Tax Policy and Capital Maintenance

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Firms adjust their capital stock through both investment in new capital and maintenance of existing capital. Omitting the maintenance decision creates two problems for standard models of tax reform. First, tax reforms reduce the cost of new investment but not maintenance, so the user cost of capital falls less than standard models imply. Second, elastic maintenance means depreciation rises when investment becomes cheaper, breaking the one-for-one mapping from investment to capital. Thus, investment subsidies promote capital churn, but not necessarily capital growth. I study the importance of these channels using freight railroad regulatory filings and corporate tax returns. The estimates imply the tax elasticities of capital, output and wages are about 70% as large as implied by standard investment models, while investment elasticities only map into half as much capital when evaluated at recent estimates. Applied to the 2017 Tax Cuts and Jobs Act, I find that it generated $240B less corporate capital than conventional estimates.

JEL-Classification: D21, D24, E22, H25, L92

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1 Introduction

Over the course of the postwar era, policymakers have repeatedly lowered the corporate tax burden through a combination of income tax cuts and investment subsidies, with the express intention of increasing growth and raising wages (Romer and Romer 2010). The predicted effectiveness of such policies rests on a particular transmission mechanism: by reducing the user cost of capital, tax cuts encourage firms to invest more. There is ample evidence that these reforms have successfully led to more investment (Hassett and Hubbard 2002; Zwick and Mahon 2017; Kennedy et al. 2023). Since workhorse investment models imply that the tax elasticity of investment *is* the tax elasticity of capital, we can directly map the observed change in investment to capital, and with additional assumptions, to output and wages (Chodorow-Reich et al. 2025). Thus, the empirical evidence suggests that policy goals have largely succeeded in leading to additional growth by directly stimulating investment. However, an overlooked yet practically important margin interrupts the transmission of tax cuts to capital, and the mapping of investment into capital: *maintenance of existing capital*.

In practice, maintenance is quantitatively large and important for tax policy. Firms spend considerable resources maintaining and repairing existing capital, which slows economic depreciation. Across industries, maintenance expenditures are 25-60% of the user cost of capital—often rivaling or exceeding investment in new capital. The substitution between these margins is economically meaningful: when supply chain disruptions made new aircraft expensive and difficult to acquire after the pandemic, airlines increased maintenance spending sharply to extend the life of existing fleets (Pfeifer 2023). Tax policy creates the same relative price distortion, but in reverse. Maintenance expenditures are fully expensed against current income, like wages or materials. By contrast, investment in new capital is typically capitalized and deducted through tax depreciation schedules over many years. This differential treatment means that when policymakers introduce investment incentives—such as bonus depreciation or investment tax credits—they make investment cheap relative to maintenance. Firms substitute accordingly, and depreciation rises. I show this asymmetry attenuates tax policy effects through two mechanisms: a scale effect operating through the level of maintenance, and a substitution effect operating through its elasticity.

Theoretical Mechanisms. Consider first how tax incentives affect the scale of capital accumulation. In standard models with fixed depreciation, the cost of capital is simply the cost of purchasing new assets—the familiar (Hall and Jorgenson 1967) user cost of capital. But the true cost of capital services includes both the initial purchase and the ongoing cost of maintaining assets over their lifetime. The effective cost of capital services is therefore a weighted average of the cost of new capital (which responds to tax incentives) and the cost of maintenance (which does not, since maintenance is already fully expensed). When policymakers introduce investment subsidies, only one component of this weighted average falls. I call this a *capital preservation effect*. The scale response is therefore smaller than standard models predict, with the magnitude of attenuation equal to the maintenance share of user cost. Standard models implicitly assume this share is zero.

Beyond the capital preservation effect, tax incentives create a relative price distortion. By reducing the cost of new capital while leaving maintenance costs unchanged, they make replacement relatively cheaper than preservation. If maintenance demand is elastic, firms substitute away from maintenance and toward investment, and economic depreciation rises. This creates an *investment-capital gap*: gross investment overstates net capital accumulation because more of the observed investment offsets higher depreciation rather than expanding the capital stock. The punchline is churn versus growth: investment subsidies make the capital stock turn over faster, not necessarily get bigger.

Both results are robust to general equilibrium. Real forces like diminishing returns work through production and affect both models equally. Price feedbacks favor the maintenance model: investment goods are globally traded, while maintenance is labor-intensive and cannot be imported. When tax cuts stimulate capital accumulation and raise wages, maintenance becomes relatively more expensive, reinforcing the substitution toward investment. Under plausible conditions, general equilibrium amplifies the attenuation rather than undoing it.

Maintenance Demand in the Data. The theoretical mechanisms depend critically on two parameters. First, the capital preservation effect requires knowing the *level* of maintenance relative to the user cost of capital. McGrattan and Schmitz Jr. (1999) points out that this is plausibly quite large in Canada, but it remains relatively underexplored in the United States. Second, the investment-capital elasticity gap depends on the *elasticity* of maintenance demand. Goolsbee (1998b) shows that the decision to *replace* capital is price-sensitive, but we lack a direct estimate of the demand elasticity.[1] A central contribution of this paper is to provide a unified estimate of a maintenance demand function using two disparate sources of data and identification strategies. One is precisely detailed at the firm-asset level, while the other is aggregated industry data, but together they tell a unified story about maintenance demand.

My first source of data comes from the regulatory filings of large freight railroads. Class I

1. Goolsbee (1998b) provides important precedent for the mechanism I study. He shows that airlines effectively increase their depreciation rates by retiring planes more quickly in response to investment subsidies. Though his setting scrappage and resale rather than maintenance decisions, the economic insight is the same: investment incentives can endogenously raise depreciation, breaking the standard one-to-one mapping from investment to capital. In a putty-clay model with vintages, his replacement effect is formally equivalent to the endogenous depreciation I model through maintenance.

freight railroads, which are roughly defined to be those with revenue over $1 billion, are required to submit detailed accounts of their financial and real activities with the Surface Transportation Board. I hand-collect and digitize these going back several decades. Although each filing is an unparalleled window into the maintenance and investment behavior of firms at the asset level, they have not been used in economics since Bitros (1976). I observe the quantity and value of each firm's locomotives and freight cars, what they spend on maintaining them, and how much of that maintenance was done internally rather than contracted out. To study maintenance demand, I focus on a period from 1999 to 2023.[2]

Three facts emerge. First, maintenance is large: the maintenance share of user cost averages 60%, implying standard user cost formulas overstate tax responsiveness by a factor of 2.5. Second, maintenance spending typically exceeds investment in new assets. Third, 65% of maintenance is performed in-house, with labor costs accounting for 40%—variation I exploit for identification.

To identify the maintenance demand elasticity, I construct a Bartik-style instrument that leverages variation in the geographic distribution and labor composition of maintenance costs by firm. By interacting pre-determined, firm-specific maintenance labor cost shares with plausibly exogenous state-level shocks to maintenance wages, this strategy isolates cost-driven shifts in the relative price of maintenance from unobserved firm-level demand shocks. The analysis yields a maintenance demand elasticity of approximately four. Crucially, this response is driven entirely by adjustments to in-house maintenance, while outsourced maintenance services do not respond. This divergence provides evidence for causality, as it confirms the instrument is isolating a supply-side cost shock rather than a confounding demand shock, which would likely cause both maintenance margins to move in tandem.

