which only encompasses external maintenance. Appendix Figure B.7 tabulates the top internal maintenance shares by industry. They tend to be equipment-intensive sectors (like agriculture and manufacturing) for which it would presumably pay off to have an internal maintenance division. In support of that, Appendix Figure B.2 plots the density decomposed between locomotives and freight cars. The distribution is more uniform for locomotives with a smaller mean internal maintenance rate. That implies more complex equipment maintenance tends to be outsourced unless firms develop internal capacity for it.

Figure 4: Ratio of Internal Maintenance to Total Maintenance

Notes: The distribution of aggregate internal maintenance rates is constructed using Table 1 from the Statistics of Income, which encompasses all firms regardless of legal type, together with input-output tables from the BEA on purchases of equipment repairs from NAICS code 811 except housing services. The distribution of the share of internal railroad equipment maintenance comes from dividing internal maintenance expenditures by total maintenance expenditures for all Class I freight railroads for locomotives and freight cars.

The internal-external margin is important because internal maintenance is more flexible than external maintenance since the latter is usually a function of predetermined contracts. For freight railroads—and probably most firms—external maintenance is generally fixed contractually and hence is less flexible than internal maintenance. If the demand for maintenance is elastic, then it will almost surely be on the internal maintenance margin.

3   A Simple Model of Capital Maintenance

This section expands on McGrattan and Schmitz Jr. (1999) to develop a simple theory of why firms maintain their capital and precisely how that affects the predictions of benchmark neoclassical models around tax reforms.

3.1   The Benchmark Neoclassical Model

As a benchmark, consider the Hall and Jorgenson (1967) neoclassical growth model with taxes, which serves as the workhorse model for tax policy analysis. Time is discrete and there is no uncertainty. A representative firm produces output $Y_t = F(K_t)$ as a concave function of capital. The produces capital with new investment I_t, where the price of a new unit of capital is p_t^I. The tax system interacts with the wage and investment costs in two ways. First, there is a tax on output τ_t^c. Second, the firm receives an investment tax credit c_t and tax depreciation $z_t \tau_t^c$. The second term captures the fact that firms are allowed to write off a certain percentage of their investment every year. z is the net present value of one dollar of such deductions. The faster the firm can write off the value of the asset, the higher z is. Putting together the tax system with private production yields the sequence of dividends

$$d_t = (1 - \tau_t^c) F(K_t) - (1 - c_t - z_t \tau_t^c) p_t^I I_t. \tag{1}$$

Capital accumulates according to $K_{t+1} = (1 - \delta) K_t + I_t$. Given some initial level of capital K_0, it is clear that the level of capital at any point in time is a function only of previous investment choices.

The firm, taking as given prices and taxes and discounting the future at rate r^k, chooses a sequence of capital and labor to maximize (1) subject to the law of motion for capital and the production technology. Let Ψ denote the user cost of capital. In steady state, optimization yields the optimality condition for capital

$$F_K = \Psi = p^I \left(\frac{1 - c - z\tau^c}{1 - \tau} \right) \left(r^k + \delta \right) \tag{2}$$

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The relevant policy question is how much capital and output change when taxes change. To simplify notation, denote the policy variables in (2) as

$$1 - \tau \equiv \frac{1 - \tau^c}{1 - c - \tau^c z}.$$

The economic effect of a tax change is given by the proportional change in user cost, which transmits to macroeconomic variables through (2). Denote the new marginal tax rate as τ', so that the new user cost is Ψ'. Under the Jorgensonian benchmark, the proportional change in user cost is

$$\boxed{\frac{\Delta \Psi}{\Psi} = \frac{\Delta \tau}{1 - \tau'}.} \tag{3}$$

Tax cuts increase the after-tax return on capital, which spurs new investment, leading to increases in capital and output. Although one can add a number of complications like convex adjustment costs (Summers 1981), lumpy adjustment (Winberry 2021), demographics (Altig et al. 2001), or firm dynamics Zeida (2022), the core of the transmission mechanism remains the same. As a simple example, suppose output is given by $Y = K^\alpha$. Changes in user cost propagate through to capital and output via

$$\frac{\Delta K}{K} = -\frac{1}{1 - \alpha} \frac{\Delta \Psi}{\Psi} \quad \text{and} \quad \frac{\Delta Y}{Y} = -\frac{\alpha}{1 - \alpha} \frac{\Delta \Psi}{\Psi}. \tag{4}$$

Moreover, the tax elasticity of investment is a sufficient statistic for the partial equilibrium changes in capital and output. In steady state, $I = \delta K$, which implies that the tax elasticities of investment and capital are the same, *i.e.*, $\varepsilon_I = \varepsilon_K$. The elasticity equivalence motivates a large empirical literature analyzing the effects of tax policy reforms on investment and is a direct consequence of the fact that capital can only be produced with investment.

3.2 Introducing Maintenance to the NGM

Having introduced the benchmark model, I now incorporate maintenance following the treatment of McGrattan and Schmitz Jr. (1999). The firm pays a maintenance cost M_t at price p_t^M. However, maintenance is fully tax-deductible, which means that dividends are given by

$$d_t = (1 - \tau_t^c) \left(F(K_t) - p_t^M M_t \right) - (1 - c_t - \tau_t^c z_t) p_t^I I_t.$$

The firm pays for maintenance because maintenance reduces the depreciation rate of existing capital through a decreasing and convex technology $\delta(m_t)$, where $m_t = M_t/K_t$ is the maintenance rate. Capital then evolves according to

$$K_{t+1} = (1 - \delta(m_t)) K_t + I_t. \tag{5}$$

Whereas the standard model assumes one input to capital accumulation, this paper emphasizes instead that, as long as the demand for maintenance is price-elastic, the sequence of capital stocks is a function of choices about both maintenance and investment.

The marginal benefit to capital maintenance is a reduction in depreciation captured by $-\delta'(m)$. The marginal cost is a unit of foregone investment, which is determined by the relative price of maintenance to investment. Considering the steady-state decision, the firm equates marginal benefit with marginal cost exactly when

$$-\delta'(m) = \frac{p^M}{p^I} \frac{1 - \tau^c}{1 - c - \tau^c z} = \frac{p^M}{p^I}(1 - \tau). \tag{6}$$

As long as $-\delta'(m) > 0$, the decision to maintain is economic rather than technical. Corporate and investment tax reforms therefore result in changes in the demand for maintenance and hence the depreciation rate of existing capital.[7] Moreover, the extent to which tax reforms induce firms to substitute maintenance for investment depends on the curvature of the depreciation technology. To put it another way, if maintenance is very "efficient" at lowering depreciation (high curvature), firms do not have to work hard—*i.e.*, they don't need to change maintenance by much—to achieve a given depreciation reduction. As a result, their maintenance demand responds less to changes in prices or tax incentives. On the other hand, if maintenance is less efficient (low curvature), firms have to adjust maintenance levels more when incentives change, leading to a higher elasticity of maintenance demand. That conclusion establishes that there is an inverse relationship between the elasticity of demand for maintenance and the maintenance elasticity of depreciation.

As a particular example, consider the depreciation technology $\delta(m) = \delta_0 - \frac{\gamma^{1/\omega}}{1-1/\omega}m^{1-1/\omega}$.

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7. New capital is more productive than old capital. That difference is loaded on the price of investment p^I. Productivity increases yield a lower price of investment. For example, the relative price of equipment has declined at a secular rate for the last sixty years, which would imply new capital is increasingly more productive than old capital. Those productivity increases stimulate less intensive maintenance through the fact that p^I has declined.

Inverting (6) yields the maintenance demand function

$$m = \gamma \left(\frac{p^M}{p^I} (1 - \tau) \right)^{-\omega}. \tag{7}$$

The price elasticity of maintenance increases in ω, while the price elasticity of depreciation decreases in ω.

Incorporating maintenance leads to an additional element in the user cost of capital, namely that an additional unit of capital must be maintained at price p^M. In steady state, firms invest until the marginal product of capital equals the user cost Ψ:

$$F_K = \Psi = \frac{p^I (1 - c - \tau^c z)}{1 - \tau^c} \left(r^k + \delta(m) \right) + p^M m, \tag{8}$$

where r^k is the discount rate and m is the optimally chosen maintenance rate given the relative price. (8) is a generalization of (2).

Now, consider a tax reform $\Delta \tau$, where τ is the marginal tax on the return to a unit of new investment. To save on notation, let $p^I = p^M$. With maintenance, the generalized user cost is

$$\boxed{\frac{\Delta \Psi}{\Psi} = \underbrace{\frac{\Delta \tau}{1 - \tau'}}_{\substack{\text{NGM} \\ \text{Benchmark}}} \underbrace{\left(1 - \frac{(1 - \tau) m}{r^k + \delta(m) + (1 - \tau) m} \right)}_{\text{Tax Shield Effect}} + \underbrace{\frac{1}{\Psi} \left(\frac{\Delta \delta(m)}{1 - \tau'} + \Delta m \right)}_{\text{Input Substitution Effect}}.} \tag{9}$$

Maintenance has two effects on the tax sensitivity of user cost in equation (9): a *tax shield effect* and an *input substitution effect*. I discuss each in turn.

Tax Shield Effect. Transmission of taxes to real variables goes through user cost and traditionally operates through (3), which is the neoclassical benchmark. As long as maintenance demand is positive, then the tax shield effect gives the traditional transmission mechanism a haircut. The size of the haircut is determined by the maintenance share of user cost. In the limiting case where $r^k \to 0$ and $\delta \to 0$ and the only cost of capital is the obligation to maintain it, then capital accumulation is wholly unaffected by changes in tax policy. This conclusion adds some nuance to a point made by House (2014) about the price elasticity of long-lived capital. House observes that because long-lived capital has a low depreciation rate, it is more price-elastic than short-lived capital. However, positive demand for maintenance implies that, all else equal, short-lived capital is *less* price-elastic because maintenance becomes a larger share of user cost. This channel would not exist if

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there were not a maintenance-investment tax distortion.

Input Substitution Effect. The second way maintenance alters user cost is through the change in demand for maintenance induced by the tax reform, which feeds through into an opposing change in depreciation. Whichever effect dominates depends on the curvature of the depreciation technology. There are three cases. If the elasticity of demand for maintenance is less than one, then the input substitution effect makes depreciation rise by more than maintenance declines. With unit elasticity, the effects are offsetting, while an elasticity of demand greater than one implies that maintenance costs decline by more than depreciation rises following a tax cut. Consequently, maintenance can amplify the effect of tax cuts on user cost if there is sufficient curvature in the maintenance demand function. However, the input substitution effect, which is emphasized by McGrattan and Schmitz Jr. (1999), is second-order for capital accumulation.[8]

Proposition 1. *To first order, the sensitivity of the user cost of capital to a tax change is strictly smaller than in the benchmark neoclassical model.*

3.3   Implications for Macro Variables

Because the transmission of tax policy into aggregate variables is directly mediated by the cost of capital, incorporating maintenance has first-order consequences for macro outcomes.

Capital, Output, and Wages. Tax reformers are typically interested in tax cuts because of their transmission into larger output and wages (Romer and Romer 2010). Although that transmission occurs in general equilibrium, it occurs via capital, which itself is determined by the user cost of capital. General equilibrium forces resulting from tax reforms like higher interest rates (from crowding out) or higher wages (via increased competition for scarce labor) are the same regardless of whether or not there is maintenance in the model. Therefore, the same haircut which applies in partial equilibrium must likewise occur in general equilibrium. That reasoning yields Corollary 1.

Corollary 1. *The tax elasticities of capital, output, and wages are strictly smaller in the maintenance model than in the benchmark model.*

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8. To see why, note that the total derivative of user cost with respect to τ is

$$\frac{\mathrm{d}}{\mathrm{d}\tau}\Psi\big(\tau, m^*(\tau)\big) \;=\; \underbrace{\frac{\partial\Psi}{\partial\tau}\big(\tau, m^*(\tau)\big)}_{\text{tax shield effect}} \;+\; \underbrace{\frac{\partial\Psi}{\partial m}\big(\tau, m^*(\tau)\big)\cdot\frac{\partial m^*(\tau)}{\partial\tau}}_{\text{input substitution effect}}.$$

But by the first-order condition at the optimum $m^*(\tau)$, we have $\frac{\partial\Psi}{\partial m}\big(\tau, m^*(\tau)\big) \;=\; 0$.

Investment. On the other hand, tax reformers often assess the consequences of particular reforms by examining the resulting effect on investment (Cummins, Hassett, and Hubbard 1994; Zwick and Mahon 2017; Chodorow-Reich et al. 2023). That inclination is sensible when maintenance demand is inelastic because the tax elasticities of investment and capital are the same, i.e., $\varepsilon_I = \varepsilon_K$. However, when the elasticity of demand for maintenance is positive, that reasoning no longer holds up. We can explicitly define steady-state investment in terms of tax rates as

$$I(\tau) = \delta\left(m(\tau)\right) \times K\left(\tau, \delta(m(\tau)), m(\tau)\right),$$

from which it follows that

$$\varepsilon_I \approx \varepsilon_\delta + \varepsilon_K. \tag{10}$$

Thus, the sensitivity of investment to tax policy depends on both the curvature of the depreciation technology and the concavity of the production function with respect to capital. As a result, the tax elasticity of investment is strictly larger than the tax elasticity of capital as long as the elasticity of demand for maintenance is positive. This conclusion means that we cannot learn about the partial equilibrium effects of tax reforms on capital accumulation solely by looking at investment elasticities; we must also know something about the depreciation technology.

The model also implies an issue with typical estimates of the tax elasticity of investment. Because empirical investigations of the tax elasticity of investment are disciplined by structural models of capital accumulation, the disconnect between capital and investment induced by maintenance also implies some degree of empirical misspecification. In standard regressions, the investment rate is regressed on a tax-adjusted user cost term that only includes a baseline depreciation rate, ignoring the fact that maintenance reduces depreciation and adds an extra cost. This omission means that the regression does not account for the component of the user cost that varies mechanically with taxes via maintenance expenditures. Thus, standard regressions suffer from omitted variable bias because the specification fails to capture the full sensitivity of the investment decision to tax-induced changes in maintenance behavior, leading to a downward bias in estimated tax elasticities of investment. Appendix A.2 shows this formally.

A second consequence of maintenance follows from examination of the steady-state investment rate, which dictates how quickly capital is renewed. It is intuitive that younger capital requires less maintenance because it is new. If tax cuts spur new investment, then the aggregate maintenance rate may decline because capital is younger in the aggregate. In the long run, the investment rate corresponds to $\frac{I}{K} = \delta(m)$, which means that tax

cuts permanently increase the investment rate and hence the age distribution of capital permanently changes.[9] That is not possible in standard models.

An Imperfectly Elastic Maintenance Supply Curve

The preceding analysis assumes that p^M and p^I are invariant to policy. Although a classic result from Goolsbee (1998a) shows that the investment supply curve is upward-sloping, newer evidence from House and Shapiro (2008), House, Mocanu, and Shapiro (2017), and Basu, Kim, and Singh (2021) show that investment good prices did not respond to tax policy changes during the 2000s. They attribute this largely to increased foreign competition in the supply of investment goods. While that may be true for investment goods, it is probably not the case for maintenance. Precisely because labor is an important maintenance cost and wages increase in response to tax cuts (Fuest, Peichl, and Siegloch 2018; Kennedy et al. 2023), it stands to reason that p^M is endogenous to tax policy. Because maintenance prices rise in response to tax cuts while investment prices are invariant, the pre-tax relative price p^M/p^I should rise as a whole. Therefore, any regression omitting the pre-tax relative price will result in a demand elasticity biased downward.

3.4 Maintenance Elasticity Dampening in General Equilibrium

This section discusses a theoretically important caveat to the preceding conclusions. In the representative firm framework, tax cuts are effective because a) all firms are taxable and b) capital is allowed to depreciate more quickly through lower maintenance. However, the full story may be rather different in a heterogeneous firm framework. It could be that tax cuts spur some firms to sell their old capital and replace it with newer, higher quality capital with lower maintenance costs (Feldstein and Rothschild 1974). On the buy side, many financially constrained firms purchase used capital and persist in maintaining it because they cannot afford newer capital (Eisfeldt and Rampini 2007; Lian and Ma 2020). We know empirically that these two motives join to create a large and active used capital market (Eisfeldt and Shi 2018), which could potentially dampen the aggregate maintenance demand elasticity and thereby change the interpretation of the macroeco-

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9. Firms typically have an additional scrappage margin for adjustment, which we know is empirically important in the context of tax reform (Goolsbee 1998b). That is implicitly accounted for here by the fact that tax cuts stimulate firms to invest at a higher rate and shed old capital more quickly through higher depreciation. A vintage model would show this more explicitly, but the scrappage channel is captured by endogenous depreciation through elastic maintenance demand. In some sense, then, the demand elasticity for maintenance may be interpreted as a reduced form tax elasticity for the age distribution of capital. This would speak directly to the indirect evidence in Goolsbee (2004) that lower taxes induce firms to buy capital with lower maintenance costs.

nomic effects of tax cuts. Thus, if tax cuts induce firms to sell capital to each other, then aggregate maintenance may fall by less than what the representative firm neoclassical model would predict, yielding a smaller demand elasticity in the aggregate.

Appendix A.3 develops a heterogeneous firm model to capture the capital reallocation induced by a tax cut. The model features firms that differ only in their tax status. A fraction of firms are taxable and enjoy tax subsidies that lower their effective cost of new capital, while the remaining untaxed firms face a higher cost of investment due to financial constraints. In practice, about half of corporate tax returns are for taxable firms. Each firm makes three key decisions—maintenance of existing capital, new investment, and trading in the used capital market—with the evolution of its capital stock depending on all three choices. Taxable firms tend to invest more in new capital and sell off older, well-maintained capital, while untaxed firms, facing a higher new investment cost, purchase used capital from the taxable firms. Importantly, taxable firms face a higher relative cost of maintenance and therefore maintain their capital less than untaxable firms. In aggregate, the user cost of capital is determined as a capital-weighted average of the marginal costs faced by taxable and untaxed firms:

$$\Psi_{\text{agg}} = \frac{\lambda \, K^T}{K} \, \Psi^T + \frac{(1 - \lambda) \, K^U}{K} \, \Psi^U, \quad \text{with } K = \lambda \, K^T + (1 - \lambda) \, K^U, \tag{11}$$

where λ is the share of taxable firms and Ψ^T is the taxable user cost. This has two effects on the proportional change in user cost.