Nevertheless, freight rail assets may not be representative of capital more broadly, and the firm-level analysis cannot capture any general equilibrium. To partially address both concerns, I turn to industry-level corporate tax returns from the Internal Revenue Service's Statistics of Income (SOI), which covers the corporate sector. The data allow for external validity on an economy-wide basis and cover any within-industry general equilibrium effects like capital reallocation, but fall short of capturing any economy-wide general equilibrium effects.

The SOI data provide a complementary story about the demand for maintenance at the nationwide level. In the SOI, the maintenance share of user cost is less than half as large as in the R-1 data, and it is only half as large as new investment in levels. However, the demand elasticity is remarkably similar to the R-1 estimates. Following the empirical *investment* literature (Zwick and Mahon 2017; Curtis et al. 2021), I exploit quasi-experimental variation in industries'

2. Before the late 1990s, there was considerable regulatory upheaval and consolidation in the freight rail industry. This makes it difficult to study. Maintenance behavior may differ if firms expect to be acquired, and part of my data only begin in the late 1990s. See (Saunders 2003) for a history of the period.

exposure to major investment incentives—namely, bonus depreciation and the 2017 Tax Cuts and Jobs Act—to identify the *maintenance* demand elasticity. Because industries differ in their capital composition, these national tax policies create differential, plausibly exogenous shocks to the after-tax price wedge between new investment and maintenance. This approach, which implicitly nets out capital reallocation within broad industries, produces an estimated demand elasticity of approximately three, which is similar to the railroad estimate. Moreover, the demand elasticity is only positive for taxable firms, which is exactly what theory predicts.

Quantitative Implications. The empirical findings—positive and elastic maintenance demand—alter both how we should interpret tax policy evidence and the predicted macroeconomic effects of tax reform.

My empirical findings have first-order implications for how we interpret evidence on tax policy. The standard approach in public finance estimates investment elasticities and treats them as equivalent to capital elasticities, implicitly assuming a one-to-one correspondence between investment and capital accumulation (Hartley, Hassett, and Rauh 2025; Chodorow-Reich et al. 2025). But accounting for maintenance breaks this correspondence. When investment incentives alter relative prices, firms substitute away from maintenance, raising depreciation endogenously. The same observed investment response therefore corresponds to a smaller capital response: a portion of gross investment now simply replaces capital that depreciates faster rather than expanding the productive stock. I derive a closed-form correction showing that the capital elasticity is approximately half the observed investment elasticity when maintenance parameters take their empirically estimated values and the investment elasticity is around four (Chodorow-Reich et al. 2025).[3] This substantial wedge—driven by the maintenance margin—matters for both policy analysis and for models calibrated to match observed investment moments.

The two mechanisms also imply smaller macroeconomic effects than standard models predict. The capital preservation effect operates through the level of maintenance: when maintenance accounts for 25-60% of user cost (as I find empirically), tax cuts reduce total capital costs by only 40-75% as much as standard models predict. The steady-state capital stock therefore rises proportionally less, with correspondingly attenuated effects on output and wages. The investment-capital gap reinforces this attenuation along the transition path. Because elastic maintenance demand breaks the one-to-one mapping between gross investment and net capital accumulation, matching observed investment responses requires higher adjustment costs in models with maintenance than in standard models. This slows convergence to the new steady state, meaning

3. The capital preservation effect also implies that standard investment regressions suffer from omitted variable bias: because maintenance costs are tax-shielded, the measured change in user cost overstates the true change, causing the estimated coefficient to be biased downward. I provide corrections for both channels.

growth effects within policy-relevant horizons—such as the ten-year budget window used for tax scoring—are even smaller than the steady-state haircut alone would suggest.

To quantify these forces, I embed the estimated maintenance function into a general equilibrium model calibrated to the U.S. economy, following the framework of Chodorow-Reich et al. (2025). I use the level of demand for maintenance from the SOI, and calibrate the elasticity by combining the R-1 and SOI estimates. Simulating the TCJA, I compare outcomes to an otherwise identical model without maintenance, isolating the haircut maintenance imposes. The results confirm the first-order importance of the maintenance margin. Across a variety of model closures, including those that account for general equilibrium effects through wages, interest rates, and maintenance prices, the ten-year responses of macroeconomic aggregates are about 50–70% as large as the standard framework, a gap that accounts for a roughly $240 billion overestimation of corporate capital identified at the outset.

Related Literature. This paper relates to four main strands of literature.

First, this paper refines the literature on multiple margins of capital adjustment by showing that the tax distortion between maintenance and investment is a first-order concern. The closest paper is McGrattan and Schmitz Jr. (1999). To my knowledge, theirs is the only other paper that explicitly studies the maintenance-investment distortion in the tax code. Their foundational work showed that maintenance dampens capital responses by providing a substitute margin for adjustment. I make three additional contributions: the capital preservation effect, which operates through the level of maintenance and directly attenuates user cost elasticities; the investment-capital gap, which shows that observed investment responses overstate capital accumulation even within the maintenance model; and general equilibrium results showing the attenuation is robust to price feedbacks. I also provide the first U.S. estimates of the maintenance demand function and show how maintenance matters for tax scoring. Other papers, including Kabir, Tan, and Vardishvili (2024), Boucekkine, Fabbri, and Gozzi (2010), and Albonico, Kalyvitis, and Pappa (2014) study maintenance and capital utilization in non-tax settings.[4] Finally, Feldstein and Rothschild (1974) and Cooley, Greenwood, and Yorukoglu (1997) study how tax policy influences capital replacement decisions in vintage capital settings. Although their models are substantially different, their points are broadly similar: tax cuts may reduce the value of existing capital relative to newer vintages and therefore lead to faster replacement.

Second, my paper relates to a literature documenting the empirical relevance of maintenance for capital. A large documents the determinants and effects of maintenance decisions for resi-

4. My analysis focuses on maintenance of private capital. Kalaitzidakis and Kalyvitis (2004), Kalaitzidakis and Kalyvitis (2005), and Dioikitopoulos and Kalyvitis (2008) study the empirical and theoretical characteristics of public capital maintenance.

dential housing, showing that it is economically large and important (Knight and Sirmans 1996; Harding, Rosenthal, and Sirmans 2007; Hernandez and Trupkin 2021).[5] On the firm side, there is some evidence of tax cuts inducing firms to replace old, higher-maintenance capital with younger capital, lower-maintenance capital. For example, Goolsbee (1998b) shows 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. Some studies—which abstract from tax distortions—rely on maintenance 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 at all or using data from the United States. This lack of direct evidence has forced prior models to rely on assumptions. My work provides the first empirical estimate of the U.S. maintenance demand function, offering a necessary parameter to correctly model capital dynamics.

Third, the results provide a universal adjustment factor for the quantitative tax reform literature. The user cost of capital is the primary transmission channel for business tax policy in virtually all modern frameworks, whether they incorporate 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), financial frictions (Occhino 2023), or global tax considerations (Chodorow-Reich et al. 2025). Because my key mechanisms directly alter this user cost, the haircut I identify in a neoclassical model should apply similarly in these richer settings. Fundamentally, maintenance acts as a powerful dampening force on the central channel of capital taxation, regardless of other model features.

Finally, my paper connects to an extensive literature in public finance on tax incentives and investment. Since Hall and Jorgenson (1967) and Summers (1981), a large literature has used theoretical models to guide investment regressions. The result, from Hassett and Hubbard (2002) and more recently Chodorow-Reich, Zidar, and Zwick (2024), is a consensus estimate of the tax elasticity of investment around -0.5 to -1, which has been confirmed in recent years by Zwick and Mahon (2017), Kennedy et al. (2023), Chodorow-Reich et al. (2025), and Hartley, Hassett, and Rauh (2025). My theoretical results highlight the divergence between capital and investment elasticities: because firms substitute away from maintenance when investment becomes cheaper, observed investment responses overstate capital accumulation.

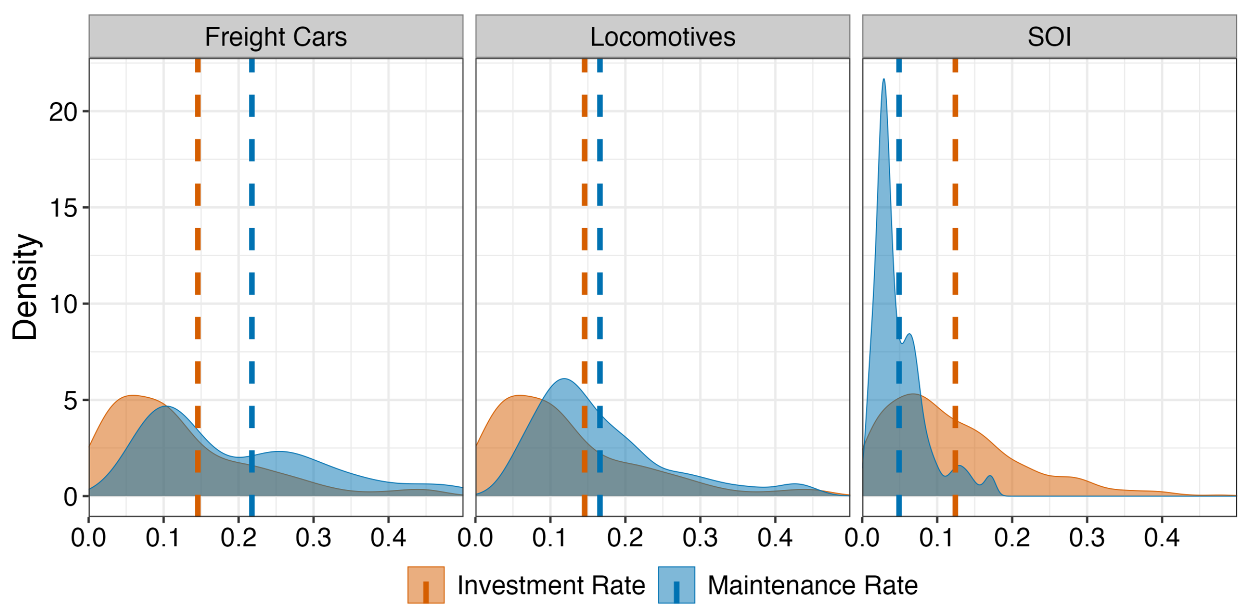
5. The investment-maintenance distortion goes the other way in the housing tax code. Whereas improvements are deductible from the capital gains tax basis, maintenance is not, which creates a distortion in favor of the former. There is no direct evidence of the importance of that margin, but Cunningham 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.

Roadmap. Section 2 presents brief institutional background on the maintenance-investment distinction. Section 3 gives a simple neoclassical model of maintenance, which I then take to the data in Sections 4, 5, and 6. Section 7 shows the importance of the theory by embedding the estimated maintenance demand function into a quantitative model of the Tax Cuts and Jobs Act. Section 8 concludes.

2 Maintenance vs. Investment

Firms engage in a wide range of activities to change the capital stock. Those activities are distinguished by maintenance, which preserves or restores capital services without improving quality, and investment, which creates or upgrades capital. 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. This distinction is not merely semantic. It maps directly to firm expenditures and how the tax code treats them.

Figure 1: Density plots for maintenance and 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. The rolling stock data span from 1999-2023, with 172 observations per asset type. There are 1116 observations in the SOI data, covering 49 major industries from 1999-2021.

Before turning to tax rules, it is useful to establish magnitudes. How large is maintenance, relative to investment? Figure 1 plots the distribution of maintenance and investment rates—measured as shares of beginning-of-period book capital—across two major railroad asset types and across all major industries from the Statistics of Income (SOI). I describe the underlying data in detail in Section 4, but include this preview here to illustrate the economic importance of maintenance expenditures. In each case, maintenance rates are substantial, suggesting that firms allocate considerable resources toward preserving existing capital, on the same order of magnitude as investment.

The tax code reinforces the distinction between maintenance and investment through differential treatment under Sections 162 and 263 of the Internal Revenue Code. In general, maintenance is immediately deductible as an operating expense, while investment must be capitalized and depreciated over time. That matters for a firm deciding whether to invest an extra dollar in new capital or spend the dollar on maintaining existing capital. Letting τ^c denote the firm's tax rate, the after-tax cost of maintenance is $1 - \tau^c$ because it is deductible. On the other hand, a new capital expenditure must be depreciated over time.[6] Let z denote the net present value of the depreciation deductions, and c denote any additional investment incentives like investment tax credits. The after-tax cost of investment is $1 - \tau^c z - c$. This implies a wedge in the maintenance-investment decision given by

$$\text{Wedge} = \frac{\text{After-tax Cost of \$1 of Maintenance}}{\text{After-tax Cost of \$1 of Investment}} = \frac{1 - \tau^c}{1 - \tau^c z - c}. \tag{1}$$

By shifting the wedge, tax reforms can shift the incentive to maintain existing capital, or invest in new capital. I make that statement precise in the following section.[7]

3 A Model of Capital Maintenance

This section develops a model where firms choose both investment and maintenance to manage their capital stock, building on Hall and Jorgenson (1967) and McGrattan and Schmitz Jr. (1999). The starting point is the standard law of motion for capital:

$$K_{t+1} = I_t + (1 - \delta)K_t \tag{2}$$

6. Firms cannot easily game this distinction because routine maintenance expenditures typically fall below a *de minimis* safe-harbor threshold, while capital improvements do not, and established case law enforces consistent application of the rules. For example, in the 2003 court case *FedEx Corp. v. United States*, FedEx disputed whether \$66M worth of expenditures on maintaining existing aircraft engines in 1993 should be considered maintenance or investment. The question decided ten percent of their tax bill for that year.

7. Appendix Figure A.1 shows how the wedge varies by asset and over time.

In steady state, investment replaces depreciated capital, so $I = \delta K$. Taking elasticities with respect to a tax reform:

$$\varepsilon_{I,\tau} = \varepsilon_{\delta,\tau} + \varepsilon_{K,\tau} \tag{3}$$

Standard models assume depreciation is fixed, so $\varepsilon_{\delta,\tau} = 0$ and $\varepsilon_{I,\tau} = \varepsilon_{K,\tau}$. This assumption justifies interpreting observed investment responses as capital responses. But when firms can maintain capital, depreciation becomes a choice variable, and this equivalence breaks down.

The key results are fourfold. First, an investment-capital gap: observed investment responses overstate capital accumulation because tax cuts endogenously raise depreciation. Second, a capital preservation effect: only fraction $(1 - s_m)$ of user cost responds to investment incentives, where s_m is the maintenance share. Third, standard investment regressions understate even the investment elasticity due to omitted variable bias. Fourth, slower convergence: when calibrated to the same short-run evidence, the maintenance model converges to steady state more slowly. These results survive general equilibrium under plausible conditions (Appendix B.2). I conclude by deriving an empirical specification for estimating the maintenance demand function.

3.1 A Model with Endogenous Depreciation

Standard models assume depreciation is exogenous. In practice, firms can influence how quickly their capital wears out by spending on maintenance, repair, and upkeep. Let M_t denote spending on maintenance and $m_t \equiv M_t/K_t$ denote the maintenance rate—maintenance expenditure per unit of capital. Depreciation depends on maintenance effort through a technology $\delta(m_t)$.