First, the first-order change in user cost is smaller with heterogeneous firms than in the maintenance model. This follows directly from the fact that the user cost of capital does not change to first order for the share of firms. Even if taxable firms respond strongly to tax changes, the overall response is muted because not all firms are exposed to the tax distortion, or at least not the same degree as in the representative firm model.

The second effect comes from reallocation of capital and results in a dampening of the input substitution effect in equilibrium. In this economy, the aggregate tax elasticity of maintenance is a weighted average of maintenance elasticities. Taxable firms maintain just like the representative firm in the main model, whereas untaxable firms typically maintain at a higher rate because they face a lower relative price of maintenance. When there is a tax cut, taxable firms respond by a) maintaining their capital less well and b) selling some of the existing capital to untaxed firms. However, precisely because untaxed firms have a low or even positive tax elasticity of maintenance, the aggregate change in maintenance is muted. As a result, depreciation typically does not change as much as we would predict with the representative firm model.

Given the potentially important effects of reallocation on dampening the maintenance elasticity in general equilibrium, we cannot rely solely on microdata to assess the aggregate effects of tax reforms. Indeed, we require aggregate data to assess the true maintenance elasticity in general equilibrium.

4 The Maintenance Demand Function

Based on the observed maintenance rates in Section 2, the tax shield effect is plausibly large and important. However, to recover the counterfactual effects of tax reform and properly contextualize the wealth of evidence we have on the tax elasticity of investment, we need to recover both the tax shield and input substitution effects. Throughout the rest of the paper, I assume that maintenance demand is constant-elasticity, so the task is to identify the coefficient ω from a regression of the log maintenance rate on the log relative price of maintenance to investment.

I rely on new microdata on Class I freight railroad equipment maintenance as well as industry-level tax data from the Statistics of Income (SOI) to estimate the demand elasticity using cross-sectional regressions. The datasets are complementary to each other because the the microdata allows for estimates at the asset level with high precision and confidence in the data quality, while the SOI data allow us to understand the aggregate, general equilibrium results of tax reforms. To estimate the data, we require maintenance rates and some variation in the relative price of maintenance to investment. Both are evident in each dataset. The remainder of this section discusses identification and results from each dataset.

4.1 Maintenance in Partial Equilibrium

I largely describe the R-1 data in Section 2. From the data, we observe for all Class I railroads detailed balance sheet and expense data for locomotives and freight cars including inventory, capacity, the book value of capital, and detailed maintenance expenditures. Importantly, the data are audited by independent private accounting firms.

The chief virtue of the data is its level of detail at the asset level for both locomotives and freight cars within each firm. We observe maintenance broken down by whether it is internal or external and whether the internal components are payments to labor or to materials. This gives a unique window into maintenance behavior at the asset-by-firm level and also allows me to construct a firm- and asset-specific relative price. I construct

that price as

$$P_{i,j,t} = \frac{p_{i,j,t}^M(1 - \tau_{i,t})}{p_{j,t}^I},$$

where $p_{i,j,t}^M$ is the pre-tax maintenance price of capital good j for firm i at time t. Because of restrictions on data availability, only the pre-tax price of maintenance varies by firm and capital type, whereas tax rates vary by firm and investment prices by capital type. The maintenance price is a weighted average of labor and materials costs, where weights come from firm-specific and material-specific cost shares. Labor costs are firm-specific and determined by the maintenance worker wage index, which I create using Wage Form A&B filed with the STB. This form details the wages of maintenance workers internally to each firm. The materials-weighted portion of the maintenance cost is the producer price index for maintenance of railway equipment and parts from the Bureau of Labor Statistics (BLS). The tax rate is a weighted average of state tax rates, with weights determined by the number of road miles in a particular state that the firm has. I extend Suárez Serrato and Zidar (2018) to the present to construct this metric and pair it with tax depreciation for freight cars and locomotives. Finally, investment prices are the respective price indices for locomotives and freight cars from the BLS. Putting that together, there is variation between capital types and firms in their exposure to relative price changes. Relative prices by firm and asset are in Figure B.1. Details on the rest of the data and summary statistics are in Appendix B.1.

I focus on locomotives and freight cars owned by seven different firms from 1998-2023. The basic regression specification estimates the maintenance elasticity of demand ω with

$$\log m_{i,j,t} = \alpha_{ij} + T_t + \omega \log P_{i,j,t} + \text{Controls} + \epsilon_{i,j,t}, \tag{12}$$

where α_{ij} is a firm-by-capital type fixed effect, T_t is a time fixed effect, and $P_{i,j,t}$ is the relative price. The coefficient ω is identified by leveraging variation in relative prices within each firm-capital type over time, with firm-by-capital type and time fixed effects controlling for all unobserved, time-invariant characteristics and common temporal shocks. In the regressions, I cluster standard errors by firm. This approach guards against the likely outcome that maintenance decisions are correlated between capital types within firms.

Identification Strategy. The relative price $P_{i,j,t}$ is likely endogenous. If firms experiencing higher maintenance demand also have systematically higher input costs or choose different factor mixes, then (12) is biased. There could be several confounding factors. For instance, unobserved firm-level supply shocks could simultaneously affect both the intensity of maintenance and the relative price of that maintenance. Similarly, unobserved

local demand conditions or region-specific economic expansions might simultaneously affect input prices and maintenance activity.

To isolate exogenous variation in the relative price, I employ a shift-share instrument. In essence, we want variation in input costs that is plausibly unrelated to firm-level or capital-type-specific unobserved factors. To motivate this approach, imagine a hypothetical experiment in which a central planner randomly assigns a series of "shifts" in national input markets. For example, consider a scenario where the federal government randomly allocates subsidies or imposes sudden global commodity price changes that affect material costs for maintenance. Likewise, imagine national-level negotiations or policies that randomly alter the prevailing wage index for certain maintenance occupations across states. In such an idealized setting, these cost changes would be as good as randomly assigned from the perspective of individual firms, ensuring that any resulting changes in maintenance input prices are not driven by firm-level or region-specific unobserved conditions. Toward approximating that idealized experiment, I construct the instrument

$$Z_{i,j,t} = \underbrace{\frac{\text{Materials}_{i,j,t-1}}{\text{Internal}_{i,j,t-1}} C_{t-1}}_{\text{Material Cost Exposure}} + \underbrace{\frac{\text{Labor}_{i,j,t-1}}{\text{Internal}_{i,j,t-1}} \sum_{s=1}^{S} \frac{\text{Rail Miles}_{i,s,t-1}}{\text{Rail Miles}_{i,t-1}} W_{s,t-1}}_{\text{Labor Cost Exposure}}. \tag{13}$$

$Z_{i,j,t}$ is the exposure of firm i and capital type j to input cost shocks, which can be broken down into material and labor cost exposure. Exposure comes from the ratio of internal materials maintenance costs to total internal maintenance costs. Figure B.6 indicates substantial variation in these shares between capital types and within firms over time. The firm i and capital type j exposure to materials cost shocks is given by the ratio of $t-1$ materials costs to total internal maintenance costs multiplied by a national materials cost index C_{t-1}, which is the producer price index "Intermediate Demand by Commodity Type: Materials and Components for Manufacturing." The idea here is to take a sufficiently broad category of materials costs that maintenance demand from freight rail could not affect. The labor cost exposure is slightly more complex. It takes the ratio of pre-period labor cost to internal maintenance cost and multiplies that ratio by a weighted average of state-level maintenance costs $W_{s,t-1}$. State weights are the ratio of rail miles in a particular state to total rail miles owned by firm i. The maintenance cost is the wage index for occupation code 49-0000, which is a broad category of maintenance workers. Within railroads, maintenance centers are geographically dispersed and not determined *ex ante* by local labor costs.

In practice, the instrument approximates the ideal experiment by using national and

state-level input cost indices as "shifts" and employing firm- and capital-type-specific cost shares as "weights." In the language of Borusyak, Hull, and Jaravel (2024), I leverage the "many exogenous shifts" approach rather than the exogenous shares approach. The instrument thus leverages exogenous variation in material and labor input costs that arises from broad economic conditions outside the firm's control. Provided that these shifts are not systematically related to unobserved local confounders—such as persistent differences in asset age that also correlate with material cost shares or local booms that simultaneously raise wages and maintenance—this approach recovers a causal elasticity.

A model extension in Appendix A.4 complements the identification strategy by formally illustrating how exogenous shifts in input costs influence a firm's maintenance choices. In the model, maintenance is disaggregated into internal and external components, with the former comprising labor and materials expenditures. The resulting first-order conditions imply that the relative price of maintenance, which is effectively a weighted average of input prices, is determined by the firm's cost exposures. This structure underpins the shift-share instrument: national materials cost indices and state-level wage indices, which serve as the "shifts," interact with firm- and capital type–specific cost shares, the "weights," to generate variation in maintenance input prices that is plausibly exogenous. Hence, theory provides a foundation for the approach.

To address potential confounding at both the unit level and the shift level, I include a number of controls. First, at the shift level, changes in local demand could lead to changes in demand for freight rail services, which may affect input costs and maintenance demand simultaneously. Consequently, I construct each firm's demand exposure as a weighted average of state-level GDP growth rates, with weights determined by freight miles in every state. Second, while the time fixed effect helps address confounding at the national level, I also include firm-specific time trends. The firm-trends help address confounding by capturing unobserved, time-varying factors that are unique to each firm and may influence maintenance demand independently of the instrument. For example, the firm-specific trend effectively controls for dynamic changes such as firm-specific technological advancements, management strategies, or responses to national economic shocks that are not fully accounted for by time fixed effects alone. At the unit level, I control for the age of capital because older capital may require more maintenance. I proxy for age with the inverse ratio of net to gross book capital.

Results. In Table 2, I present estimates of (12), where standard errors are clustered by firm and capital type. Columns (1) and (2) are OLS estimates of the maintenance elasticity of demand, while columns (3) and (4) use the exposure instrument defined above as an instrument. Columns (2) and (4) use GDP exposure and capital age—defined as

the ratio of net capital to gross capital—as controls. The price elasticity is consistently statistically significant between two and 3.5, although the estimates without controls in columns (2) and (4) are slightly smaller and the IV estimates are larger than the OLS estimates. For comparison, the tax elasticity of the investment rate is generally between 0.5 and 1 (Hassett and Hubbard 2002), while other studies have found values about twice as large (Zwick and Mahon 2017). Consequently, my estimated partial equilibrium maintenance elasticities are about twice as large as prevailing partial equilibrium investment elasticity estimates.

Table 2: The Effect of Relative Price Changes on Maintenance Rates

	Dependent Variable: $\log m_{i,j,t}$			
	(1)	(2)	(3)	(4)
$\log P_{i,j,t}$	-2.116**	-2.679***	-3.058*	-3.442***
	(0.852)	(0.419)	(1.438)	(0.590)
Capital Age		0.778***		0.768***
		(0.149)		(0.141)
GDP Exposure		0.025		0.027*
		(0.013)		(0.012)
Observations	342	342	342	342
R^2	0.646	0.836	0.641	0.833
F-stat			132.9	132.4
Type	OLS	OLS	IV	IV
Firm-Year Trends	N	Y	N	Y

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: This table estimates regressions using (12). The first two columns are OLS regressions and the second two use the exposure share IV discussed in the main text. Columns 1 and 3 are the baseline regression of a log maintenance variable on log relative prices. Columns 2 and 4 add controls for the age of capital, local GDP exposure, linear firm-year trends, and quadratic firm-year trends. Age is net capital stock scaled by gross capital stock. All regressions include year and firm-capital type fixed effects. Standard errors are clustered by firm.

I present three checks of the results in the appendix. First, I construct a measure of the capital stock which is purely physical rather than in dollar value. This is consistent

with a one-hoss shay depreciation profile for capital and hence is an extreme assumption. However, it is a useful assumption because it provides a bound on the degree of measurement error in the capital stock. I measure the stock of locomotive capital in units of horsepower and the stock of freight cars in tons of capacity. Both figures come from Schedule 710 of the R-1 report. These measures have a high correlation (0.9) with the book value of the capital stock. As such, they yield essentially practically the same estimates for both the reduced form and instrumental variables regressions in Appendix Table B.2. Second, Appendix Table B.3 examines the validity of the instrument when broken down into its respective components. Splitting the instrument into labor or materials yields the same results and the F-statistic remains greater than 100, indicating that the results are not primarily driven by one of them. Third, it is plausible that maintenance behavior is sticky. To test that, I re-estimate equation (12) using the lagged log maintenance rate as a control in Table B.4. This substantially diminishes the short-run price elasticity in both magnitude and significance, but the long-run elasticity is unchanged. Since the theoretical motivation comes from steady-state reasoning, that leaves our main results unchanged.

The main results aggregate external and internal maintenance into a single homogeneous input. That is probably not the case in practice. While both internal and external maintenance rely on contracts which are presumably sticky, there are reasons to think that the latter would be stickier. With internal maintenance, firms can respond to price changes by reallocating labor within the firm to other tasks or simply choosing not to maintain if materials prices rise too much. In contrast, external maintenance contracts are typically specified in advance and usually result from the original purchase. That suggests some degree of heterogeneity in the maintenance demand elasticity, something I explore theoretically in Appendix A.4. Table 3 offers a more precise window into what drives the change in demand for maintenance. Splitting into internal and external maintenance and re-running (12) yields that the estimated elasticity is around six for internal maintenance and zero for external maintenance. Thus, the main result—that maintenance is price-elastic—is driven by internal maintenance.

Table 3: The Effect of Relative Price Changes on Maintenance Rates

	(1)	(2)	(3)	(4)
LHS: $\log m_{i,j,t}$ (Internal Maintenance Rate)				
$\log P_{i,j,t}$	−4.159*	−4.314**	−6.249*	−6.343***
	(1.819)	(1.185)	(3.117)	(1.699)
Capital Age		1.056***		1.034***
		(0.174)		(0.184)
GDP Exposure		0.017		0.022
		(0.024)		(0.020)
R^2	0.658	0.817	0.640	0.800
LHS: $\log m_{i,j,t}$ (External Maintenance Rate)				
$\log P_{i,j,t}$	1.312**	0.287	1.056	1.208
	(0.467)	(0.709)	(1.663)	(0.907)
Capital Age		0.641***		0.651***
		(0.125)		(0.164)
GDP Exposure		0.019		0.016
		(0.019)		(0.020)
R^2	0.659	0.814	0.659	0.812
Observations	342	342	342	342
F-stat		131.3	133.0	
Type	OLS	OLS	IV	IV
Firm-Year Trends	N	Y	N	Y

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: This table estimates regressions using (12). The first two columns are OLS regressions and the second two use the exposure share IV discussed in the main text. Columns 1 and 3 are the baseline regression of a log maintenance variable on log relative prices. Columns 2 and 4 add controls for the age of capital and either log investment (for the case with maintenance in levels) or a log investment rate (when the maintenance rate is on the LHS). Age is net capital stock scaled by gross capital stock. All regressions include firm, year, and capital type fixed effects. Standard errors are clustered by firm.

4.2   Maintenance in General Equilibrium

In general equilibrium, firms may sell used capital to each other, resulting in a smaller reduction in maintenance than we would predict from simply observing the decline in maintenance expenditures from an individual firm in partial equilibrium. An extension of the baseline model to include reallocation in Appendix A.3 shows how this channel would depress the aggregate maintenance elasticity. As an aggregate check on the R-1 data, I rely on a stratified industry-level sample of unaudited corporate tax returns produced by the Statistics of Income Division (SOI) of the IRS. In contrast to the R-1 data, which uses the asset-firm as the observational unit, we can broadly interpret an industry-level demand elasticity from the SOI as reflecting an aggregate elasticity which nets out any reallocation. That relies on the assumption that the SOI industries are sufficiently broad and capital use sufficiently specific that any capital sales following a tax cut would remain within the corresponding industry. While that assumption is reasonable for some industries, it is more difficult to make that argument for others. For example, an oil rig is essentially useless outside the oil industry, while a used rental car from Hertz can be used in essentially any industry.

Corporations report a large number of operating expenses and balance sheet items as line items on their tax forms to the IRS. The SOI is the only economy-wide collection of maintenance data at an annual frequency in the United States. I rely on Table 12 (now known as Table 5.3), which excludes filings made with Forms 1120S, 1120-REIT, and 1120-RIC. Economists have used the underlying microdata to estimate tax elasticities of investment (Zwick and Mahon 2017; Kennedy et al. 2023). I do not have access to the administrative data and so I rely on the industry-level sample, which I aggregate to fifty industries at the the approximately three-digit NAICS level.[10]

Identification Strategy.   I rely on a classic identification strategy in empirical public finance to estimate the maintenance demand elasticity. Because industries vary in their capital compositions, they also vary in their marginal tax rates. Through variation in industry production technologies, we observe variation in tax wedges. Some industries use more structures, while others use more equipment. The end result, due to differential capital taxation, is that marginal tax rates vary widely by industry. For any capital type j,

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10. Because I rely on BEA data to construct tax rates and other variables and the number of SOI industries fluctuates over time but is always weakly larger than the number of BEA industries, I map the SOI industries into BEA industries for consistency and use the latter as a unit of observation. There are 49 such industries after excluding the financial sector. I use the BEA industry definition for two reasons. First, I mix the BEA and SOI data in some robustness checks. Second, the BEA industry definition is more aggregated across SOI samples than the SOI data, which helps maintain definitional consistency and also supports the GE interpretation of the data I prefer.

the marginal tax rate is

$$\tau_{j,t} = 1 - \frac{1 - \tau_t^c}{1 - z_{j,t}\tau_t^c}.$$

Under the permanent component of current law, investment in a locomotive is depreciated over fifteen years, meaning that it is expensed in pre-determined parts over that time frame. By contrast, nonresidential structures are expensed over several decades. The difference in the timing of tax deductions yields differences in tax rates due to discounting. Such differences are determined by an asset's categorization in the IRS's Modified Accelerated Cost Recovery System (MACRS). Given a mapping from House and Shapiro (2008) of BEA assets to MACRS and capital weights for each industry from the BEA, I construct a panel of marginal tax rates by industry.