Assumption 1 (Production Technology)**.** *The production function $F : \mathbb{R}_+ \to \mathbb{R}_+$ is twice continuously differentiable with $F'(K) > 0$ and $F''(K) < 0$.*

Assumption 2 (Depreciation Technology)**.** *The depreciation function $\delta : \mathbb{R}_+ \to (0, 1)$ satisfies:*

(i) $\delta'(m) < 0$ for all $m > 0$: maintenance reduces depreciation;

(ii) $\delta''(m) > 0$ for all $m > 0$: diminishing returns to maintenance.

One can think of capital services as being produced by two distinct inputs: investment and maintenance. In the canonical model, capital is produced only by investment, and there is no real choice between inputs. The only way to disinvest is by allowing capital to depreciate. Here, firms can add to the capital stock in two ways—by investing or by maintaining—and have a technology which can effectively slow the destruction of capital.

The capital accumulation equation becomes:

$$K_{t+1} = I_t + (1 - \delta(m_t))K_t \tag{4}$$

Assumption 3 (Tax Treatment of Maintenance)**.** *Maintenance is an operating expense, immediately deductible at rate τ^c. The after-tax cost of one dollar of maintenance is $(1-\tau^c)$. Maintenance receives no investment tax credits and is unaffected by the parameters (z, c, τ^c) governing investment incentives.*

This asymmetry is the key feature of the model. Investment is capitalized and benefits from accelerated depreciation (z) and tax credits (c). Maintenance is simply expensed at the statutory rate. When investment incentives are generous, investment becomes tax-advantaged relative to maintenance. The firm's after-tax dividends are:

$$d_t = (1-\tau^c)\left[F(K_t) - p_t^M M_t\right] - (1-\tau^c z - c)p_t^I I_t \tag{5}$$

where p_t^M is the price of maintenance services. The firm chooses sequences $\{I_t, M_t, K_{t+1}\}_{t=0}^{\infty}$ to maximize:

$$V_0 = \max \sum_{t=0}^{\infty}\left(\prod_{s=0}^{t-1}\frac{1}{1+r_s}\right)d_t \quad \text{s.t.} \quad (4) \text{ and } (5) \tag{6}$$

The firm's first-order conditions are:

$$\begin{aligned}(1-\tau_t^c z_t - c_t)p_t^I = \frac{1}{1+r_{t+1}}\Big\{&(1-\tau_{t+1}^c)F'(K_{t+1}) \\ &+ (1-\tau_{t+1}^c z_{t+1} - c_{t+1})p_{t+1}^I\big[1-\delta(m_{t+1})+\delta'(m_{t+1})m_{t+1}\big]\Big\}\end{aligned} \tag{7}$$

$$(1-\tau_t^c)p_t^M = (1-\tau_t^c z_t - c_t)p_t^I\big[-\delta'(m_t)\big] \tag{8}$$

I evaluate and discuss the maintenance and capital conditions in the following sections, which then deliver the main theoretical results.

3.2 The Investment-Capital Gap

In the standard model, depreciation is fixed at $\bar{\delta}$, so steady-state investment is $I = \bar{\delta}K$ and $\varepsilon_{I,\tau} = \varepsilon_{K,\tau}$. With endogenous maintenance, this identity no longer holds. To see why, consider the firm's optimal maintenance choice. Because maintenance is chosen each period without adjustment costs—i.e., there is no "stock of repair" that accumulates over time—the decision is static. The firm equates the marginal benefit of maintenance (reduced depreciation) with its marginal cost:

$$-\delta'(m^*) = \frac{p^M}{p^I}(1-\tau)$$

Lemma 1 (Comparative Statics)**.** *Under Assumptions 1–3:*

(i) $\partial m^*/\partial p^M < 0$: higher maintenance prices reduce maintenance intensity

(ii) $\partial m^*/\partial p^I > 0$*: higher investment prices increase maintenance intensity*

(iii) $\partial m^*/\partial(1-\tau) < 0$*: tax cuts reduce maintenance intensity*

Proof: Appendix B.1.

Part (iii) is central. When investment becomes tax-advantaged—higher z or c, which raises $(1-\tau)$—the firm substitutes away from maintenance toward investment. This raises the depreciation rate $\delta(m^*)$ endogenously.

The consequence for the investment-capital relationship is immediate. In steady state, investment replaces depreciated capital: $I = \delta(m^*)K$. Unlike the standard model, $\delta(m^*)$ now depends on tax policy through m^*. Taking logs and differentiating:

$$\varepsilon_{I,\tau} = \varepsilon_{\delta,\tau} + \varepsilon_{K,\tau}$$

The investment response has two components: the capital accumulation effect ε_K, which reflects changes in the desired capital stock, and the depreciation effect ε_δ, which reflects changes in the rate at which capital must be replaced.

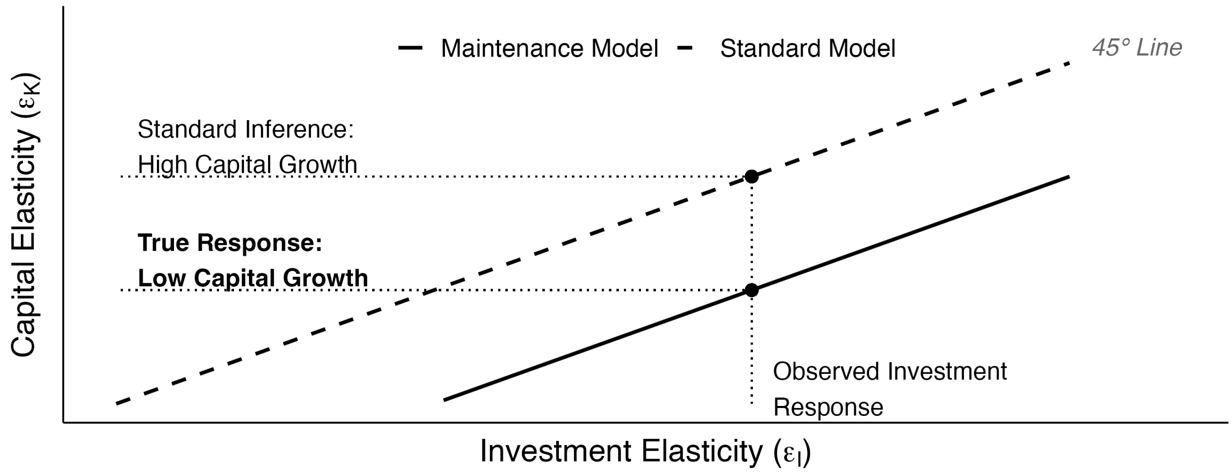
Proposition 1 (Investment-Capital Gap)**.** *Under Assumptions 1–3, tax cuts raise depreciation (*$\varepsilon_{\delta,\tau} > 0$*) and raise capital (*$\varepsilon_{K,\tau} < 0$*). Therefore:*

$$|\varepsilon_{I,\tau}| > |\varepsilon_{K,\tau}|$$

Proof: Appendix B.1.

In the standard model, $\varepsilon_{\delta,\tau} = 0$ and the proposition collapses to $\varepsilon_{I,\tau} = \varepsilon_{K,\tau}$. With maintenance, the depreciation effect drives a wedge. When policymakers introduce tax cuts, firms respond on two margins. First, the lower user cost raises desired capital, generating new investment. Second, the tax advantage of investment over maintenance induces substitution: firms reduce upkeep, depreciation rises, and more investment is required simply to maintain the higher capital stock. Observed investment responses capture both effects, but only the first represents net capital accumulation.

Figure 2: The Investment-Capital Elasticity Gap



Note: This figure plots capital elasticity against investment elasticity. The dashed 45-degree line is the standard model, where $\varepsilon_{K,\tau} = \varepsilon_{I,\tau}$. The solid line is the maintenance model, where $\varepsilon_{K,\tau} < \varepsilon_{I,\tau}$. The vertical gap measures how much standard inference overstates capital accumulation.

The gap implies that investment subsidies promote capital churn, not necessarily capital growth. In steady state, $I/K = \delta(m)$. A tax cut that makes investment cheaper also makes maintenance relatively expensive, raising $\delta(m)$ as firms let capital wear out faster. The investment rate increases permanently, but this reflects faster replacement of a younger capital stock, not a larger capital stock.[8] Standard models with fixed depreciation miss this distinction entirely.

The magnitude of the gap depends on the elasticity of maintenance demand. If maintenance demand is inelastic, the depreciation effect is small and investment responses are good proxies for capital responses. If maintenance demand is elastic, a substantial fraction of observed investment replaces endogenously higher depreciation rather than building new capital. Figure 2 illustrates this wedge.

3.3 The Capital Preservation Effect

Evaluating the firm's optimality conditions in steady state reveals a second main result: only a fraction of user cost is sensitive to tax incentives. The rest—the maintenance component—is already fully expensed and receives no additional benefit from policies like bonus depreciation or investment tax credits.

8. Firms also have a scrappage margin, which Goolsbee (1998b) shows is empirically important for tax reform. Endogenous depreciation captures this channel in reduced form: tax cuts induce firms to shed old capital more quickly. In this sense, the maintenance demand elasticity can be interpreted as a reduced-form tax elasticity for the age distribution of capital.

Evaluating the capital FOC (7) in steady state and using the optimal maintenance condition (8) to substitute out the $\delta'(m)m$ term yields:

$$F'(K) = \frac{p^I(r + \delta(m^*))}{1 - \tau} + p^M m^* \equiv \Psi \tag{9}$$

The user cost Ψ has two components: an investment component capturing financing and depreciation replacement, and a maintenance component capturing upkeep expenditure.

Definition 1 (User Cost Components). The investment component and maintenance component of user cost are

$$\Psi^I \equiv \frac{p^I(r + \delta(m^*))}{1 - \tau}, \qquad \Psi^M \equiv p^M m^*$$

so that $\Psi = \Psi^I + \Psi^M$.

Definition 2 (Maintenance Share). The maintenance share of user cost is $s_m \equiv \Psi^M/\Psi$. The investment share is $1 - s_m = \Psi^I/\Psi$.

This share governs the attenuation of user cost responses. At a common steady state where the standard model has depreciation $\bar{\delta} = \delta(m^*)$, the standard Hall-Jorgenson user cost equals only the investment component: $\Psi^I = (1 - s_m)\Psi$. The standard model ignores maintenance entirely—it captures only fraction $(1 - s_m)$ of the true user cost. Figure 3 illustrates the decomposition. The left bar shows the standard model, which treats the entire user cost as tax-sensitive. The right bar shows the maintenance model: only the investment component (fraction $1 - s_m$) responds to tax incentives; the maintenance component (fraction s_m) is tax-insensitive. How does this affect the response to tax policy?

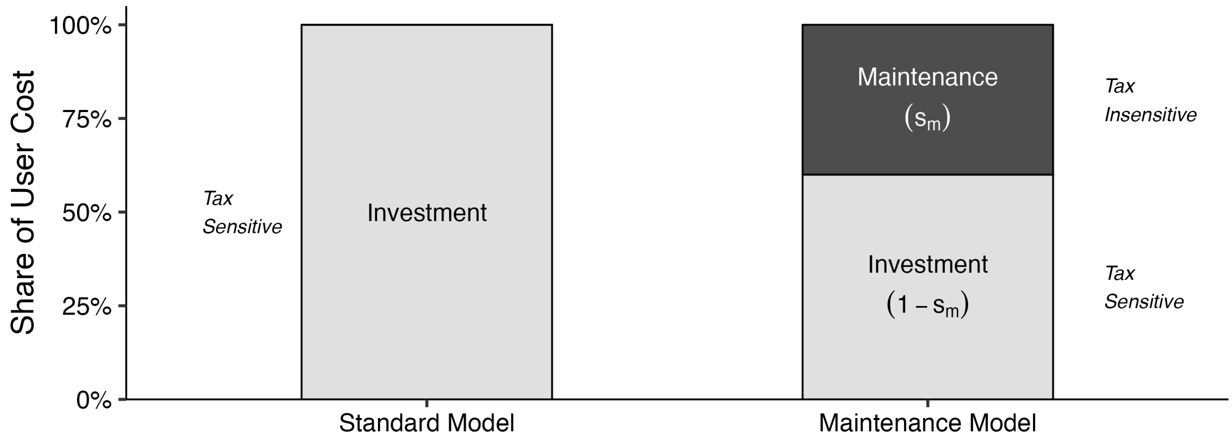
Proposition 2 (Capital Preservation Effect)**.** *At a common steady state where* $\bar{\delta} = \delta(m^*)$*:*

$$\varepsilon_{\Psi,\tau} = (1 - s_m)\frac{\tau}{1 - \tau} \tag{10}$$

Similarly for elasticities with respect to r *and* p^I*. The elasticity with respect to* p^M *is* $\varepsilon_{\Psi,p^M} = s_m$*.*
Proof: Appendix B.1.

The proof applies the envelope theorem: at the optimum, the firm has already adjusted maintenance to minimize costs, so a small change in tax policy affects user cost only through the direct channel. The indirect effect through induced changes in m^* vanishes. Since the direct effect operates only on Ψ^I, which is fraction $(1 - s_m)$ of total user cost, the elasticity is attenuated by $(1 - s_m)$.

Figure 3: Decomposition of User Cost



Note: This figure decomposes the user cost of capital into investment and maintenance components. In the standard model (left), the entire user cost responds to tax incentives. In the maintenance model (right), only the investment component (share $1 - s_m$) is tax-sensitive. The maintenance component (share s_m) is already fully expensed and does not respond.

The intuition is straightforward. Tax incentives operate through the tax wedge τ (via z, c, or τ^c), but only the investment component Ψ^I responds—the maintenance component Ψ^M is already fully expensed and receives no additional benefit. In the standard model, the user cost elasticity is $\frac{\tau}{1-\tau}$. With maintenance, the elasticity is $(1 - s_m)\frac{\tau}{1-\tau}$. If maintenance accounts for half of user cost, the response is halved. This is particularly important in the context of long-lived assets which require heavy maintenance. If maintenance dominates user cost, the user-cost elasticity would collapse to zero, and capital would not respond to taxes at all. Thus long-lived assets that also require heavy upkeep can be less tax-elastic than short-lived ones, reversing the standard "long-lived assets are more price-elastic" result in House (2014) and Koby and Wolf (2020).

Remark (General Equilibrium). The $(1 - s_m)$ attenuation survives general equilibrium. When maintenance prices are more sensitive to capital accumulation than investment prices—plausible since maintenance is labor-intensive and locally supplied while investment goods are globally traded—general equilibrium amplifies the attenuation. Appendix B.2 provides the formal treatment.