There have been two broad categories of tax changes since 9/11 that have led to policy variation. First, since the early 2000s, the federal government has repeatedly turned to bonus depreciation for equipment—but not structures—as a means of promoting both short-run stimulus and long-run growth. Bonus depreciation allows firms to deduct an extra percentage of their investment expenditures every year for particular types of capital goods. Usually, firms are allowed to deduct from gross income a certain percentage of their investment according to guidance from the IRS determined by the Modified Asset Cost Recovery System. Let the net present value of one dollar of these deductions be denoted as z_t. If the bonus depreciation percentage is θ, then the effective present value of depreciation deductions is $\tilde{z}_t = \theta + (1 - \theta) z_t$. When $\theta > 0$, which is when bonus depreciation is in effect, then firms get to deduct more of their investment upfront. Because some industries rely more on capital exposed to bonus than others, this leads to exogenous variation in tax policy across firms. Indeed, a large battery of studies from House and Shapiro (2008), Kitchen and Knittel (2011), Zwick and Mahon (2017), Garrett, Ohrn, and Suárez Serrato (2020) show that such policies had large effects on firm-level investment and employment outcomes. Second, the 2017 Tax Cuts and Jobs Act increased bonus from 50% to 100% for eligible capital and also slashed the corporate rate from 35% to 21%. Although this made the marginal rate zero for bonus-eligible capital, the absolute change in tax rates was larger for ineligible capital. This, once more, led to variation across industries in exposure to tax policy, which Kennedy et al. (2023) and Chodorow-Reich et al. 2023 show substantially boosted investment.

I leverage cross-sectional variation in industry exposure to tax policy together with time series variation in tax policy to identify the coefficient ω in

$$\log m_{i,t} = \alpha_i + T_t + \omega \log (1 - \tau_{i,t}) + \text{Controls} + \varepsilon_{i,t}, \tag{14}$$

where α_i is an industry fixed effect and T_t is a time fixed effect. To construct the tax instrument $\tau_{i,t}$, I use a mix of pre-period capital weights through 2011 and capital weights lagged by ten years from 2012 onward. The idea is that, since the sample period is 1998-2019 and there were policy changes from essentially 2002 onward, it is best to strike a balance between exogeneity and relevance. Full exogeneity would guarantee weights are independent of future policy. This is what Zwick and Mahon (2017) rely on, but their study only runs through 2010 and hence weights from 1998 would plausibly still be relevant for the end of the sample period. On the other hand, capital weights from 1998 are considerably less relevant for firms in 2017 leading up to the Tax Cuts and Jobs Act than more recent weights, but weights from 2017 would similarly be endogenous to contemporaneous factors stemming from reverse causality and omitted variable bias. Figure B.9 plots $\tau_{i,t}$ by industry over the sample period.

The primary assumption is that the industry-by-year level policy variations are independent of other industry-by-year shocks that could simultaneously affect maintenance rates. These shocks might simultaneously influence both the implementation of tax policies and maintenance behaviors within industries, violating the assumption that policy variations are independent of other industry-year level factors. For example, policy around Covid-19 would plausibly not meet this criteria. Without adequately controlling for these time-varying confounders, the estimated relationship between tax policy and maintenance rates could be confounded by these unobserved influences. Toward mitigating that, I include broad linear and quadratic industry trends at the two-digit NAICS level.

Results. The first two columns of Table 4 show estimates of (14). The first column of each group is a simple regression of the log maintenance rate on the log tax term, while the second column includes a control for the age of capital proxied by the ratio of gross to net book capital, and both include linear and quadratic trends for two-digit NAICS industries. Controlling for age accounts for the fact that older capital may require more maintenance. In the bottom row, I estimate an implied value for γ by taking the sample mean of maintenance rates within the sample and dividing by the mean of the tax term raised to ω. Compared to the partial equilibrium R-1 coefficient, the SOI general equilibrium coefficient is only about half as large and is marginally statistically significant. The gap between the two suggests some reallocation between firms following tax cuts, resulting in a smaller decline in aggregate maintenance than we observe at the micro level. However, that conclusion must be tempered by the fact that there is some omitted variable bias introduced by the omission of a pre-tax price of maintenance in the SOI regression.

Table 4: The Effect of Tax Changes on Industry-Level Maintenance Rates

	All Firms		Taxable Firms		Untaxable Firms	
	(1)	(2)	(3)	(4)	(5)	(6)
$\log(1 - \tau_{i,t})$	−2.032*	−2.157*	−4.265***	−3.978***	2.684	2.702
	(1.121)	(1.179)	(1.368)	(1.247)	(1.773)	(1.719)
Capital Age		0.237**		0.223**		0.119
		(0.108)		(0.085)		(0.096)
Implied γ	0.052	0.051	0.039	0.041	0.054	0.054
Observations	1067	1064	1023	1014	1021	1012
R^2	0.910	0.913	0.750	0.754	0.612	0.620
Industry Trends	Y	Y	Y	Y	Y	Y

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: This table estimates regressions using (14). The columns are grouped into three different categories. The first two contain estimates from the SOI sample including all firms, the second two contain firms with positive net income, and the final two for firms without net income. The first column in each group estimates the baseline regression of the log maintenance rate on the log tax rate for taxable firms with two-way fixed effects and both linear and quadratic industry trends. The second column in each group adds age, proxied as the ratio of gross to net book capital, as a control. In all regressions, standard errors are clustered by industry. In the bottom row, I estimate an implied value for γ by taking the sample mean of maintenance rates within the sample and dividing by the mean of the tax term raised to the estimated ω in the corresponding column.

In the aggregate, some reallocation seems to be taking place and resulting in maintenance dampening. To partially test for that, I split the sample into firms with positive net income ("taxable") and untaxable firms. The mapping is rough because some of the firms in the untaxable sample have positive net operating losses, so they are not actually taxable. In principle, maintenance should rise for untaxable firms and decline for taxable firms following a tax cut if the reallocation model is qualitatively correct. Even if no reallocation takes place, the demand elasticity should be significantly larger for taxable than untaxable firms. To account for that, columns 3 and 4 in Table 4 re-estimate (14) for the sample of firms with taxable income. The maintenance demand elasticity doubles to around four and becomes more statistically significant, which is quite similar to the par-

tial equilibrium estimate in Table 2. Columns 5 and 6 estimate the demand elasticity for untaxable firms. Such firms weakly increase their maintenance intensity following a tax cut, but the result is not statistically significant.

There are two potential sources of measurement error with the maintenance rate, both of which may plague the estimates. The first comes from the denominator, which is the lagged capital stock. Because that measure of capital is tax book capital and is inherently determined by tax policy, there is industry-specific and time varying measurement error by construction. The set of controls largely deal with this. The industry fixed effects account for time-invariant characteristics and baseline differences across industries that would otherwise systematically distort capital measurements. Since the time fixed effects isolate industry-specific variation in exposure to tax policy changes, including linear and quadratic industry trends captures time-varying unobserved factors within industries. Finally, by construction, the tax term itself explicitly models the varying degrees of tax policy exposure across industries and therefore directly addresses the primary source of measurement error related to tax policy differences.

Appendix Table B.8 presents separate estimates of the maintenance elasticity using a BEA measure of capital instead. These data come from the detailed fixed asset tables by industry and come with the corresponding issue that the capital stock is a mix of corporate and non-corporate capital. Nevertheless, it is encouraging that the estimates are similar across specifications, though they become statistically insignificant for the All Firm sample. Another source of error, which is only relevant for the taxable and untaxable samples, is that lagged capital is for a different set of firms in the current than the previous period. I correct for this by using contemporaneous rather than lagged capital. The corresponding estimates in Appendix Table B.9 are largely the same as in Table 4.

Another source of concern is the internal-external maintenance margin, which I showed in Table 3 is important. Since the aggregate elasticity is a weighted average of the contributions of internal and external maintenance, the coefficient may be biased in the main specification. Indeed, if there is considerable heterogeneity by industry, then exposure to tax policy changes depends not only on the composition of capital but on the composition of internal versus external maintenance as well. I cannot separately test internal or external maintenance for the SOI, but because it seems as if the distribution of internal maintenance rates is fairly uniform from Figure 4, the coefficient is probably not biased very much.

There are two further potential issues. First, the SOI changed the number of industries sampled after 2013. Because some of the sampled industries are too small in that period, the IRS censored their reporting meant that some industries did not report maintenance

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expenditures, resulting in the possibility of some aggregation error. Second, there is some concern about endogeneity of the capital weights because they are not fixed starting in 2011. Toward addressing both issues at once, I re-estimate (12) using fixed weights over the period 1999-2013 in Appendix Table B.10. The results for the taxable and untaxable firm samples is largely the same as in the main text, but the all firm sample results are statistically insignificant. Finally, Appendix Figure B.10 plots the estimated tax elasticities as a function of the capital weight lag length. The shorter the lag length, the greater the endogeneity concern and the lesser the relevance concern. Although coefficients are larger with shorter lag length, they do not change very much as the lag length increases.

5   Capital Maintenance and the 2017 Tax Cuts and Jobs Act

Theory suggests that positive and elastic maintenance demand significantly dampens traditional capital deepening effects of tax reform. In late 2017, Congress passed the Tax Cuts and Jobs Act, which considerably reduced the cost of corporate capital. Lawmakers permanently reduced the corporate tax rate from 35% to 21% and introduced 100% bonus depreciation for certain types of equipment.[11] The latter policy allows firms to immediately deduct investment from their tax bill, thereby eliminating the tax wedge in the maintenance-investment choice. President Trump's Council of Economic Advisors described the motivation and mechanism for the law's domestic business tax provisions through the traditional capital deepening channel:

> A primary mechanism through which changes in corporate tax rates and depreciation allowances affect business investment is their effect on the user cost of a capital investment—which can be thought of as the rental price of capital, and is the minimum return required to cover taxes, depreciation, and the opportunity costs of investing in capital accumulation versus financial alternatives. A decrease in the user cost increases the desired capital stock, and thereby induces gross investment. (CEA 2018, p. 57)

Subsequent analyses started from the same perspective. For example, Chodorow-Reich et al. (2023) examine the empirical and quantitative dynamic effects of TCJA using a multinational Hall-Jorgenson framework, while Barro and Furman (2018) focus solely on the steady state effects in a closed economy neoclassical model featuring heterogeneous

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11. See Gale et al. (2018) and Gale, Hoopes, and Pomerleau (2024) for a broad overview of the law, Clausing (2024) for description and analysis of the international provisions, and Chodorow-Reich et al. (2023) and Kennedy et al. (2023) for corresponding analysis of the business tax provisions.

capital. In this section, I present a quantitative version of the model in Section 3 to study the effects of TCJA on domestic corporate capital. My approach takes the CEA view as given and asks how much maintenance alters the transmission mechanism beyond the traditional capital deepening channel.

5.1 Model and Calibration

The model is largely the same as in Section 3. There are several key differences which enable us to map short-run changes in the partial equilibrium model from Section 3 into the long run and from partial into general equilibrium. I largely rely on the domestic block of Chodorow-Reich et al. (2023) to carry out both mappings.

Environment. The model environment is largely the same as in Section 3 and is directly comparable to Chodorow-Reich et al. (2023). Time is discrete and infinite. There are two production sectors producing a final output good: a corporate sector and a non-corporate sector. Both have identical production functions which are Cobb-Douglas in capital and labor with respective shares α_K and α_L. Using the properties of Cobb-Douglas production, we can rewrite output net of the wage bill as

$$K_t^{\alpha_K} L_t^{\alpha_L} - w_t L_t = Z_t K_t^{\alpha},$$

where

$$\alpha \equiv \frac{\alpha_K}{1 - \alpha_L} \quad \text{and} \quad Z_t \equiv (1 - \alpha_L) \left(\frac{\alpha_L}{w_t} \right)^{\frac{\alpha_L}{1 - \alpha_L}}.$$

To calibrate the model, I normalize corporate productivity to one and set non-corporate productivity A such that the ratio of corporate to non-corporate gross output is 0.35, consistent with the Flow of Funds. Table C.1 gives a summary of the calibrated parameters.

Consistent with a constant elasticity maintenance demand function, I assume that

$$\delta(m_t) = \delta_0 - \frac{\gamma^{1/\omega}}{1 - 1/\omega} m_t^{1-1/\omega},$$

which maps neatly into estimated empirical moments. Following the empirical estimates from the All Firms sample in the SOI, I set the maintenance demand elasticity $\omega = 2$.[12] To calibrate γ, I solve $\gamma = \bar{m} \times (1 - \bar{\tau})^2 \times \frac{1}{0.7}$, where $\bar{m}$ and $\bar{\tau}$ are the average maintenance and tax rates in the SOI data in the All Firm sample. I further adjust this for parameter for the fact that labor is not included in the SOI maintenance costs, yielding $\gamma = 0.052$. The

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12. Since not all firms are taxable, the aggregate elasticity should reflect the All Firm sample.

factor of adjustment for labor costs comes from the R-1 data and the labor cost share in the maintenance and repair sector (NAICS code 811), both of which have a labor cost share of 0.3. I set $\delta_0 = 0.1449$ such that the pre-TCJA ratio of gross investment to gross output is 0.15, consistent with the average ratio of corporate physical investment to corporate net output in the pre-reform period. Next, I calibrate the tax change by taking a capital-weighted average of the domestic block in Table E.10 of Chodorow-Reich et al. (2023). To maintain comparability with that paper, I assume that bonus depreciation is permanent and the non-corporate sector is taxed at 28% pre- and post-TCJA.[13]

Short-run$\rightarrow$ Long-run. The mapping from short-run into long-run arises from assuming that firms pay a convex Hayashi-style adjustment cost in units of labor given by

$$\Phi(M_t, I_t, K_t) = \frac{1}{\phi} \left(\frac{I_t}{K_t} - \delta(m_t) \right)^2 K_t.$$

Note that this version of adjustment costs implies that maintenance instantaneously adjusts. I rely on capital adjustment costs because it allows for an easier comparison with Chodorow-Reich et al. (2023), which uses the same specification. I calibrate adjustment costs using the tautological relationship between the ratio of short-run to long-run investment elasticities χ_{SR}, the long-run tax elasticity of investment ε_X, and the short-run tax elasticity of investment β:

$$\frac{\beta}{\varepsilon_I} = \chi_{SR}.$$

The ratio χ_{SR} pins down the adjustment cost parameter ϕ. This approach is identical to Chodorow-Reich et al. (2023), but with three key differences. First, I take β and ε_I as exogenous rather than χ_{SR}. The reasoning is that, in the limit as $\gamma \rightarrow 0$, the long-run tax elasticity of investment is the same as in Chodorow-Reich et al. (2023) because I calibrate α using their parameterization, which makes my estimates directly comparable to theirs as maintenance demand goes to zero. Second, because maintenance is in the model, we have to adjust the empirical short-run elasticity for that. In Appendix A.2, I show that my parameterization of the depreciation technology implies that estimated investment elasticities should generally be adjusted upward by a factor of 1.5. Using the Chodorow-Reich et al. (2023) estimate of the short-run tax elasticity of investment therefore implies that $\beta \approx -6$. Third, the long-run elasticity of investment does not equal the long-run tax

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13. Because I assume, following Zwick and Mahon (2017), that non-corporate tax policy is static, I assume that the non-corporate sector does not maintain its capital. This assumption is irrelevant since I am similarly assuming that its tax treatment does not change.

elasticity of capital. In particular Appendix A.1 shows that

$$\varepsilon_I \approx \varepsilon_\delta + \varepsilon_K,$$

which is strictly larger than the NGM tax elasticity of investment in the case with $\omega, \gamma > 0$ and strictly smaller when $\omega \to 0$. Under my calibration the tax elasticity of investment is $\varepsilon_I \approx -4.6$, which means that $\chi_{SR} \approx 1.32$. This estimate is close to the ratio used in Chodorow-Reich et al. (2023) of 1.3 and well within the broad range of 1-1.6 they consider.

Partial Equilibrium → General Equilibrium. I map partial into general equilibrium in the labor market following Chodorow-Reich et al. (2023) and in the capital market following Barro and Furman (2018). On the labor side, note that productivity Z_t in the corporate sector is a function of the wage rate. In partial equilibrium, the elasticity of supply for labor is infinite, so wages do not change in response to tax reforms. In general equilibrium, the corporate and non-corporate sectors compete in a frictionless labor market for a perfectly inelastic supply of homogeneous labor (consistent with balanced growth preferences). The competition bids the wage up and attenuates the effect of the tax reform on macro outcomes.

On the capital market side, interest rates may rise in response to how the policy is financed. I take an *ad hoc* approach to accounting for that. The static net cost of the corporate provisions is around $0.7T. If that is financed with lump sum taxes, then there would be no endogenous response of r^k. On the other hand, if the tax reform is deficit-financed and the government does not have access to lump-sum taxes, then there may be an endogenous response of r^k. Laubach (2009) and Engen and Hubbard (2004) show that a ten percentage point increase in the debt/GDP ratio raises interest rates between 20 and 40 basis points. I take the midpoint of that range to estimate the degree of crowding out. Given the Congressional Budget Office estimate of GDP in 2027 and combining the dynamic response of output in the general equilibrium model *before accounting for crowding out* with the static cost estimate, r^k would increase by around 7 basis points in the NGMM and 6 basis points in the NGM. Thus, crowding out is negligible here.

5.2 Capital Accumulation and TCJA

Table 5 summarizes the long-run effects of TCJA on maintenance, investment, and capital accumulation in partial equilibrium and general equilibrium across the neoclassical model with maintenance (NGMM) and the neoclassical growth model. The latter is the

exact same model as the NGMM but with $\gamma = 0$. The NGMM partial equilibrium increase in capital is around 6.9%, while the general equilibrium increase is 3.4%. The corresponding figures in the NGM are 10.9% and 6.4%, respectively. The NGM results are similar to those reported byChodorow-Reich et al. (2023) on domestic capital. The general equilibrium results are also similar to those from Sedlacek and Sterk (2019) and Zeida (2022) despite the fact that both focus on firm dynamics and so the transmission of tax policy to growth is different. In both partial and general equilibrium, the NGMM increase in capital is approximately half as large as the NGM prediction.

Table 5: Long-run Responses of Maintenance, Investment, and Capital to TCJA

| | Partial Equilibrium | | | General Equilibrium | | | |
	M	X	K	M	X	K	w
NGMM	-0.2%	18.0%	6.9%	-3.4%	14.2%	3.4%	0.36%
NGM		10.9%	10.9%		6.4%	6.4%	0.59%

The partial equilibrium estimates assume the wage is fixed, while the general equilibrium estimates assume perfectly inelastic labor supply rationed across corporate and non-corporate sectors.
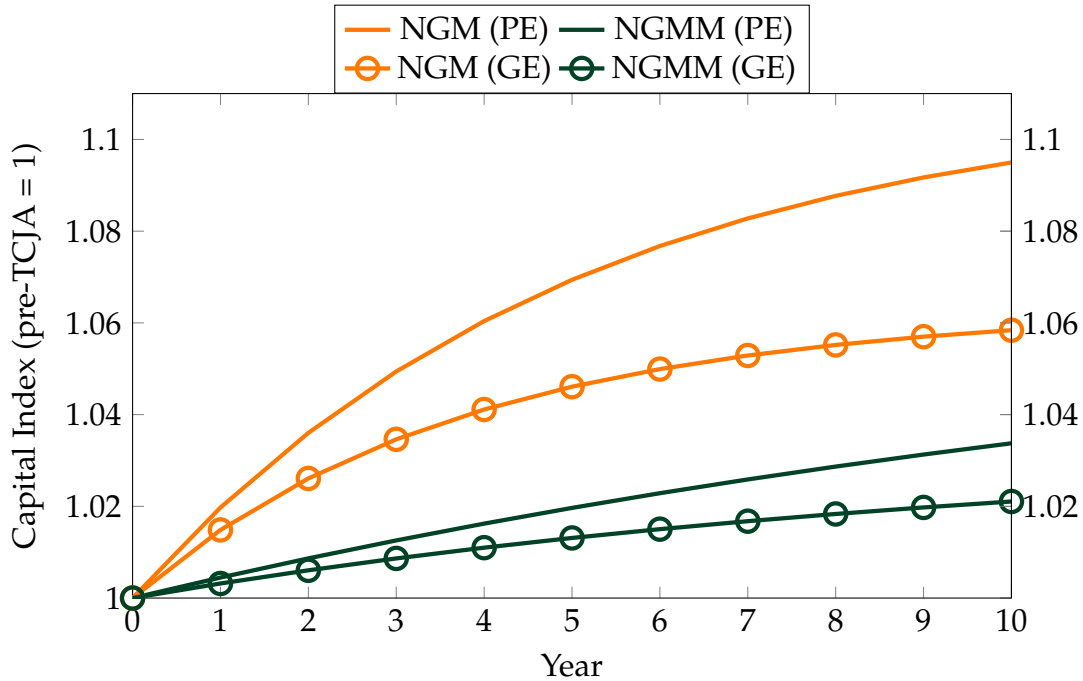
The source of the discrepancy between the NGM and the NGMM is the broken link between the capital and investment elasticities in the NGMM. In the standard model, the long-run elasticity of investment is identical to the long-run elasticity of capital. With a second input to produce capital, investment becomes about three times as responsive as capital to changes in tax policy, which implies that the investment elasticity is uninformative about capital and wages unless we know the maintenance elasticity. Indeed, in the NGMM, investment increases in the long run by more three times as much as capital.

There are two convenient ways to contextualize the results. First, the difference between partial and general equilibrium capital accumulation in the NGM is about as large as the difference in capital accumulation between the NGM and the NGMM in partial equilibrium. That is, accounting for maintenance is quantitatively equivalent to going from partial to general equilibrium in the NGM. Second, accounting for maintenance is roughly equivalent to cutting the profit elasticity by 50%. Consequently, if going from partial to general equilibrium or cutting the profit elasticity is quantitatively important in the NGM, then so is accounting for maintenance.

Figure 5 plots the partial and general equilibrium paths of capital in the NGM and

the NGMM. Since the implied adjustment costs are higher in the NGMM, the difference between the two models is more dramatic in the short run. Capital adjustment costs are higher in the NGMM than the NGM to account for the fact that both inputs to capital are more elastic than in the standard NGM. For example, by 2027, projected capital growth in the NGMM is about 30% as large as in the NGM. Given an initial level of corporate physical capital of $17T, that amounts to a difference of around $650B worth of corporate capital ten years out.

Figure 5: Path of Domestic Corporate Capital

Notes: The solid lines plot the partial equilibrium paths of domestic capital and the solid lines with circles plot the general equilibrium paths. The green lines are for the NGMM and the orange lines for the NGM.

Appendix C contains two additional results. First, Appendix C.4 gives the maintenance, investment, and capital elasticities across a variety of values for the maintenance elasticity of demand. Because the input substitution effect is second order, the resulting change in the capital stock does not vary much across different values of the demand elasticity ω. For example, if $\omega = 0$, then capital increases by 4.1%. In this edge case, the capital and investment elasticities are the same, but are nevertheless given a haircut by the existence of the maintenance-investment distortion. As ω rises, the change in capital does not vary by much, but the way capital changes does. As the demand elasticity rises, maintenance and investment become increasingly substitutable. Second, Appendix C.5

breaks down the change in capital for equipment and structures. There is little hetero-geneity in capital accumulation across capital types.

Altogether, the results suggest that the maintenance channel is quantitatively impor-tant for analyzing the consequences of capital tax policy for capital accumulation, and hence for wages, productivity, and output. Although most quantitative analyses of TCJA include a rich array of elements that my simple model does not, they tend to agree on the magnitude of the gains in domestic capital accumulation on the order of 5-7% in general equilibrium (Sedlacek and Sterk 2019; Zeida 2022; Chodorow-Reich et al. 2023). Mainte-nance may interact with capital in different ways in richer settings with more frictions, but fundamentally, the the lesson for tax models of all kinds is simply that maintenance acts as a powerful dampening force regardless of frictions.

6   Concluding Remarks

In this paper, I discuss the theoretical, empirical, and quantitative relevance of physical capital maintenance behavior around tax policy. I provide a parsimonious and flexible framework for evaluating the likely consequences on the short-run and long-run impacts on allocations of maintenance, investment, and capital. Additionally, I provide two novel sources of evidence on the price elasticity of maintenance. First, I put together an entirely new dataset on the maintenance and investment behavior of Class I freight railroads using financial filings from the Surface Transportation Board. Second, I leveraged maintenance data from corporate tax returns at the industry level from the IRS. These sources agree that the maintenance demand elasticity is plausibly around two. Quantitatively, this in-dicates a tax elasticity of the capital stock about half as large as we would predict using a standard neoclassical model. Importantly, it does not require any frictions and in fact re-lies entirely on combining a simple neoclassical model with an important but overlooked tax distortion.

Positive and elastic maintenance demand raises troubling questions for standard ap-proaches to capital theory and measurement. Perhaps the central issue in capital theory is the fact that capital is unobserved. To varying degrees of uncertainty, we observe what are presumably inputs into capital accumulation like investment, but it has historically been a source of controversy how to translate those observations into capital itself (Hayek 1935; Pigou 1941; Feldstein and Rothschild 1974). In recent years, this issue has become particularly salient for many types of intangible capital (Peters and Taylor 2017; Haskel and Westlake 2018; McGrattan 2020). A differentially taxed secondary input for physical capital production implies that measurement issues are perhaps as abundant for phys-

ical capital production as they are for intangibles. This finding raises a host of difficult questions far beyond the issues discussed in this paper around tax policy counterfactuals. Indeed, practically any researcher who relies on proper measurement of the capital stock and the cost of capital must consider the extent to which their question is contaminated by maintenance, which extends from growth accounting to the labor share and beyond.

More work needs to be done by economists on rigorously evaluating the empirical maintenance demand curves by capital type, which requires, in turn, that government agencies take a more active role in making maintenance data available to them. Given the groundwork laid here and in prior work by McGrattan and Schmitz Jr. (1999) and Goolsbee (2004), the case for public finance and macroeconomists to undertake these studies is, I think, too big to ignore.

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Appendices

A   Model Derivations

A.1   The Tax Elasticity of Investment

In steady state, investment is given by $I = \delta(m)K$. Defined explicitly in terms of tax rates,

$$I(\tau) = \delta(m(\tau)) \cdot K(\tau, m(\tau), \delta(m(\tau))) \tag{A.1}$$

To first order,

$$\varepsilon_I \approx \tau \left[\frac{\delta'(m(\tau))}{\delta(m(\tau))} m'(\tau) + \frac{1}{K} \left(\frac{\partial K}{\partial \tau} + \frac{\partial K}{\partial m(\tau)} m'(\tau) + \frac{\partial K}{\partial \delta(m(\tau))} \delta'(m(\tau)) m'(\tau) \right) \right] \tag{A.2}$$

$$= \varepsilon_\delta + \varepsilon_K.$$

With the Cobb-Douglas user cost specification and a depreciation technology

$$\delta(m) = \delta_0 - \frac{\gamma^{1/\omega}}{1 - 1/\omega} m^{1 - 1/\omega}$$

and replacing m with the corresponding optimality condition, steady state investment becomes

$$X = \left(\delta_0 - \frac{\gamma}{1 - 1/\omega} (1 - \tau)^{1 - \omega} \right) \left(\frac{r^k + \delta_0 + \frac{\gamma}{1 - \omega} (1 - \tau)^{1 - \omega}}{\alpha(1 - \tau)} \right)^{\frac{-1}{1 - \alpha}}, \tag{A.3}$$

I derive each in component in steps. Given τ small,

$$\delta(m) \approx \delta_0 + \frac{\gamma \omega}{1 - \omega} \left(1 - (1 - \omega)\tau \right).$$

Since

$$\frac{\partial \delta(m)}{\partial \tau} = -\gamma \omega,$$

the tax semi-elasticity is

$$\varepsilon_\delta \approx \frac{-\gamma \omega}{\delta_0 + \frac{\gamma \omega}{1 - \omega}}, \tag{A.4}$$

where I assume that $\tau \approx 0$. Since the pre-reform tax rate is 4%, this is a sensible approxi-

mation. Now consider the tax semi-elasticity of capital. In the first step,

$$\frac{\partial K}{\partial \tau}\frac{1}{K} = \frac{-1}{1-\alpha}\left(\frac{\alpha(1-\tau)}{r^k + \delta_0 + \frac{\gamma}{1-\omega}(1-\tau)^{1-\omega}}\right)\left(\frac{\alpha\left(\gamma(1-\tau)^{1-\omega} + r^k + \delta_0 + \frac{\gamma}{1-\omega}(1-\tau)^{1-\omega}\right)}{(\alpha(1-\tau))^2}\right)$$

$$= \frac{-1}{1-\alpha}\frac{1}{1-\tau}\left(1 - \frac{\gamma(1-\tau)^{1-\omega}}{r^k + \delta_0 + \frac{\gamma}{1-\omega}(1-\tau)^{1-\omega}}\right)$$

To first order, the semi-elasticity becomes approximately

$$\varepsilon_K \approx \frac{-1}{1-\alpha}\left(1 - \frac{\gamma}{r^k + \delta_0 + \frac{\gamma}{1-\omega}}\right). \tag{A.5}$$

Consequently, the tax semi-elasticity of investment is approximately

$$\varepsilon_I \approx \varepsilon_\delta + \varepsilon_K$$

$$\approx \frac{-\gamma\omega}{\delta_0 + \frac{\gamma\omega}{1-\omega}} + \frac{-1}{1-\alpha}\left(1 - \frac{\gamma}{r^k + \delta_0 + \frac{\gamma}{1-\omega}}\right). \tag{A.6}$$

Applying the parameters used in the quantitative section implies that $\varepsilon_I \approx -5$.

A.2 Omitted Variable Bias in Investment Regressions

Standard approaches to recovering the tax elasticity of investment are flawed. A typical approach runs a cross-sectional regression like

$$f\left(I_{i,t}, K_{i,t}\right) = \alpha_i + T_t + \hat{\beta}\log\left(\frac{r^k + \delta}{1 - \tau_{i,t}}\right) + \epsilon_{i,t}, \tag{A.7}$$

where $f\left(I_{i,t}, K_{i,t}\right)$ is typically the investment rate $I_{i,t}/K_{i,t}$ or $\log I_{i,t}$, α_i is a firm fixed effect, and T_t is a time fixed effect. The estimated coefficient $\hat{\beta}$ yields the price elasticity of investment. For example, Kitchen and Knittel (2011), Zwick and Mahon (2017), and Garrett, Ohrn, and Suárez Serrato (2020) use such regressions to evaluate bonus depreciation, while Kennedy et al. (2023) and Chodorow-Reich et al. (2023) do the same for the the 2017 Tax Cuts and Jobs Act. The maintenance model suggests that (A.7) is misspecified. Instead, economists should estimate

$$f\left(I_{i,t}, K_{i,t}\right) = \alpha_i + T_t + \beta\log\left(\frac{r^k + \delta(m_{i,t})}{1 - \tau_{i,t}} + m_{i,t\cdot}\right) + \epsilon_{i,t}. \tag{A.8}$$

Misspecification arises because the demand for investment depends on the demand for maintenance and hence standard regressions do not properly capture the true change in the incentive to build new capital. This introduces an omitted variable bias in standard regressions which biases downward estimated investment elasticities. The insight is analogous to the lesson of Goolsbee (1998a), which emphasizes that an underlying model of a perfectly competitive capital goods market leads to an underestimate of the investment demand elasticity if the supply of equipment is not perfectly competitive. In the same way that regressing investment on a tax term alone assumes perfect competition in the supply of investment goods, so too does omitting maintenance imply a particular model of capital production.

Corollary 2. *With a constant elasticity of demand for maintenance $m_{i,t} = \gamma(1 - \tau_{i,t})^{-\omega}$ and baseline depreciation δ_0, the true price elasticity of investment β is equal to*

$$\beta = \frac{\hat{\beta}}{1 - \frac{\gamma}{r^k + \delta_0 + \frac{\gamma}{1-\omega}}}, \tag{A.9}$$

so the true investment elasticity is strictly larger if $\gamma > 0$.

Proof: Appendix A.2.

Proposition 2 *With a constant elasticity of demand for maintenance $m_{i,t} = \gamma(1 - \tau_{i,t})^{-\omega}$, the true price elasticity of investment is*

$$\beta \approx \frac{\hat{\beta}}{1 - \frac{\gamma}{r^k + \delta_0 + \frac{\gamma}{1-\omega}}}. \tag{A.10}$$

Proof. Consider the regressions

$$f(I_{i,t}, K_{i,t}) = \alpha_i + T_t + \hat{\beta} \log\left(\frac{r^k + \delta}{1 - \tau_{i,t}}\right) + \epsilon_{i,t}, \tag{A.11}$$

and

$$f(I_{i,t}, K_{i,t}) = \alpha_i + T_t + \beta \log\left(\frac{r^k + \delta(m_{i,t})}{1 - \tau_{i,t}} + m_{i,t}\right) + \epsilon_{i,t}. \tag{A.12}$$

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Under the assumption that $\tau_{i,t}$ is small, the omitted term is

$$\text{Omitted Term} = \log\left(\frac{r^k + \delta_0 + \frac{\gamma}{1-\omega}(1-\tau_{i,t})^{1-\omega}}{1-\tau_{i,t}}\right) - \log\left(\frac{r^k+\delta}{1-\tau_{i,t}}\right)$$

$$\approx \log\left(\frac{r^k + \delta_0 + \frac{\gamma}{1-\omega}(1-(1-\omega)\tau_{i,t})}{r^k+\delta}\right)$$

$$= \log\left(\frac{r^k + \delta_0 + \frac{\gamma}{1-\omega}}{r^k+\delta}\left(1 - \frac{\gamma\tau_{i,t}}{r^k+\delta_0+\frac{\gamma}{1-\omega}}\right)\right)$$

$$\approx \frac{\gamma\tau_{i,t}}{r^k+\delta_0+\frac{\gamma}{1-\omega}},$$

where I omit the constants since they will not affect the covariance. Using that, the omitted variable bias is given by:

$$\text{Bias} = \beta \cdot \frac{\text{Cov}\left(\log\left(r^k+\delta\right) - \log\left(1-\tau_{i,t}\right), \frac{\gamma\tau_{i,t}}{r^k+\delta_0+\frac{\gamma}{1-\omega}}\right)}{\text{Var}\left(\log\left(\frac{r^k+\delta}{1-\tau_{i,t}}\right)\right)}$$

$$\approx \beta \cdot \frac{\text{Cov}\left(\tau_{i,t}, \frac{\gamma\tau_{i,t}}{r^k+\delta_0+\frac{\gamma}{1-\omega}}\right)}{\text{Var}\left(\tau_{i,t}\right)} \qquad (\text{A.13})$$

$$= \beta \cdot \frac{\gamma}{r^k+\delta_0+\frac{\gamma}{1-\omega}}$$

Since we can write

$$\hat{\beta} = \beta\left(1+\text{Bias}\right),$$

a general expression for the true elasticity parameter is

$$\beta \approx \frac{\hat{\beta}}{1 - \frac{\gamma}{r^k+\delta_0+\frac{\gamma}{1-\omega}}}. \qquad (\text{A.14})$$

Therefore, we cannot use the standard tools of public finance to assess the effects of tax reforms unless we also know the maintenance demand function. Under this paper's parameterization, a maintenance-corrected coefficient boosts the estimated elasticity by a factor of about 1.5. Note, moreover, that this formula corresponds to many estimated elasticities. For example, many papers regress investment or the investment rate on the tax term alone, which itself comes from an approximation of the log user cost above. Therefore, the consensus range of investment rate elasticities from Hassett and Hubbard

(2002) of 0.5-1 is perhaps more like 0.75-1.5. □

A.3 Capital Reallocation

This subsection extends the base model to heterogeneous firms which only differ in their tax status. That leads to reallocation through variation in the marginal product of capital. A fraction $\lambda \in (0,1)$ of firms is taxable (Type T) and the remaining $1 - \lambda$ are untaxed (Type U). Variation in taxability comes from realization of an i.i.d. fixed cost F, which is assumed to be sufficiently large that it exceeds profits. Untaxed firms also pay a higher cost of investment $p^I + b$, which is meant to account (in a reduced-form way) for the fact that untaxable firms often face some kind of financial constraint that hinders their ability to access new investment (Lian and Ma 2020). This formulation allows us to model the fact that investment is typically more expensive for unprofitable firms without explicitly modeling the borrowing constraint.

Each period, a firm observes its tax type $\theta \in \{T, U\}$:

- Type T (taxable) firms face corporate tax τ^c.

- Type U (untaxed) firms pay no corporate tax because they have a fixed cost F. They also have a higher cost of investment $p^I + b$.