3.4 Implications for Transition Dynamics

The preceding results characterize steady states: user cost elasticities are attenuated by the maintenance share, and investment overstates capital accumulation. The maintenance channel also affects how quickly the economy adjusts to a new steady state.

In practice, researchers often estimate short-run investment responses to tax changes and use these to infer long-run effects on capital. This requires a model of transition dynamics. With adjustment costs, capital converges gradually to its new steady state. Suppose the transition path for investment following a permanent tax change takes the form:

$$\varepsilon_{I,\tau}(t) = \varepsilon_{I,\tau}^{LR}\left[1 - (1-\theta)e^{-\lambda t}\right] \tag{11}$$

Definition 3 (Transition Parameters). The *impact effect* $\theta \in (0,1)$ is the fraction of the long-run response achieved on impact: $\theta = \varepsilon_{I,\tau}(0)/\varepsilon_{I,\tau}^{LR}$. The *convergence rate* $\lambda > 0$ governs the speed of subsequent adjustment.

Different adjustment cost specifications generate different feasible (θ, λ) pairs, but standard specifications share a common property: higher θ is associated with higher λ.

Proposition 3 (Slower Convergence)**.** *Suppose the set of feasible (θ, λ) pairs is co-monotonic. If both the standard model and the maintenance model are calibrated to match the same short-run investment elasticity at horizon T, then the maintenance model has a lower convergence rate.*
Proof: Appendix B.5.

The intuition follows from the investment-capital gap. In steady state, investment replaces depreciated capital: $I = \delta(m)K$. The long-run investment elasticity with maintenance therefore exceeds that without:

$$\varepsilon_{I,\tau}^{LR} = \varepsilon_{K,\tau} + \varepsilon_{\delta,\tau} > \varepsilon_{K,\tau}$$

Both models are calibrated to match the same ε_I^{SR} at horizon T. From (11), this requires $(1-\theta)e^{-\lambda T} = 1 - \varepsilon_I^{SR}/\varepsilon_I^{LR}$. Since the maintenance model has a higher long-run target, the right-hand side is larger, requiring a larger $(1-\theta)e^{-\lambda T}$. Co-monotonicity then implies lower λ. Appendix B.5 verifies this condition for the Summers (1981) specification, which remains commonly used (Koby and Wolf 2020; Chodorow-Reich et al. 2025).

The combination—slower convergence to a smaller steady state—has direct implications for dynamic scoring of tax reforms. Budget scores are typically computed over ten-year windows, well before the economy reaches its new steady state. The maintenance channel reduces both where the economy is heading and how quickly it gets there, compressing growth effects within policy-relevant horizons. Section 7.3 quantifies these effects for the 2017 Tax Cuts and Jobs Act.

3.5 Bias in Investment Regressions

The preceding sections show that investment responses overstate capital accumulation: the investment-capital gap operates in steady state, and slower convergence means short-run responses are farther from long-run values than standard models imply. This subsection shows the problem begins earlier. The canonical investment regression is derived from Hall-Jorgenson user cost theory, which guides both the specification and the interpretation of estimates. When that theory omits maintenance, the regression inherits the omission—and the resulting coefficients are biased.

The canonical regression in the investment literature estimates the short-run response of investment to user cost:

$$f(I_{i,t}, K_{i,t-1}) = \beta \times \log(\Psi_{i,t}) + X_{i,t} + u_{i,t}, \tag{12}$$

where $f(\cdot)$ is either $\log I_{i,t}$ or the investment rate $I_{i,t}/K_{i,t-1}$, and $X_{i,t}$ includes controls and fixed effects.[9] This specification is not atheoretical: researchers regress on $\log \Psi$ because Hall-Jorgenson theory says investment responds to user cost, and they construct user cost as $\frac{p^I(r+\delta)}{1-\tau}$ because theory says that is the relevant price. When theory omits maintenance, the regressor becomes Ψ^I rather than $\Psi = \Psi^I + \Psi^M$—and the measured price change overstates the true price change.

The intuition is straightforward. When policymakers cut taxes on investment, the measured user cost Ψ^I falls by more than the true user cost Ψ because maintenance expenditures are already fully deductible and do not benefit from the tax cut. The econometrician observes a large measured reduction in user cost but only a modest investment response, and concludes that investment demand is relatively inelastic. In reality, investment demand may be quite elastic—the problem is that the measured price change overstates the true price change.

This parallels Goolsbee (1998a), who shows that regressing investment on tax terms alone implicitly assumes perfectly elastic supply of investment goods. When supply is upward-sloping, tax cuts raise investment prices, and the observed quantity response understates demand elasticity. The maintenance bias operates through similar logic but on a different margin: by omitting maintenance from user cost, standard regressions overstate the price reduction from tax cuts, biasing estimated demand elasticities downward.

Proposition 4 (Bias in Investment Regressions)**.** *Suppose the econometrician regresses investment on $\log \Psi^I$ when the true user cost is $\Psi = \Psi^I + \Psi^M$. The estimated short-run coefficient is biased toward zero, with the true short-run coefficient β related to the estimated coefficient $\hat{\beta}$ by*

$$\beta \approx \frac{\hat{\beta}}{1 - s_m} \tag{13}$$

The correction factor is independent of the choice of $f(\cdot)$ on the left-hand side.
Proof: Appendix B.4.

The correction can be substantial. If maintenance accounts for 25% of user cost, the true short-

9. See Cummins, Hassett, and Hubbard (1996), Desai and Goolsbee (2004), Edgerton (2010), and Hartley, Hassett, and Rauh (2025) for examples.

run elasticity is one-third larger than the estimated elasticity. Section 7.3 applies this correction to estimates from the literature.

Omitting maintenance from user cost theory thus distorts empirical work in three ways. First, the regressor is wrong: the measured price change overstates the true change, biasing estimated coefficients toward zero (Proposition 4). Second, the interpretation is wrong: even correctly estimated investment elasticities overstate capital elasticities because the investment-capital gap breaks the standard equivalence (Proposition 1). Third, the calibration is wrong: using biased short-run estimates to infer long-run effects compounds the error, since the maintenance model converges more slowly than standard models imply (Proposition 3). These are not independent corrections—they are four manifestations of one theoretical omission.

3.6 Taking the Model to Data

The theoretical results identify four channels through which the maintenance margin affects the transmission of tax incentives. First, the investment-capital gap (Proposition 1): observed investment responses overstate capital accumulation because $\varepsilon_{I,\tau} = \varepsilon_{\delta,\tau} + \varepsilon_{K,\tau}$, and $\varepsilon_{\delta,\tau} > 0$ when maintenance demand is elastic. Second, the capital preservation effect (Proposition 2): user cost elasticities are attenuated by factor $(1-s_m)$, where s_m is the maintenance share of user cost. Third, bias in investment regressions (Proposition 4): standard estimates understate even the short-run investment response by the same factor. Fourth, slower convergence (Proposition 3): the maintenance model converges more slowly when calibrated to the same short-run evidence.

Two parameters govern the quantitative importance of these channels:

1. **The maintenance share** s_m: This determines the capital preservation effect and the OVB correction directly. Higher s_m means a larger fraction of user cost is tax-insensitive, so the attenuation $(1 - s_m)$ is more severe and the bias in standard regressions is larger.

2. **The elasticity of maintenance demand** ω: This determines how much firms substitute between maintenance and investment when relative prices change. Appendix B.3 shows that the depreciation elasticity is
$$\varepsilon_{\delta,\tau} = \frac{\gamma\omega}{\delta_0 + \frac{\gamma\omega}{1-\omega}} \tag{14}$$
which governs both the investment-capital gap ($\varepsilon_{I,\tau} - \varepsilon_{K,\tau} = \varepsilon_{\delta,\tau}$) and slower convergence.