After observing its type, a firm chooses:

1. Maintenance expenditure M, with $m = \frac{M}{K}$ being the maintenance intensity.

2. Investment I (at new capital price p^I).

3. Net used-capital sales s, where $s > 0$ indicates selling a fraction of the capital and $s < 0$ indicates buying used capital. Firms pay a convex adjustment cost $G(s)$ for participating in the used capital market, which can be thought of as accounting for information frictions in a reduced-form way. For example, a firm selling a used car much furnish information about the vehicle, which is costly to do. The equilibrium used-capital price is denoted by q.

Putting together maintenance expenditures $m = M/K$, investment I, and capital sales s, the law of motion for capital (independently of tax status) is

$$K' = \left[1 - \delta(m)\right](1 - s)K + I. \tag{A.15}$$

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Because firms vary in their tax status, they also vary in their cash flows. Profitable firms have cash flows

$$\pi^T = (1 - \tau^c)\Big[F(K) - p^m M + q\, s\, K - G(s)\Big] - (1 - c - \tau^c z)\, p^I I,$$

where z incorporates the possibility that the firm may be untaxable in the future and hence will not always be able to take advantage of a tax depreciation allowance. Note that capital sales are taxed at rate τ^c, reflecting current policy practice. Given those cash flows, we get the following recursive formulation for a firm choosing K', s, M:

$$V^T(K) = \max_{m,s,K'} \bigg\{ (1 - \tau^c)\Big[F(K) - p^m\, mK + q\, s\, K - G(s)\Big]$$
$$- (1 - c - \tau^c z)\, p^I \Big(K' - [1 - \delta(m)](1 - s)K\Big) + \frac{V^*(K')}{1 + r^k} \bigg\}, \tag{A.16}$$

where
$$V^*(K') = \lambda\, V^T(K') + (1 - \lambda)\, V^U(K')$$

is the expected continuation value. Taxable firms therefore have the following FOCs:

$$\textbf{Investment: :} \quad \frac{V^{*'}(K')}{1 + r^k} = (1 - c - \tau^c z)\, p^I \tag{A.17}$$

$$\textbf{Maintenance: :} \quad -\delta'(m) = \frac{1 - \tau^c}{1 - c - \tau^c z}\frac{p^m}{p^I} \tag{A.18}$$

$$\textbf{Sales: :} \quad (1 - \tau^c)\Big[q - G'(s)\Big] = (1 - c - \tau^c z)\, p^I\, [1 - \delta(m)]. \tag{A.19}$$

On the other hand, untaxed type U firms do not face any tax, so their cash flows are

$$\pi^U = F(K) - p^m M + q\, s\, K - G(s) - (1 - \tau^c \tilde{z})(p^I + b)X - F.$$

Importantly, $\pi^U \leq 0$ due to the fixed cost. Note that $\tilde{z} < z$ and is meant to account for the fact that while firms are not able to take account of tax depreciation in this period, they may be able to in the future.

Given those cash flows, we get the following recursive formulation for a firm choosing

K', s, M:

$$V^U(K) = \max_{m,s,K'} \left\{ F(K) - p^m\, mK + q\, s\, K - G(s) \right]$$

$$\left. - (1 - \tau^c \tilde{z})(p^I + b)\left(K' - [1 - \delta(m)](1-s)K \right) + \frac{V^*(K')}{1 + r^k} \right\}. \tag{A.20}$$

The type U FOCs are:

$$\textbf{Investment:} \quad \frac{V^{*'}(K),}{1 + r^k} = p^I \tag{A.21}$$

$$\textbf{Maintenance:} \quad \delta'(m) = \frac{p^m}{(1 - \tau^c \tilde{z})(p^I + b)}(1-s), \tag{A.22}$$

$$\textbf{Sales:} \quad q - G'(s) = (1 - \tau^c \tilde{z})(p^I + b)\left[1 - \delta(m)\right]. \tag{A.23}$$

The envelope condition enables us to define the user cost of capital in this economy. For taxed firms,

$$V^{T'}(K) = (1 - \tau^c)\left[F'(K) - p^m\, m^T + q\, s^T \right] + (1 - c - \tau^c z)\, p^I\, (1 - \delta(m^T)),$$

while for untaxed firms we have

$$V^{U'}(K) = F'(K) - p^m\, m^U + q\, s^U + (1 - \tau^c \tilde{z})(p^I + b)\,(1 - \delta(m^U)).$$

The combined envelope condition puts those together:

$$V^{*'}(K) = \lambda\, V^{T'}(K) + (1 - \lambda)\, V^{U'}(K).$$

Equilibrium

An equilibrium in this economy is a collection of policies $\{V^T, V^U\}$, prices $\{q, p^I, p^M\}$ (the latter two exogenous) and allocations $\{m^T, s^T, K'^T, m^U, s^U, K'^U\}$ such that:

1. For all K, the Bellman equations for $V^T(K)$ and $V^U(K)$ are satisfied with the corresponding optimal policies.

2. The chosen policy functions satisfy the FOCs for investment, maintenance, and used-capital sales (with type–specific controls m^θ and s^θ) and the envelope conditions hold.

3. The law of motion for capital, $K' = \left(1 - \delta(m^\theta(K))\right)K + I$ is satisfied for each firm.

4. The used-capital market clears at the equilibrium price q; that is, the total net sales of used capital by all firms (taxable and untaxed) sum to zero:

$$\int s^T(K)\, d\mu(K) + \int s^U(K)\, d\nu(K) = 0,$$

   where $\mu(K)$ and $\nu(K)$ are the distributions of capital among taxable and untaxed firms, then the price q must be such that this condition is met.

5. The expected continuation value is given by $V^*(K') = \lambda\, V^T(K') + (1-\lambda)V^U(K')$, and firms form rational expectations consistent with the aggregate outcomes

Trading Conditions

Trading of used capital will only arise under certain conditions. In particular, an active trading market is characterized by:

- Taxable firms choosing $s^T > 0$ (selling used capital) because their subsidized cost $\frac{1-c-\tau^c z}{1-\tau^c}\, p^I(1-\delta(m^T))$ is lower than that faced by untaxed firms.

- Untaxed firms choosing $s^U < 0$ (buying used capital) because the equilibrium used capital price q (adjusted by the marginal cost $G'(s^U)$) falls below the cost of acquiring new capital $p^I(1-\delta(m^U))$.

- An equilibrium price q that satisfies

$$q = \frac{1-c-\tau^c z}{1-\tau^c}\, p^I(1-\delta(m^T)) + G'(s^T) = (1-\tau^c \tilde{z})(p^I + b)\,(1-\delta(m^U)) + G'(s^U),$$

   along with the market clearing condition

$$\lambda\, s^T + (1-\lambda)\, s^U = 0.$$

Essentially, we require that the gap between the pre-tax price and after-tax price of new capital is sufficiently large that it is worth it for firms to sell used capital and for untaxable firms to buy it, *i.e.*, $p^I(1 - \tau^c z - c) < q < (1 - \tau^c \tilde{z})(p^I + b)\,(1-\delta(m^U))$. I focus on this equilibrium because we observe active used capital trading in practice.

Aggregate User Cost of Capital

It is straightforward to observe that the aggregate user cost of capital in this economy is a weighted average of user costs for the taxable and untaxable firms:

$$\boxed{\Psi_{\text{agg}} = \frac{\lambda\, K^T}{K}\, \Psi^T + \frac{(1-\lambda)\, K^U}{K}\, \Psi^U, \quad \text{with } K = \lambda\, K^T + (1-\lambda)\, K^U.}$$

Indeed, one can observe that the proportional change in user cost will be strictly smaller to first order in this economy than in the representative firm economy in the main model because the share of untaxable firms will not react very much. Moreover, capital sales will prop up the maintenance rate (since the maintenance optimality condition implies a higher maintenance rate for untaxable firms), so maintenance and depreciation change less in this economy in the aggregate.

A.4 Extension to Multiple Maintenance Inputs

In this section, I extend the model to consider multiple inputs to maintenance production as well as a choice between using internal or external maintenance services. Production is carried out entirely using capital:

$$Y_t = F(K_t).$$

Capital evolves according to

$$K_{t+1} = \Big[1 - \delta(m_{I,t}, m_{E,t})\Big] K_t + I_t,$$

where $m_{I,t}$ is internal maintenance intensity and $m_{E,t}$ is external maintenance intensity. I assume that internal maintenance is the sum of labor and materials purchases

$$M_{I,t} = g(L_{m,t}, I_{m,t}).$$

The firm purchases internal maintenance labor at price w_t materials at price p_t^X. External maintenance $m_{E,t} = M_{E,t}/K_t$ is purchased at price p_t^m and faces some convex cost of adjustment $C(M_{E,t}, M_{E,t-1})$, with $C(M_E, M_E) = 0$ in steady state. This is to reflect the fact that external maintenance contracts are typically quite sticky. Since internal maintenance also includes labor, then internal maintenance is also sticky, but presumably less so than external maintenance because internal resources can be reallocated more quickly. I could capture that by having an outside option for labor or introducing a separate adjustment

cost for internal maintenance, but it would be unneccessarily complicated. Note that with multiple maintenance types, the price of maintenance is a weighted average of each.

Taking K_0 as given, the firm chooses the sequence $\{K_{t+1}, L_{m,t}, I_{m,t}, M_{E,t}\}_{t\geq 0}$ to maximize

$$\mathcal{L} = \sum_{t=0}^{\infty} \left(\frac{1}{1+r^k}\right)^t \left\{ (1-\tau_t^c)\left[F(K_t) - w_t\, L_{m,t} - p_t^I\, I_{m,t} - M_{E,t} - C\big(M_{E,t}, M_{E,t-1}\big)\right] \right.$$
$$\left. - (1-\tau_t^c z_t)p_t^I\left[K_{t+1} - \left(1 - \delta\big(m_{I,t}, m_{E,t}\big)\right)K_t\right] \right\},$$

subject to $m_{i,t} = \frac{g(L_{m,t}, I_{m,t})}{K_t}$. The first-order conditions are not substantially different from the baseline model. Starting with the capital Euler equation, we have The capital Euler equation is:

$$(1-\tau_t^c z_t)p_t^I = \frac{1}{1+r^k}\left\{ (1-\tau_{t+1}^c)\,F_K(K_{t+1}) + (1-\tau_{t+1}^c z_{t+1})\,p_{t+1}^I\left[1 - \delta\big(m_{I,t+1}, m_{E,t+1}\big)\right.\right.$$
$$\left.\left. + p_{t+1}^{M,I}m_{I,t+1} + p_{t+1}^{M,E}m_{E,t+1}\right] \right\},$$

$$(A.24)$$

which in steady state simplifies to

$$F_K = p^I(1-\tau^c z)\left(\frac{r^k + \delta(m_I, m_E)}{1 - \tau^c}\right) + p^{M,I}m_I + p^{M,E}m_E,\qquad (A.25)$$

where $p^{M,I}$ is the price of internal maintenance. If internal maintenance is a CES aggregator of labor and materials, then $p^{M,I}$ would just be the usual CES price index of p^I and w.

There are three maintenance choices. Beginning with the choice of internal labor $L_{m,t}$, the firm's optimal choice is satisfied when

$$-\delta_1(t)\,g_L(t) = \frac{(1-\tau_t^c)w_t}{(1-\tau_t^c z_t)p_t^I}.\qquad (A.26)$$

Similarly, optimal materials is given by

$$-\delta_1(t)\,g_M(t) = \frac{(1-\tau_t^c)p_t^X}{(1-\tau_t^c z_t)p_t^I},\qquad (A.27)$$

which implies the marginal rate of substitution between materials and labor is

$$\frac{g_L(t)}{g_M(t)} = \frac{p_t^I}{w_t}.$$

(A.28)

On the other hand, external maintenance choice is given by

$$-\delta_2(t) = \frac{(1 - \tau_t^c)\left[1 + C_1(t)\right] + \frac{1}{1+r^k}(1 - \tau_{t+1}^c)\,C_2(t+1)}{(1 - \tau_t^c z_t)p_t^I}.$$

(A.29)

B Data

B.1 Freight Rail

All variables from the freight rail data come from R-1 filings with the Surface Transportation Board (STB). I used Amazon Textract to extract the relevant data from filings prior to 2012; all data after that date is available on the STB website. Each variable comes from the following part of the R-1 filing:

- All components of **maintenance** come from Schedule 410, Line 202 (Locomotives) and Line 221 (Freight Cars)

- All components of investment and capital come from Schedules 330 and 335 from the lines pertaining to locomotives and equipment

- The miles of rail per state come from Schedule 702

- Data on capital inventories come from Schedule 710

I construct the relative price $P_{i,j,t} = \frac{p_{i,j,t}^m(1-\tau_{i,t})}{p_{j,t}^I}$ as follows:

1. **Price of investment.** The price of investment does not vary by firm, only by capital type. It is simply the BLS's producer price index for locomotives and freight cars.

2. **Tax term.** The tax term varies by firm but not by capital type because rolling stock are taxed at the same rate. However, there is variation between firms because firms vary in their geographic area and hence their exposure to state tax policy. R-1 Schedule 702 details the mileage of track by state for each firm. I use that information to construct a weighted tax term. I extend the dataset of Suárez Serrato and Zidar (2018) to construct the tax term through 2023.

3. **Price of maintenance.** The price of maintenance is a weighted average of labor and material costs. Labor costs are firm-specific and come from each firm's Wage Form A&B filed with the Surface Transportation Bureau. The materials cost index is from the Bureau of Labor Statistics. I weight each input with the cost share from Schedule 410, which breaks down maintenance expenditures by labor cost and materials for both locomotives and freight cars.
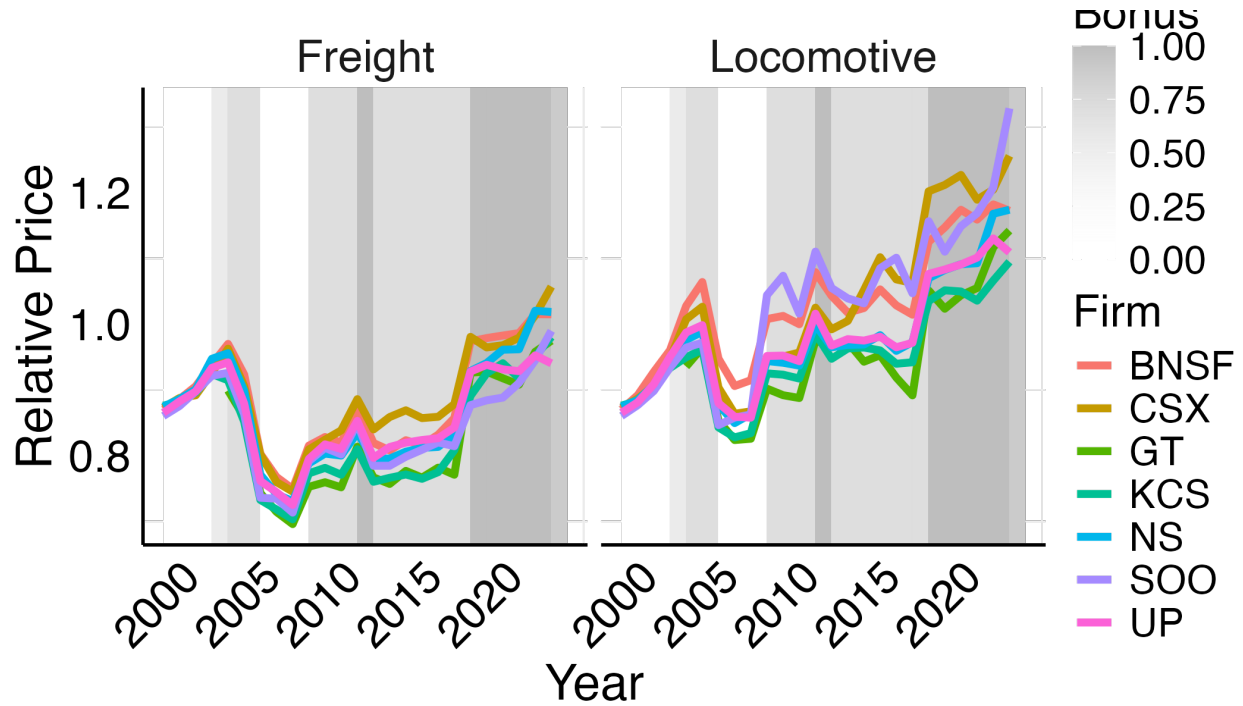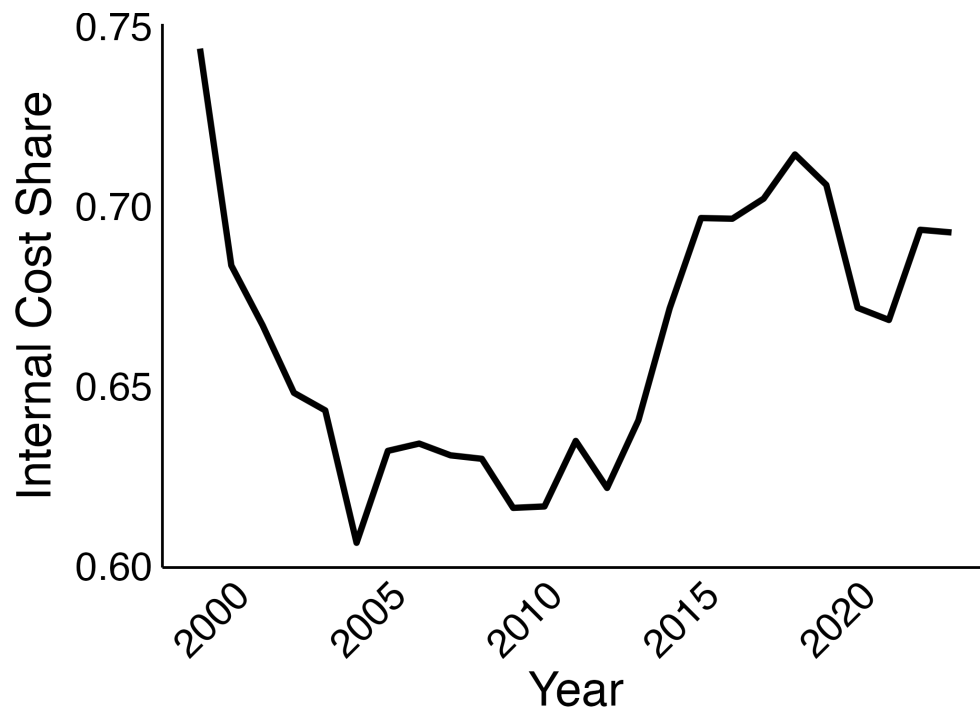

Figure B.1: The relative price of maintaining freight cars (left) and locomotives (right). The degree of shading corresponds to the strength of bonus depreciation.

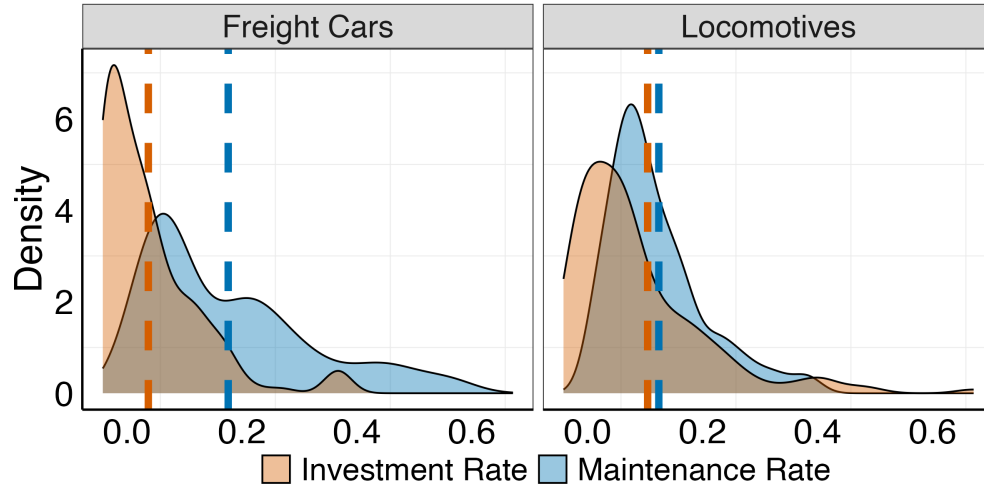Table B.1: Summary statistics for variables from R-1 financial statements.

Variable	Mean	10th Percentile	Median	90th Percentile	Count
Freight					
$m_{i,j,t}$ (Total)	0.218	0.079	0.158	0.454	171
$m_{i,j,t}$ (Internal)	0.152	0.049	0.104	0.345	171
$m_{i,j,t}$ (External)	0.066	0.022	0.052	0.121	171
$m_{i,j,t}$ (Physical)	0.034	0.016	0.032	0.057	171
$\log M_{i,j,t}$	11.709	10.346	11.926	13.034	171
$x_{i,j,t}$	0.079	0.002	0.054	0.187	171
$\log I_{i,j,t}$	9.141	5.539	10.327	11.828	171
$P_{i,j,t}$	0.857	0.757	0.857	0.964	171
Materials Cost Share	0.617	0.503	0.611	0.744	171
Capital Age	1.595	1.183	1.624	1.931	171
$Z_{i,j,t}$	114.842	75.420	115.364	151.858	171
$Z_{i,j,t}$ (Labor)	7.272	4.922	7.428	9.023	171
$Z_{i,j,t}$ (Materials)	107.570	67.947	107.723	145.385	171
C_t	172.475	127.392	177.175	219.012	171
W_t	19.241	15.391	19.082	23.477	171
Locomotives					
$m_{i,j,t}$	0.166	0.073	0.140	0.296	171
$m_{i,j,t}$ (Internal	0.108	0.041	0.094	0.191	171
$m_{i,j,t}$ (External)	0.057	0.005	0.047	0.115	171
$m_{i,j,t}$ (Physical)	0.025	0.016	0.023	0.036	171
$\log M_{i,j,t}$	11.995	10.348	12.375	13.415	171
$x_{i,j,t}$	0.146	0.022	0.099	0.283	171
$\log I_{i,j,t}$	11.193	9.112	11.681	13.019	171
$P_{i,j,t}$	0.995	0.870	0.973	1.147	171
Materials Cost Share	0.591	0.436	0.625	0.708	171
Capital Age	1.478	1.241	1.514	1.687	171
$Z_{i,j,t}$	110.050	78.919	110.708	143.870	171
$Z_{i,j,t}$ (Labor)	7.882	5.019	7.486	11.594	171
$Z_{i,j,t}$ (Materials)	102.168	66.417	104.370	138.301	171
C_t	172.475	127.392	177.175	219.012	171
W_t	19.241	15.391	19.082	23.477	171
Year	2011.246	2001.000	2011.000	2021.000	171
Local GDP Growth Exposure	1.996	-0.209	2.133	4.096	171

Figure B.2: Density plots for maintenance and gross investment rates.

Note: Each density plot is constructed with beginning of period book capital in the denominator. The dashed lines are mean maintenance and investment rates. For freight cars, the mean maintenance rate is 21.4% and mean investment rate is 8.2%, while the corresponding figures for locomotives are 16.5% and 14.4%, respectively.

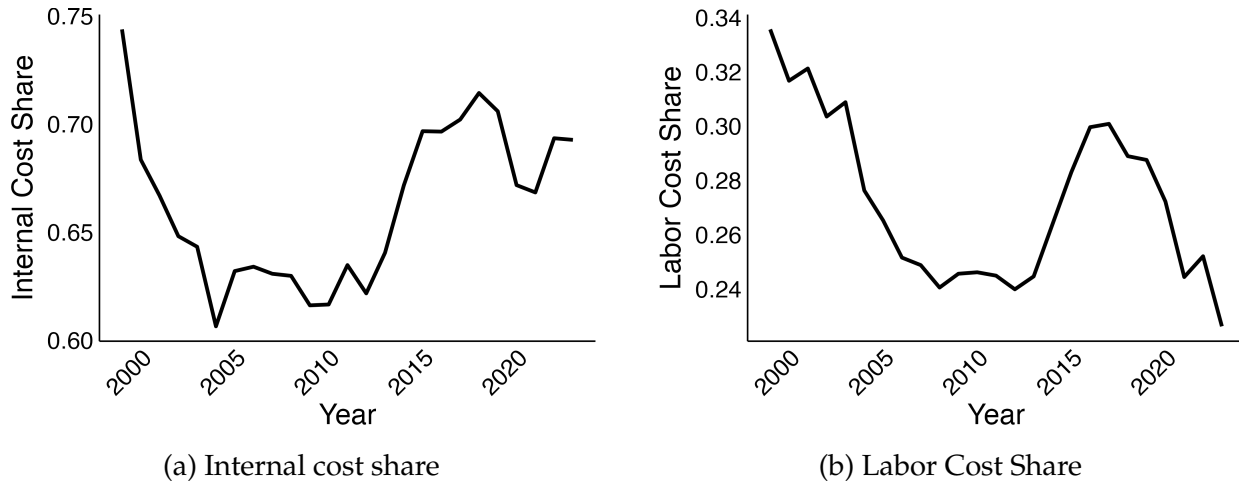Figure B.3: Density plots for maintenance and gross investment rates.

Note: Each density plot is constructed with beginning of period book capital in the denominator. The dashed lines are mean maintenance and investment rates. For freight cars, the mean maintenance rate is 21.4% and mean investment rate is 8.2%, while the corresponding figures for locomotives are 16.5% and 14.4%, respectively.

Figure B.4: Aggregate internal and labor cost share

(a) Internal cost share

(b) Labor Cost Share

Notes: Both figures compute their respective cost share as a ratio of total maintenance costs. Note that internal costs are the sum of materials and labor costs.

There is significant variability between firms and capital types in their internal maintenance practices. Figure B.5 plots the share of internal maintenance done by firms on freight cars and locomotives, respectively. The shares are quite persistent within firms and capital types but vary considerably. For example, Norfolk Southern does practically all of their locomotive maintenance internally, whereas their main similarly sized regional

competitor, CSX, does only around 30% internally. Additionally, variability is considerably larger for locomotives than freight cars, which may be because locomotives are more complicated capital types. In the aggregate, around 65% of total maintenance is internal. This is important because internal maintenance is more flexible than external maintenance since the latter is usually a function of predetermined contracts. If the demand for maintenance is elastic, then it will almost surely be solely on the internal maintenance margin in the short run.

Figure B.5: Internal Maintenance Share by Firm & Capital Type

Notes: The internal maintenance share is computed as the ratio of internal to total maintenance costs.

Firms and capital types also vary in how much of their internal maintenance expenditures are devoted to labor and materials. Figure B.6 plots the internal labor cost share by firm and capital type. Labor costs are typically between 20% and 70% of the total internal maintenance costs and on average around 30% of total maintenance expenditures. Whereas labor costs are typically fixed in advance by union contracts, materials costs are a function of the capital types themselves and the productivity of internal labor. Labor cost shares are considerably less persistent than internal cost shares, which suggests that factors like shocks to materials prices drive changes in the internal composition of maintenance spending.

Figure B.6: Internal Labor Cost Share by Firm & Capital type

Notes: The internal labor cost share is computed by taking the ratio of labor costs to the sum of labor and materials costs. Dots are colored according to firm. Ratios are winsorized to the 2nd and 98th percentile within capital types.

Table B.2: The Effect of Relative Price Changes on Maintenance Rates (Physical Capital)

	(1)	(2)	(3)	(4)
		LHS: $\log m_{i,j,t}$		
$\log P_{i,j,t}$	−1.916**	−2.056***	−2.283*	−2.453*
	(0.569)	(0.545)	(1.168)	(1.054)
Capital Age		−0.177*		−0.181*
		(0.087)		(0.080)
GDP Exposure		0.022*		0.023**
		(0.009)		(0.009)
Observations	342	342	342	342
R^2	0.790	0.836	0.788	0.834
F-stat			131.3	133.0
Type	OLS	OLS	IV	IV
Firm-Year Trend	N	Y	N	Y

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: This table estimates regressions using (12) with a measure of physical capital in the denominator. The first two columns are OLS regressions and the second two use the exposure share IV discussed in the main text. Columns 1 and 3 are the baseline regression of a log maintenance variable on log relative prices. Columns 2 and 4 add controls for the age of capital, local GDP exposure, and both linear and quadratic firm-year trends. Age is the inverse net capital stock scaled by gross capital stock. All regressions include firm-type and year fixed effects. Standard errors are clustered by firm and capital type.

Table B.3: The Effect of Relative Price Changes on Maintenance Rates Broken Down by Instrument Type

| | Dependent Variable: $\log m_{i,j,t}$ | | | |
	(1)	(2)	(3)	(4)
$\log P_{i,j,t}$	−3.327*	−3.479***	−3.119*	−3.447***
	(1.413)	(0.649)	(1.452)	(0.595)
Capital Age		0.772***		0.773***
		(0.138)		(0.138)
GDP Exposure		0.026*		0.026*
		(0.012)		(0.012)
Observations.	342	342	342	342
R^2	0.640	0.834	0.642	0.834
F-stat	132.0	137.7	131.7	133.8
Firm-Year Trends	N	Y	N	Y

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: This table estimates regressions using (12) broken down by the components of the instrument. The first two columns are the labor component of the instrument and the second two use the materials component. Columns 1 and 3 are the baseline regression of a log maintenance variable on log relative prices. Columns 2 and 4 add controls for the age of capital, local GDP exposure, and linear and quadratic firm-year trends. Age is net capital stock scaled by gross capital stock. All regressions include year and firm-capital type fixed effects. Standard errors are clustered by firm.

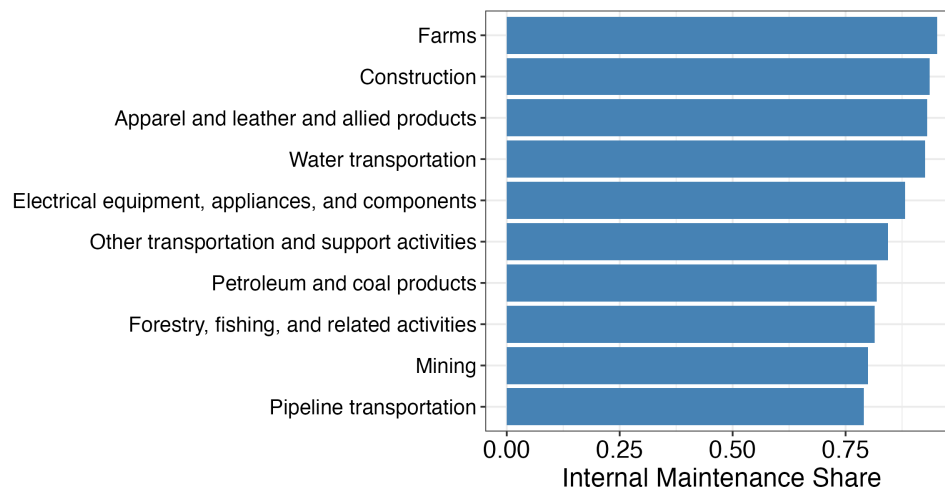Table B.4: The Effect of Relative Price Changes on Maintenance Rates

| | Dependent Variable: $\log m_{i,j,t}$ | | | |
	(1)	(2)	(3)	(4)
$\log P_{i,j,t}$	-0.487	-1.082**	-1.146***	-1.228*
	(0.543)	(0.330)	(0.270)	(0.612)
$\log m_{i,j,t-1}$	0.833***	0.668***	0.816***	0.660***
	(0.040)	(0.061)	(0.036)	(0.073)
Capital Age		0.443**		0.444**
		(0.128)		(0.121)
GDP Exposure		-0.042**		-0.041**
		(0.012)		(0.014)
Observations	328	328	328	328
F-stat			111.6	84.0
Type	OLS	OLS	IV	IV
Firm-Year Trends	N	Y	N	Y

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: This table estimates regressions using (12). The first two columns are OLS regressions and the second two use the exposure share IV discussed in the main text. Columns 1 and 3 are the baseline regression of a log maintenance variable on log relative prices. Columns 2 and 4 add controls for the age of capital, local GDP exposure, linear firm-year trends, and quadratic firm-year trends. Age is net capital stock scaled by gross capital stock. All regressions include year and firm-capital type fixed effects. Standard errors are clustered by firm.

B.2   SOI

Figure B.7: Top industries by internal maintenance share

Note: The top ten industries are constructed by taking the ratio of internal to total maintenance (as described in the main text) and arranging in a descending order.

Figure B.8: Top industries by maintenance rate

Note: The top ten industries are constructed by taking the mean maintenance rate in the SOI and arranging in a descending order. I do not try to correct for labor in this figure.

Table B.5: Summary statistics for the SOI.

Variable	Mean	10th Percentile	Median	90th Percentile	Count
All Firms					
Age	2.207	1.663	2.144	2.813	1067
Equipment-Capital Ratio	0.429	0.132	0.466	0.646	1067
Capital Age	2.206	1.663	2.144	2.813	1067
Equipment-Capital Ratio	0.429	0.132	0.466	0.646	1067
$m_{i,t}$	0.049	0.017	0.037	0.093	1067
$1 - \tau_{i,t}$	0.862	0.787	0.855	0.933	1067
Net Investment Rate	0.051	-0.139	0.060	0.218	1067
year	2009.442	2001.000	2009.000	2018.000	1067
Firms with Net Income					
Capital Age	2.263	1.710	2.195	2.955	1023
Equipment-Capital Ratio	0.427	0.130	0.465	0.649	1023
$m_{i,t}$	0.052	0.016	0.040	0.109	1023
$1 - \tau_{i,t}$	0.860	0.787	0.854	0.930	1023
Net Investment Rate	0.081	-0.477	0.049	0.581	1023
year	2009.087	2001.000	2009.000	2018.000	1023
Firms without Net Income					
Capital Age	2.140	1.537	2.073	2.791	1021
Equipment-Capital Ratio	0.428	0.130	0.466	0.650	1021
$m_{i,t}$	0.054	0.013	0.039	0.120	1021
$1 - \tau_{i,t}$	0.860	0.787	0.854	0.930	1021
Net Investment Rate	0.134	-0.391	0.026	0.839	1021
year	2009.092	2001.000	2009.000	2018.000	1021

Notes: The maintenance rate is defined as the ratio of the maintenance and repairs line item divided by book capital. Similarly, the net investment rate is net investment divided by net book capital, and age is proxied by the ratio of gross to net book capital. The capital age, net investment, and maintenance rates are winsorized at the 2% and 98% level.

Table B.6: NAICS Industries and Maintenance Rates

NAICS Industry Name	NAICS Code	Maintenance Rate
Agriculture, Forestry, Fishing and Hunting	11	0.112
Mining, Quarrying, and Oil and Gas Extraction	21	0.014
Utilities	22	0.020
Construction	23	0.049
Manufacturing	31	0.034
Manufacturing	32	0.024
Manufacturing	33	0.029
Wholesale Trade	42	0.035
Retail Trade	44	0.057
Retail Trade	45	0.041
Transportation and Warehousing	48	0.082
Transportation and Warehousing	49	0.051
Information	51	0.031
Real Estate and Rental and Leasing	53	0.031
Professional, Scientific, and Technical Services	54	0.071
Management of Companies and Enterprises	55	0.069
Administrative Services	56	0.068
Educational Services	61	0.069
Health Care and Social Assistance	62	0.064
Arts, Entertainment, and Recreation	71	0.035
Accommodation and Food Services	72	0.048
Other Services (except Public Administration)	81	0.159

Notes: This table computes the mean maintenance rate for NAICS two-digit industries in the SOI from 1998-2019 using the All Firms sample.

Tax Policy Construction

Toward creating a database of industry marginal effective tax rates (METR) on corporate capital, I combine data from the BEA and the IRS to follow the methodology of House and Shapiro (2008). Tax rates may differ between industries because there are differences in how assets are taxed and the mix of assets owned by industries may differ. Consequently, as long as we know who owns which assets and the tax rates on those assets, we can construct an industry-specific marginal effective tax rate. The Fixed Asset Tables from the BEA are convenient for this purpose for two reasons. First, Section 2 of the Fixed Asset tables contains data on 36 physical assets which are relatively easy to map to tax policy, make up the vast majority of physical investment, and can be categorized as either equipment or structures. I focus on these assets over the period 1998-2021 which relies solely on the Modified Accelerated Cost Recovery System (MACRS). Second, the underlying detailed estimates for nonresidential investment can be mapped from BEA industries into three-digit NAICS codes. The BEA provides a bridge for this purpose.