To estimate these parameters, I adopt a constant-elasticity specification for the depreciation technology:
$$\delta(m) = \delta_0 - \frac{\gamma^{1/\omega}}{1 - 1/\omega} m^{1-1/\omega} \tag{15}$$

where $\delta_0 > 0$ is baseline depreciation without maintenance, $\gamma > 0$ shifts the level of maintenance, and $\omega > 1$ governs the curvature. This specification satisfies Assumption 2: it is decreasing and convex in m.

Proposition 5 (Maintenance Demand)**.** *Under the constant-elasticity depreciation technology, optimal maintenance is:*

$$m^* = \gamma \left(\frac{p^M}{p^I} (1 - \tau) \right)^{-\omega} \tag{16}$$

The parameter ω is the price elasticity of maintenance demand.

The proof follows directly from the maintenance first-order condition. The level parameter γ determines the maintenance share: at prevailing prices, optimal maintenance is $m^* = \gamma(\bar{p}^M / \bar{p}^I (1-\bar{\tau}))^{-\omega}$, and the maintenance share is $s_m = p^M m^* / \Psi$. Given observed (m^*, s_m) and prices, one can recover γ by inverting the demand function. Thus γ and s_m are interchangeable for quantifying the capital preservation effect and the OVB correction.

Taking logs of the demand function yields the estimating equation:

$$\log m_{it} = \alpha_i + \lambda_t - \omega \log \left(\frac{p^M_{it}}{p^I_{it}} (1 - \tau_{it}) \right) + u_{it} \tag{17}$$

where α_i and λ_t are firm and time fixed effects. The coefficient ω is identified from within-firm variation in the after-tax relative price of maintenance. The fixed effects absorb $\log \gamma$ along with other time-invariant and common factors.

The empirical task is therefore twofold: measure s_m from the level of maintenance expenditures, and estimate ω from variation in relative prices. Section 4 describes two data sources: detailed firm-level data from railroad regulatory filings and industry-level data from corporate tax returns. Section 5 measures the maintenance share of user cost, and Section 6 estimates the demand elasticity.

4 Data

This section introduces two novel sources of maintenance data for the United States. First, I digitize regulatory filings from Class I freight railroads spanning 1999-2023, providing firm-asset level detail on maintenance expenditures, capital stocks, and input costs. To my knowledge, this is the first use of R-1 data in modern economics since Bitros (1976). Second, I construct industry-level measures from IRS Statistics of Income (SOI) corporate tax returns covering 1999-2019. While the SOI has been used to study investment (e.g., Zwick and Mahon (2017)), this is the first application to maintenance. Given the theory, each dataset must provide two objects: the maintenance share of user cost s_m, which requires data on maintenance expenditures, capital stocks, depreciation rates, and interest rates; and variation in relative prices sufficient to estimate the elasticity of maintenance demand ω. These datasets provide complementary evidence: the railroad data offer precision and detailed variation in firm behavior, while the SOI provides economy-wide coverage.

4.1 R-1 Data from the Surface Transportation Board

Class I freight railroads—defined as having revenue exceeding roughly $1 billion—account for about 40% of U.S. freight transportation. Following industry consolidation in the 1980s and early 1990s, the sector has consisted of approximately seven large firms in stable competitive equilibrium since the late 1990s.[10] By regulation, these firms must file annual R-1 reports with the Surface Transportation Board (STB). These reports detail the size and composition of firms' capital in value and quantities, trackage by state, taxes paid, capital expenditures, and maintenance expenditures broken down by capital type and input source (materials, labor, or purchased services). Reports are independently audited and provide an unparalleled window into firm capital structure and maintenance behavior. The data span 1999-2023.

For this paper, I maintain a narrow focus on freight cars and locomotives. These assets offer two advantages for studying maintenance demand. First, maintenance activities and associated prices can be straightforwardly identified in the data, whereas this is not true for other capital types. Second, track maintenance is strictly regulated by the Federal Railroad Administration, while locomotive and freight car maintenance faces considerably less regulatory constraint. This provides meaningful variation in firm maintenance choices, which is essential for identification.

The main measure of the maintenance rate is the ratio of maintenance expenditures to lagged book capital. I also construct two alternative metrics: a physical maintenance rate (maintenance expenditures per horsepower for locomotives or per freight ton capacity for freight cars), and separate internal and external maintenance rates. The distribution of maintenance rates for both asset types appears in Figure 1.

Next, I construct firm- and asset-specific relative prices as

$$P_{i,j,t} = \frac{p^M_{i,j,t}}{p^I_{j,t}} \frac{1-\tau_{i,t}}{1-\tau_{i,t}z_t}, \tag{18}$$

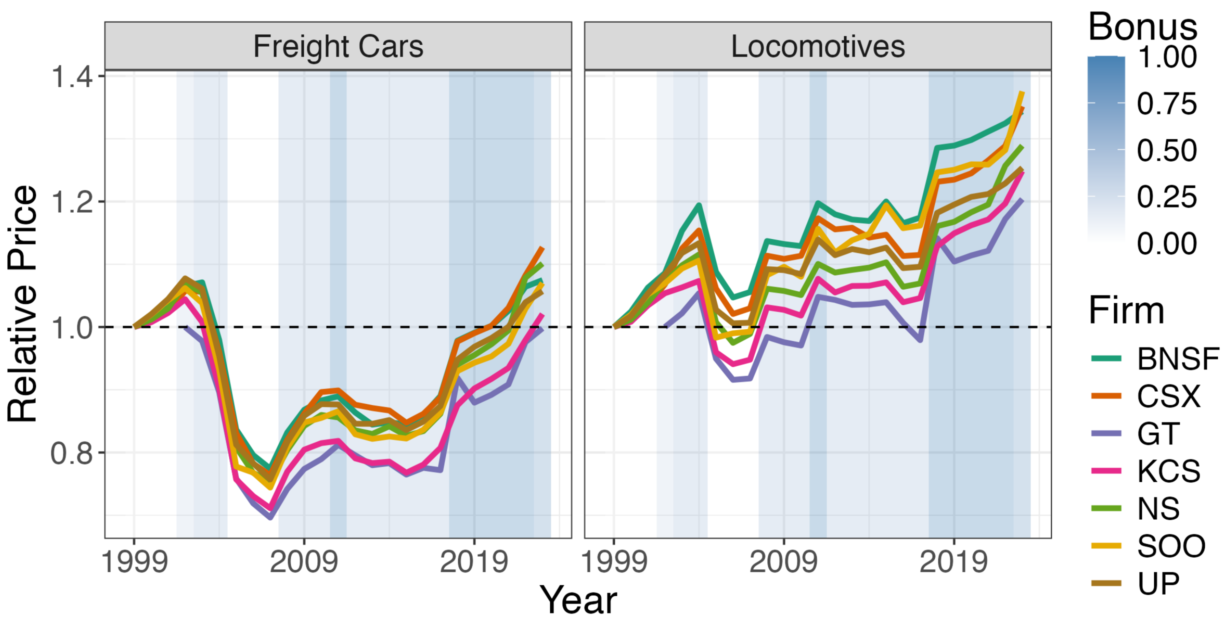
where $p^M_{i,j,t}$ is the pre-tax maintenance price of capital good j for firm i at time t, $p^I_{j,t}$ is the investment price of asset j, and $\tau_{i,t}$ is the firm-specific tax rate. Due to data availability, only

10. The seven firms are CSX, Burlington Northern & Santa Fe, Union Pacific, Norfolk Southern, Kansas City Southern, Soo Line, and Grand Trunk (operated by Canadian National Railway). I end the sample in 2023 due to subsequent industry consolidation.

the pre-tax price of maintenance varies by firm and capital type, whereas tax rates vary by firm and investment prices by capital type. Tax rates do not vary between assets because the IRS places locomotives and freight cars in the same depreciation category. Further details on data construction and summary statistics are in Appendix C.1.