There are three steps to constructing industry-specific marginal effective tax rates:

1. Calculate asset-specific marginal effective tax rates $\tau_{i,t}$ for asset i.

2. For each industry j, compute asset weights $\alpha^a_{i,j,t}$.

3. Putting Steps 1 and 2 together, compute the industry-specific tax rate as

$$\tau_{j,t} = \sum_{i=1}^{N} \alpha_{i,j,t} \tau_{i,t}$$

where there are N types of capital and $\sum_{i=1}^{N} \alpha_{i,j,t} = 1$.

I go through each step in turn. Define the asset-specific METR as

$$\tau^a_{i,t} = 1 - \frac{1 - \tau^c_t}{1 - \text{ITC}^a_{i,t} - z^a_{i,t}\tau^c_t}, \tag{A.30}$$

where τ^c_t is the corporate tax rate, $\text{ITC}_{i,t}$ is the investment tax credit on asset i, and $z_{i,t}$ is the net present value of tax depreciation allowances on asset i. Hence there are three components for each asset. First, the corporate tax rate τ^c_t is straightforward to obtain. Since the ITC has been zero since 1986, I set it to zero.

$z_{i,t}$ is more difficult and requires some level of judgment. Suppose an asset has allowable depreciation $D^a_{i,t}$ and define $d^a_{i,t}$ as the share of the asset's allowable depreciation

under tax law each period. This is nontrivial because companies are allowed to use different methods of depreciation. For each asset j, I define the present value of depreciation allowances as

$$z_{i,t}^a = \sum_{t=0}^{\infty} \left(\frac{1}{1+r^k} \right)^t d_{i,t}^a.$$

I assume that $r^k = 0.06$. While this assumption is clearly not innocuous, it is comparable to some of the recent literature. This is the same discount rate as in Chodorow-Reich et al. 2023, but is lower than in Barro and Furman (2018) and Gormsen and Huber (2022). Earlier literature on tax policy from the 1980s (see, e.g., Auerbach (1983) and Jorgenson and Yun (1991)) tends to use lower discount rates. $z_{i,t}$ varies both across assets and between tax eras. I discuss each era in chronological order. I relied heavily on Brazell, Dworin, and Walsh (1989) for understanding each era.

The Tax Reform Act of 1986 changed depreciation schedules and got rid of the ITC while retaining much of the simplicity of the ACRS era. House and Shapiro (2008) map each asset to a corresponding depreciation table in IRS Publication 946. I use their matching scheme and assumptions about which depreciation method firms use. For example, most equipment is depreciated with the double-declining balance method, while structures are often depreciated with the straightline method. Using the House-Shapiro mapping scheme, it is straightforward to compute $z_{i,t}$. However, the U.S. government has allowed firms to take bonus depreciation on certain types of capital investment. Defining θ_t as the allowable bonus depreciation in year t, let the net present value of tax depreciation allowances be

$$\tilde{z}_{i,t}^a \begin{cases} \theta + (1 - \theta_t) z_{i,t}^a & \text{if eligible} \\ z_{i,t}^a & \text{if ineligible,} \end{cases} \tag{A.31}$$

where $\tilde{z}_{i,t}^a$ takes the place of $z_{i,t}^a$ in equation A.30. At various points, $\theta = 1$ for some assets, so the marginal effective tax rate is zero. Conveniently, House and Shapiro (2008) also map whether or not each BEA asset is eligible for bonus depreciation, so I use their mapping.

To get the industry-asset weights $\alpha_{i,j,t}$ within each major asset category, I use the underlying detail data from the BEA Fixed Asset Table. Each BEA industry has a matrix of assets for nominal investment, real investment, and historical and current-cost net capital stocks and depreciation. I use capital weights from the current year to determine weights on each asset for each industry. That is,
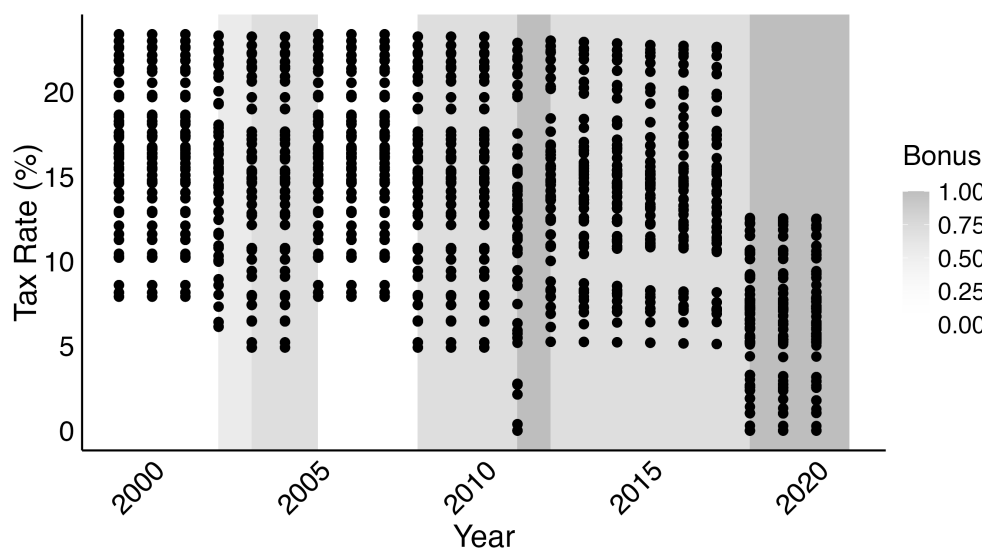
$$\alpha_{i,j,t} = \frac{k_{i,j,t}^a}{K_{j,t}^a},$$

where $k_{i,j,t}$ is stock of capital type i from industry j and $K_{j,t}$ is the total capital stock in year t by industry j in the corresponding major asset category. I restrict attention to the 36 assets I obtain METRs for. Of course, I could have also used stocks as weights or previous year investment flows or some rolling average of investment flows. The results are largely similar regardless.

Putting together weights weights and marginal tax rates, the marginal effective tax rate on industry j is

$$\tau_{j,t} = \sum_{i=1}^{36} \alpha_{i,j,t} \tau_{i,t}.$$

Figure B.9: Marginal tax rates by industry

Notes: Industry tax rates are constructed by taking a capital-weighted average of capital-specific tax rates using the BEA's detailed fixed asset data. Bonus corresponds to the parameter θ in $\tilde{z}_t = \theta + (1 - \theta) z_t$.

Table B.7: The Tax Treatment of Investment and Maintenance for a 15-Year Asset (150% DB Switching to Straight-Line)

Year:	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total	z
Investment																		
Deductions (000s)	50	95	80	80	80	80	80	80	80	80	80	80	14	14	14	13	1000	
Tax benefit ($\tau = 35\%$)	17.5	33.3	28	28	28	28	28	28	28	28	28	28	4.9	4.9	4.9	4.6	350	0.69
Tax Benefit (Present Value)	17.5	31.1	24.4	22.9	21.4	20	18.7	17.4	16.3	15.2	14.3	13.3	2.2	2	1.9	1.6	240	
Maintenance																		
Deductions (000s)	1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1000	
Tax benefit ($\tau = 35\%$)	350	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	350	1.00
Tax Benefit (Present Value)	350	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	350	

Notes: This table, adapted from Zwick and Mahon (2017), compares the tax depreciation of a new 15-year asset versus the full expensing of maintenance. Investment deductions are based on a hypothetical MACRS schedule using 150% declining balance switching to straight-line (with a half-year convention) so that annual deductions sum to 1000 (in 000s). Tax benefits at a 35% rate total 350, and when each year's tax benefit is discounted at 7% per period, the present value sums to approximately 240, yielding a present value factor $z \approx 0.69$. Maintenance costs are fully expensed in Year 0.

B.3 Additional Results

Table B.8: The Effect of Tax Changes on Industry-Level Maintenance Rates (BEA Capital)

	All Firms		Taxable Firms		Untaxable Firms	
	(1)	(2)	(3)	(4)	(5)	(6)
$\log(1 - \tau_{i,t})$	-0.755	-0.671	-3.353	-3.163	2.631	2.787
	(0.929)	(0.922)	(2.042)	(2.095)	(2.156)	(2.124)
Capital Age		-0.131		-0.208		0.090
		(0.137)		(0.136)		(0.179)
Observations	732	732	735	735	733	733
R^2	0.987	0.987	0.969	0.970	0.898	0.898
Industry Trends	Y	Y	Y	Y	Y	Y

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: This table estimates regressions using (14). These estimates use BEA capital as the denominator, which come from estimates of the net capital stock in the detailed fixed asset data. The columns are grouped into three different categories. The first two contain estimates from the SOI sample including all firms, the second two contain firms with positive net income, and the final two for firms without net income. The first column in each group estimates the baseline regression of the log maintenance rate on the log tax rate for taxable firms with two-way fixed effects and industry linear and quadratic trends. The second column in each group adds age, proxied as the ratio of gross to net book capital, as a control. In all regressions, standard errors are clustered by industry. In the bottom row, I estimate an implied value for γ by taking the sample mean of maintenance rates within the sample and dividing by the mean of the tax term raised to the estimated ω in the corresponding column.

Table B.9: The Effect of Tax Changes on Industry-Level Maintenance Rates
(Contemporaneous Capital)

	All Firms		Taxable Firms		Untaxable Firms	
	(1)	(2)	(3)	(4)	(5)	(6)
$\log(1 - \tau_{i,t})$	−1.938*	−2.064*	−3.950***	−3.686***	2.614	2.631
	(1.105)	(1.163)	(1.296)	(1.177)	(1.772)	(1.720)
Capital Age		0.238**		0.219**		0.109
		(0.107)		(0.082)		(0.093)
Implied γ	0.053	0.051	0.041	0.043	0.053	0.053
Observations	1067	1064	1023	1014	1021	1012
R^2	0.912	0.915	0.758	0.762	0.615	0.623
Industry Trends	Y	Y	Y	Y	Y	Y

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: This table estimates regressions using (14) using contemporaneous capital in the denominator. The columns are grouped into three different categories. The first two contain estimates from the SOI sample including all firms, the second two contain firms with positive net income, and the final two for firms without net income. The first column in each group estimates the baseline regression of the log maintenance rate on the log tax rate for taxable firms with two-way fixed effects and linear and quadratic industry trends. The second column in each group adds age, proxied as the ratio of gross to net book capital, as a control. In all regressions, standard errors are clustered by industry. In the bottom row, I estimate an implied value for γ by taking the sample mean of maintenance rates within the sample and dividing by the mean of the tax term raised to the estimated ω in the corresponding column.
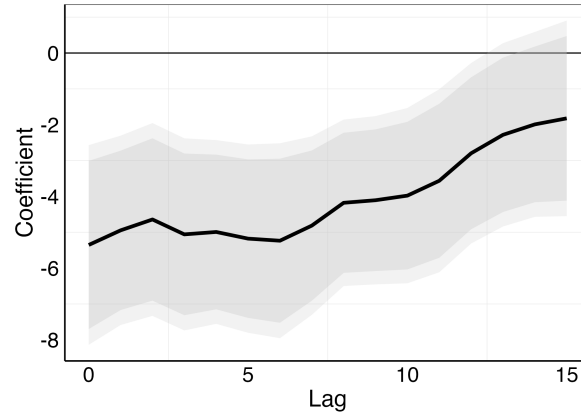
Table B.10: The Effect of Tax Changes on Industry-Level Maintenance Rates (1998-2013)

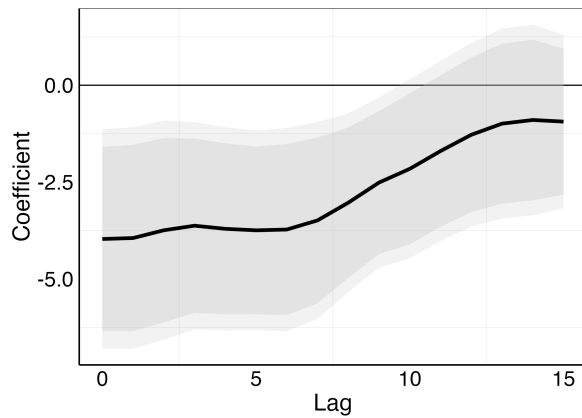|	All Firms		Taxable Firms		Untaxable Firms	
	(1)	(2)	(3)	(4)	(5)	(6)
$\log(1 - \tau_{i,t})$	−0.676	−0.602	−4.280*	−4.415**	3.954	4.190
	(0.753)	(0.786)	(2.259)	(2.157)	(2.741)	(2.775)
Capital Age		0.291***		0.224**		0.109
		(0.072)		(0.093)		(0.128)
Implied γ	0.056	0.053	0.036	0.035	0.075	0.075
Observations	733	733	735	735	733	733
R^2	0.930	0.934	0.790	0.792	0.635	0.635
Industry Trends	Y	Y	Y	Y	Y	Y

* p < 0.1, ** p < 0.05, *** p < 0.01

Notes: This table estimates regressions using (14) from 1998-2013 with fixed tax exposure weights. The columns are grouped into three different categories. The first two contain estimates from the SOI sample including all firms, the second two contain firms with positive net income, and the final two for firms without net income. The first column in each group estimates the baseline regression of the log maintenance rate on the log tax rate for taxable firms with two-way fixed effects and linear and quadratic industry trends. The second column in each group adds age, proxied as the ratio of gross to net book capital, as a control. In all regressions, standard errors are clustered by industry. In the bottom row, I estimate an implied value for γ by taking the sample mean of maintenance rates within the sample and dividing by the mean of the tax term raised to the estimated ω in the corresponding column.
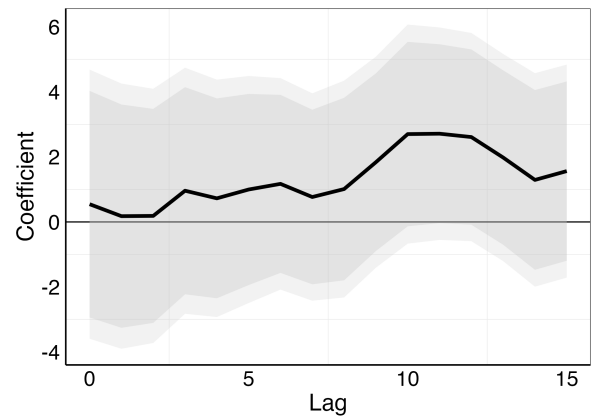
Figure B.10: Maintenance demand elasticity coefficients as a function of capital weight lag length

(a) Taxable Firms

(b) All Firms

(c) Untaxable Firms

Notes: Each figure estimates the maintenance elasticity using a different lag length for the capital tax weights. In the baseline regressions, the lag length is ten, meaning that all data from 1998-2011 use fixed weights averaged over 1998-2000 prior to the start of bonus depreciation, while all years after that use a lag length of ten. The same applies to all lags in the figures above. For example, if the x-axis has Lag = 4, that means all years from 1998-2005 use fixed weights from the 1998-2000 period, while all years past 2005 use capital weights from four years prior. All regressions use two-way industry and year fixed effects, control for linear and quadratic industry-year trends at the NAICS two-digit level, control for the age of capital, and cluster standard errors by industry.

C   Quantification

Table C.1: Calibrated Parameters

Parameter Name	Symbol	Value	Source
Maintenance Demand Elasticity	ω	2	Empirical moment
Maintenance Demand Level	γ	0.052	SOI (adjusted for labor)
Depreciation Level	δ_0	0.1449	Corporate Physical X/Y from BEA
Discount Rate	r^k	0.06	Chodorow-Reich et al. (2023)
Short-Run Investment Elasticity	β	-6.02	Chodorow-Reich et al. (2023) adjusted for maintenance
Profit Elasticity	α	0.67	Chodorow-Reich et al. (2023)
Labor Share	α_L	0.65	Chodorow-Reich et al. (2023)
Capital Share	α_K	0.235	Chodorow-Reich et al. (2023)
Adjustment Cost (NGM)	ϕ	1.18	Estimated moment
Adjustment Cost (NGMM)	ϕ	5.17	Estimated moment
Crowding out (NGM)	Δr^k	5.7 bps	See main text
Crowding out (NGMM)	Δr^k	6.5 bps	See main text
Non-corporate TFP (NGM)	A	0.7701	Set to match ratio of corporate to non-corporate gross output
Non-corporate TFP (NGMM)	A	0.9059	
Tax Change	$\Delta \tau$	0.033	Chodorow-Reich et al. (2023)

 Notes: All parameters are described in the main text except for the tax change variable. That variable comes from a weighted average of domestic tax changes in Table E.10 of Chodorow-Reich et al. (2023). The ratio of noncorporate to corporate gross output is 0.35.

C.1   Profit Function

Consider a firm with Cobb-Douglas production

$$F(K_t, L_t) = K_t^{\alpha_K} L_t^{\alpha_L}.$$

The firm pays a wage bill $w_t L_t$. We can use the first-order condition to write the expression $F(K_t, L_t) - w_t L_t$ entirely in terms of labor by manipulating the static optimization problem for labor demand. Since

$$w_t = \alpha_L K_t^{\alpha_K} L_t^{\alpha_L - 1},$$

we can rewrite income net of the wage bill as

$$
\begin{aligned}
K_t^{\alpha_K} L_t^{\alpha_L} - w_t L_t &= (1 - \alpha_L) K_t^{\alpha_K} L_t^{\alpha_L} \\
&= (1 - \alpha_L) K_t^{\alpha_K} \left(\frac{\alpha_L K_t^{\alpha_K}}{w_t} \right)^{\frac{\alpha_L}{1 - \alpha_L}} \\
&= Z_t K_t^{\alpha},
\end{aligned}
$$

where

$$\alpha \equiv \frac{\alpha_K}{1 - \alpha_L} \quad \text{and} \quad Z_t \equiv (1 - \alpha_L) \left(\frac{\alpha_L}{w_t} \right)^{\frac{\alpha_L}{1 - \alpha_L}}.$$

C.2 Linearized System

As in Chodorow-Reich et al. (2023), I make the assumption that the tax policy parameters are already at their steady state values. That means maintenance is already at its steady state value when considering convergence toward the post-TCJA steady state and hence depreciation is also fixed. Let variables with hats denote log-deviations and note that the deviation for λ_t is additive, *i.e.*, $\hat{\lambda}_t = \lambda_t - \bar{\lambda}$. In steady state,

$$h(\bar{\lambda}) = 0 \tag{A.32}$$

$$h'(\bar{\lambda}) = \frac{1}{\phi(1 - \tau)}. \tag{A.33}$$

The linearized system therefore reduces to

$$\hat{\lambda}_t (1 + r^k) = (1 - \tau) F''(\bar{K}) \bar{K} \hat{K}_{t+1} + \hat{\lambda}_{t+1} \left(1 - \delta(m) + \delta'(\bar{m}) \bar{m} \right) \tag{A.34}$$

$$\hat{K}_{t+1} = \frac{\hat{\lambda}_t}{\phi(1 - \tau)} + \hat{K}_t \tag{A.35}$$

From Equations (A.34) and (A.35), the system can be represented as:

$$
\begin{bmatrix} \hat{\lambda}_{t+1} \\ \hat{K}_{t+1} \end{bmatrix} = A \begin{bmatrix} \hat{\lambda}_t \\ \hat{K}_t \end{bmatrix}
$$

where

$$A = \begin{bmatrix} \dfrac{1 + r^k - \dfrac{1}{\phi}F''(\bar{K})\bar{K}}{1 - \delta(\bar{m}) + \delta'(\bar{m})\bar{m}} & \dfrac{-(1-\tau)F''(\bar{K})\bar{K}}{1 - \delta(\bar{m}) + \delta'(\bar{m})\bar{m}} \\ \dfrac{1}{\phi(1-\tau)} & 1 \end{bmatrix}$$

This matrix has eigenvalues

$$\mu = \frac{C_1 \pm \sqrt{C_1^2 - 4(1 + r^k)C_2}}{2C_2}$$

where

$$C_1 = 2 + r^k - \delta(\bar{m}) + \delta'(\bar{m})\bar{m} - \frac{1}{\phi}F''(\bar{K})\bar{K}$$

$$C_2 = 1 - \delta(\bar{m}) + \delta'(\bar{m})\bar{m}$$

and associated eigenvector

$$\mathbf{v} = \begin{bmatrix} 1 \\ \dfrac{-1}{\phi(1-\tau)(1-\mu)} \end{bmatrix}.$$

C.3   Short-Run to Long-Run Investment Ratio χ_{SR}

This subsection shows that there is a constant ratio between investment deviations in the short run and the long run. The proof is similar to Chodorow-Reich et al. (2023), but instead is in discrete time. Because maintenance instantaneously adjusts, it suffices to show that the ratio of capital deviations is constant. First, note that

$$\begin{aligned} \frac{K_{t+1} - K_t}{K_0} &= \frac{\bar{K}}{K_0} \frac{K_{t+1} - K_t}{\bar{K}} \\ &= \frac{\bar{K}}{K_0} \frac{(K_{t+1} - \bar{K}) - (K_t - \bar{K})}{\bar{K}} \\ &= \frac{\bar{K}}{K_0} \left(\hat{K}_{t+1} - \hat{K}_t \right) \\ &= \frac{\bar{K}}{K_0} \left(\mu_1^{t+1} \hat{K}_0 - \mu_1^t \hat{K}_0 \right) \\ &= (\mu_1 - 1)\mu^t \frac{\bar{K}}{K_0} \hat{K}_0 \\ &= (1 - \mu_1)\mu_1^t \tilde{k}, \end{aligned}$$

where

$$\tilde{k} = \frac{\bar{K} - K_0}{K_0}$$

is the long-run change in capital given the initial position K_0. We can then derive the average change in investment from period zero to T relative to period zero as

$$\frac{1}{T+1} \sum_{t=0}^{T} \frac{I_t - I_0}{I_0} = \frac{1}{T+1} \sum_{t=0}^{T} \frac{K_{t+1} - (1 - \delta(m))K_t - \delta(m)K_0}{\delta(m)K_0}$$

$$= \frac{1}{\delta(m)(T+1)} \sum_{t=0}^{T} \left(\delta(m) \frac{K_t - K_0}{K_0} + \frac{K_{t+1} - K_t}{K_0} \right)$$

$$= \frac{1}{\delta(m)(T+1)} \sum_{t=0}^{T} \left(\delta(m) \frac{K_t - K_0}{K_0} + (1 - \mu_1)\mu_1^t \tilde{k} \right)$$

$$\approx \frac{1}{\delta(m)(T+1)} \sum_{t=0}^{T} \left(\delta(m) \left(\tilde{k} + \frac{K_t - \bar{K}}{K_0} \right) + (1 - \mu_1)\mu_1^t \tilde{k} \right)$$

$$\approx \frac{1}{\delta(m)(T+1)} \sum_{t=0}^{T} \left(\delta(m) (\tilde{k} - \mu_1^t \tilde{k}) + (1 - \mu_1)\mu_1^t \tilde{k} \right)$$

$$= \tilde{k} \left(1 + \frac{(1 - \mu_1 - \delta(m))(1 - \mu^{T+1})}{\delta(m)(1 - \mu_1)(T+1)} \right)$$

Therefore the ratio of short-run to long-run investment is a constant:

$$\chi_{SR} = \frac{\text{Average Deviation}}{\text{Long-Run Deviation}} = \tilde{k} \left(1 + \frac{(1 - \mu_1 - \delta(m))(1 - \mu^{T+1})}{\delta(m)(1 - \mu_1)(T+1)} \right) / \tilde{k}$$

$$= 1 + \frac{(1 - \mu_1 - \delta(m))(1 - \mu^{T+1})}{\delta(m)(1 - \mu_1)(T+1)}. \tag{A.36}$$

C.4 Robustness to variation in ω

Table C.2: Results for Alternative Maintenance Demand Parameter Combinations

Parameter			GE Outcomes		
ω	γ	δ_0	$\Delta M(\%)$	$\Delta X(\%)$	$\Delta K(\%)$
0	0.07	0.0324	0	4.1	4.1
1.5	0.056	0.2024	-1.5	13.8	3.7
2	0.052	0.1389	-3.0	17.0	3.9
3	0.44	0.1008	-6.0	22.3	4.2
4	0.39	0.0875	-9.0	27.1	4.3

Notes: Given ω, the parameter γ is set to match the mean maintenance rate in the SOI, δ_0 is set to match the pre-reform corporate investment-output ratio of 0.13, and non-corporate TFP is set to match the ratio of non-corporate to corporate gross output.

C.5 Heterogeneous Capital

In addition to predicting a reduced tax elasticity of capital, Proposition 1 highlights that tax policy should have heterogeneous effects across capital types. In particular, if maintenance is larger as a share of pre-reform user cost, then the tax shield effect causes additional dampening and grows by less. This is a plausibly important channel because both depreciation and maintenance rates vary by asset type, which implies that the degree of dampening should likewise vary by capital type.

The key question is the extent to which maintenance dampens the long-run response of each capital type to changes in tax policy. That requires three new calibrations. First, suppose that capital is a Cobb-Douglas aggregator of structures and equipment
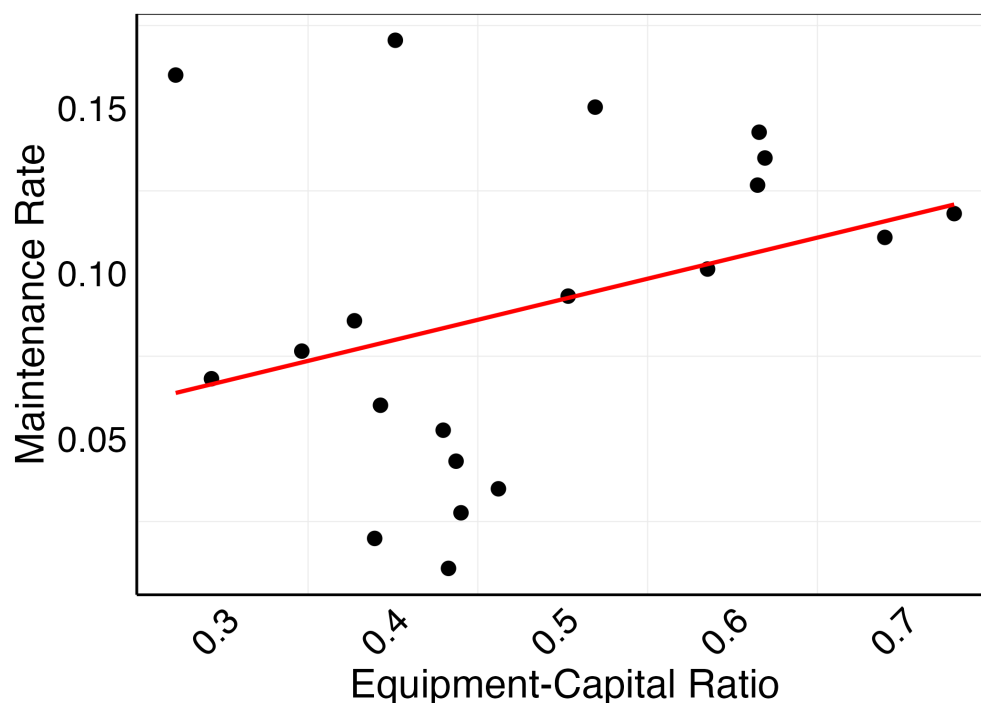
$$K_t^\alpha = K_{t,S}^{\alpha_S} K_{t,E}^{\alpha_E}.$$

I calibrate the capital shares using Barro and Furman (2018). That step involves rescaling each capital share such that the profit elasticity $\alpha_S + \alpha_E = 0.67$.

Calibrating the depreciation technologies is more difficult. While we cannot granularly identify differences in specific types of capital with SOI data, we can approximate an answer for equipment and structures. Figure C.1 bins maintenance rates into twenty

points and plots the sample mean industry equipment-capital ratio on the x-axis against the corresponding maintenance rate on the y-axis. There is a moderately positive relationship. Consequently, it appears that equipment is more intensively maintained than structures, which is suggestive of heterogeneity in tax elasticities. A simple OLS regression of the full sample maintenance rate on the equipment-capital ratio yields an intercept of 0.045 (SE = 0.003) with a coefficient of 0.016 (SE = 0.006). That suggests a small but economically significant difference in the baseline levels of maintenance rates and hence tax elasticities of capital. For example, suppose maintenance demand is completely inelastic, the discount rate r^k is 0.06 and the depreciation rates are $\delta_S = 0.03$ and $\delta_E = 0.12$. The depreciation rates are consistent with BEA data. In that case, after making the adjustment for labor cost exclusion, equipment has a tax elasticity of capital 67% as large as in the baseline no-maintenance model, while the structures elasticity is 58% as large.
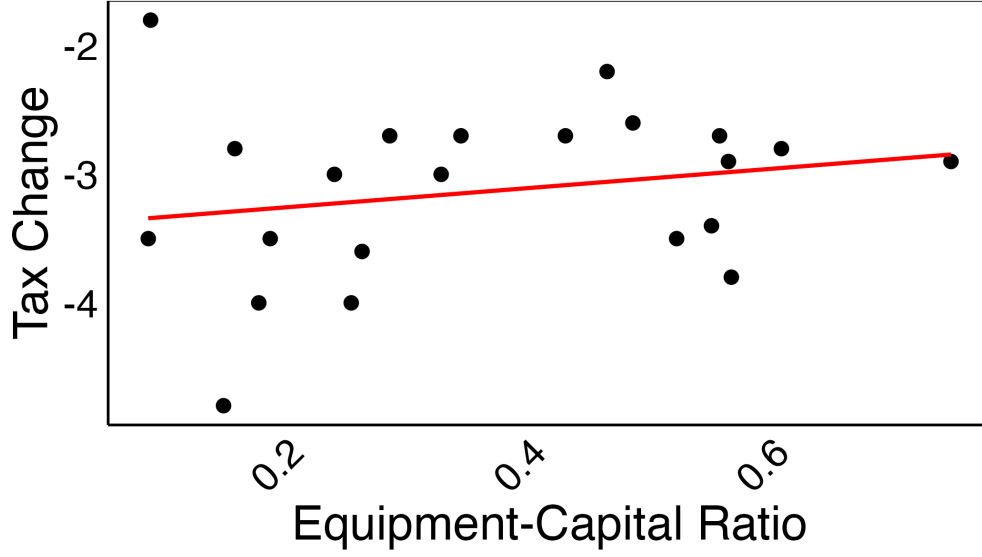
Figure C.1: The maintenance rate increases for shorter-lived capital.

Notes: The x-axis is the ratio of equipment to physical capital computed using the BEA's fixed asset tables. The y-axis is binned maintenance rates from the SOI's All Firm sample.

An ideal approach to estimating heterogeneous elasticities would rely on a version of

Figure C.2: Relationship between Equipment Share and TCJA Tax Change

(14) through the regression

$$\log m_{i,t} = \alpha_i + T_t + \omega_1 \log\left(1 - \tau_{i,t}\right) + \omega_2 \left(\frac{K_{E,i,t}}{K_{i,t}}\right) \times \log\left(1 - \tau_{i,t}\right)$$

$$+ \beta \left(\frac{K_{E,i,t}}{K_{i,t}}\right) + \text{Controls} + \epsilon_{i,t},$$

(A.37)

where $\frac{K_{E,i,t}}{K_{i,t}}$ is the ratio of equipment capital to total physical capital for industry i. The sum of ω_1 and ω_2 therefore would give the demand elasticity for equipment, while ω_1 would be the structures demand elasticity. This suffers from the fatal flaw that the tax rate and the equipment-capital ratio are highly correlated. Since the results from the homogeneous capital case suggest that setting the elasticity right is only about composition of capital and not the outcome itself, I calibrate both elasticities to be the same.
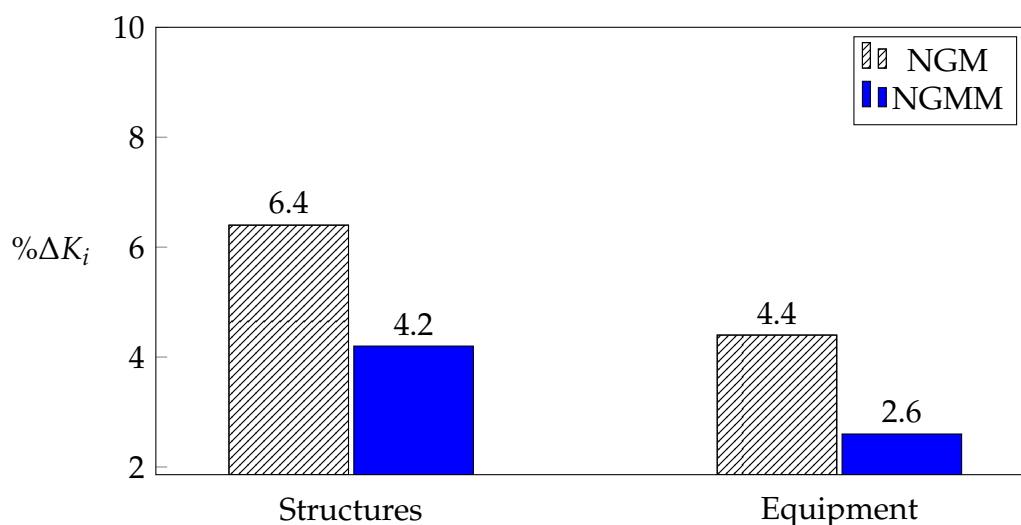
Chodorow-Reich et al. (2023) do not break down the change in marginal tax rates by asset type. I take Table E.14 from their Appendix, which breaks down the tax change by domestic industry, and plot the domestic tax rate change against the 2017 equipment-capital ratio in Figure C.2 where the equipment-capital ratio comes from the BEA fixed asset table. The line of best fit has an intercept of -3.4 (SE = 0.32) with a slope of 0.75 (SE = 0.76). Although the slope is insignificant, I choose to interpret it as saying that the tax rate change was smaller for equipment than for structures by the size of the slope.

I calibrate the demand functions by setting a common ω and solving for γ_S and γ_E using the baseline equipment and structures maintenance rates from the regression of

maintenance on the equipment-capital ratio. Finally, I set $\delta_{0,S}$ and $\delta_{0,E}$ such that the pre-reform investment-output ratios are 4.6% and 8.4%, respectively. These figures are consistent with the 2000-2016 average of the respective corporate investment-gross output ratios from the BEA. A summary of calibrated parameters is in Table C.3.

I focus on partial equilibrium because the relevant question is the comparison between predictions in the NGM in which $\gamma \to 0$ and the NGMM. Following TCJA, the NGMM predicts that the steady-state user cost for equipment would decline by 1.64%, which is about 56% as large as the NGM prediction of a 2.73% decline. By comparison, the NGMM user cost for structures declines by 2.77%, which is 62% as large as the 4.15% decline in the NGM. Figure C.3 translates those percent changes in user cost into percent changes in capital. The left-hand side compares structures, while the right-hand side compares equipment between models. Evidently, the effect of maintenance is more important for equipment than structures. The NGMM changes for each capital type relative to the NGM are about the same, so the effects are essentially homogeneous.

Figure C.3: Heterogeneous Effects of Maintenance on Capital Accumulation

Notes: This figure compares the percent change in capital for each capital type between the case in which maintenance is assumed to be zero (NGM) and when maintenance is realistically calibrated (NGMM). General equilibrium effects are omitted.

Table C.3: Additional Calibrated Parameters

Parameter Name	Symbol	Value	Source
Structures			
Maintenance Demand Level	γ_S	0.0299	Empirical moment
Maintenance Elasticity	ω_S	2	Empirical moment
Depreciation Level	$\delta_{0,S}$	0.088	I_S/Y from the BEA
Capital Share	α_S	0.315	Barro and Furman (2018)
Tax Change	$\Delta\tau_S$	-0.034	Chodorow-Reich et al. (2023)
Equipment			
Maintenance Demand Level	γ_E	0.0535	Empirical moment
Maintenance Elasticity	ω_E	2	Empirical moment
Depreciation Level	$\delta_{0,E}$	0.135	I_E/Y from the BEA
Capital Share	α_E	0.355	Barro and Furman (2018)
Tax Change	$\Delta\tau_E$	-0.0265	Barro and Furman (2018)

Notes: All variables are described in the main text. From Barro and Furman (2018), the net present value of structures depreciation allowances is $z_S = 0.493$ and the corresponding value for equipment is $z_E = 0.884$. I magnify the γ_i by 1.4 to account for missing labor costs.