Figure 4 plots the after-tax relative price of maintenance to investment for all Class I railroads since 1999. The price of maintaining locomotives has persistently increased since 2000, while the pattern is more U-shaped for freight cars. Background shading indicates periods of bonus depreciation, which reduced the relative price of investment and thus increased the maintenance-investment wedge. However, since all equipment here is in the same tax category, there is no variation between assets or across firms.

Figure 4: After-tax relative price of maintenance to investment



Notes: I construct the after-tax relative price of maintenance to investment as described in the main text and in Appendix C.1. Background shading is for bonus depreciation.

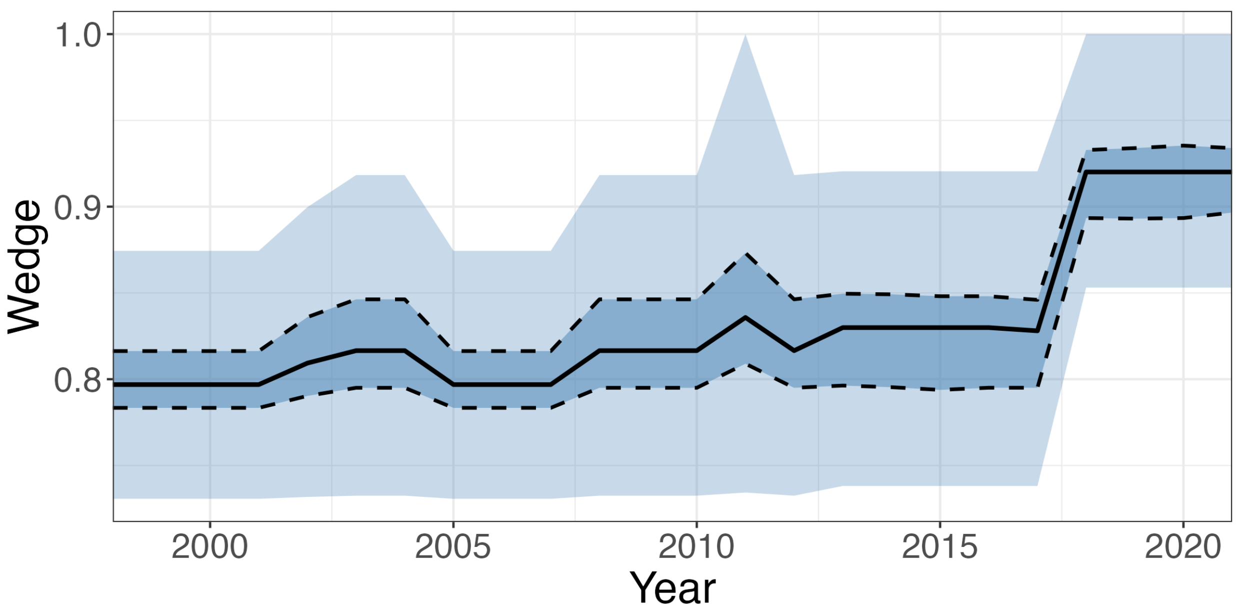
To construct the maintenance share of user cost, I also require depreciation rates and a cost of capital. I use economic depreciation rates for railroad equipment (4% for locomotives, 3% for freight cars) and the industry-average discount rate for NAICS 48 from Gormsen and Huber (2022). Appendix C.1 provides details.

4.2 Industry Data from the Statistics of Income

The IRS Statistics of Income (SOI) aggregates corporate tax returns into industry-level samples at approximately the three-digit NAICS level. This is the only economy-wide collection of maintenance data at annual frequency in the United States. Corporations report maintenance expenditures and book capital as line items on their tax forms, which the SOI aggregates across firms within industries. I use SOI data from 1999-2019, aggregating to 49 industries to correspond with Bureau of Economic Analysis (BEA) classifications.[11] For some analyses, I separate the sample into taxable firms (those with positive net income) and non-taxable firms.

The SOI maintenance rate—the ratio of maintenance expenditures to lagged book capital—is noisier than the R-1 measure for two reasons. First, because labor expenditures appear as a separate line item on tax forms, reported maintenance largely reflects spending on materials and external services, understating total maintenance costs.[12] Second, the capital stock denominator uses tax depreciation schedules to construct book capital, which may not accurately reflect economic capital stocks. Despite these measurement issues, the resulting maintenance rates are similar to those observed in aggregate Canadian data.[13] Figure 1 plots the distribution of SOI maintenance rates across industries and years.

Figure 5: Distribution of industry-specific wedges over time



Notes: Every line is a quartile of the industry-specific wedge defined in the main text.

Because there is no easily identifiable measure of relative prices at the industry level, my identification strategy for the SOI data relies on the policy wedge defined in equation 1. I con-

11. I exclude filings made with Forms 1120S, 1120-REIT, and 1120-RIC, and remove the financial sector. See Appendix C.2 for details on the SOI-BEA industry mapping and why I use the BEA definition.

12. The labor cost share in maintenance is typically 30-45%. Appendix C.2 discusses a potential correction and shows that the main results of this paper are conservative as a result.

13. See Appendix Figure C.5 for a comparison.

struct asset-specific wedges for every BEA asset using the mapping from assets to the tax code in House and Shapiro (2008). I then aggregate the asset-specific wedges into a capital-weighted industry-specific wedge, where the weights reflect each industry's capital composition. Industries with more equipment-intensive capital structures face larger policy-driven changes in the maintenance-investment wedge when tax incentives vary.[14]

Figure 5 plots the distribution of industry-specific wedges over time. Tax reforms throughout the 2000s—particularly expansions of bonus depreciation—tended to reduce the wedge proportionally more for equipment-intensive industries, while structures-intensive industries saw little change until the TCJA in 2017. There is significant variation in the incentive to substitute between maintenance and investment over time, which is exactly what I require to estimate the elasticity of maintenance demand.

To construct the maintenance share, I use industry-specific depreciation rates from the BEA Fixed Asset Tables and industry-specific discount rates from Gormsen and Huber (2022). Appendix C.2 provides details.

With these two complementary data sources in hand—detailed firm-level variation from railroads and broad industry coverage from the SOI—I now turn to measuring the key parameters from the theory.

5 The Maintenance Share of User Cost

Standard models of capital taxation assume the entire user cost responds to tax incentives. In practice, only the investment component responds, while the maintenance component is already fully expensed. The maintenance share of user cost $s_m \equiv p^M m^* / \Psi^{NGMM}$ therefore governs how much investment tax actually reduce the cost of capital services. If maintenance accounts for half of user cost, tax incentives are half as effective as standard models predict. Figure 6 presents estimates from both the freight rail and SOI datasets.

The railroad data show maintenance shares averaging nearly 60% for both locomotives and freight cars. Keeping rolling stock in service requires continuous upkeep, and these costs rival the financing and depreciation costs of the equipment itself. At $s_m = 0.6$, standard models overstate the responsiveness of user cost to tax policy by a factor of 2.5.[15]

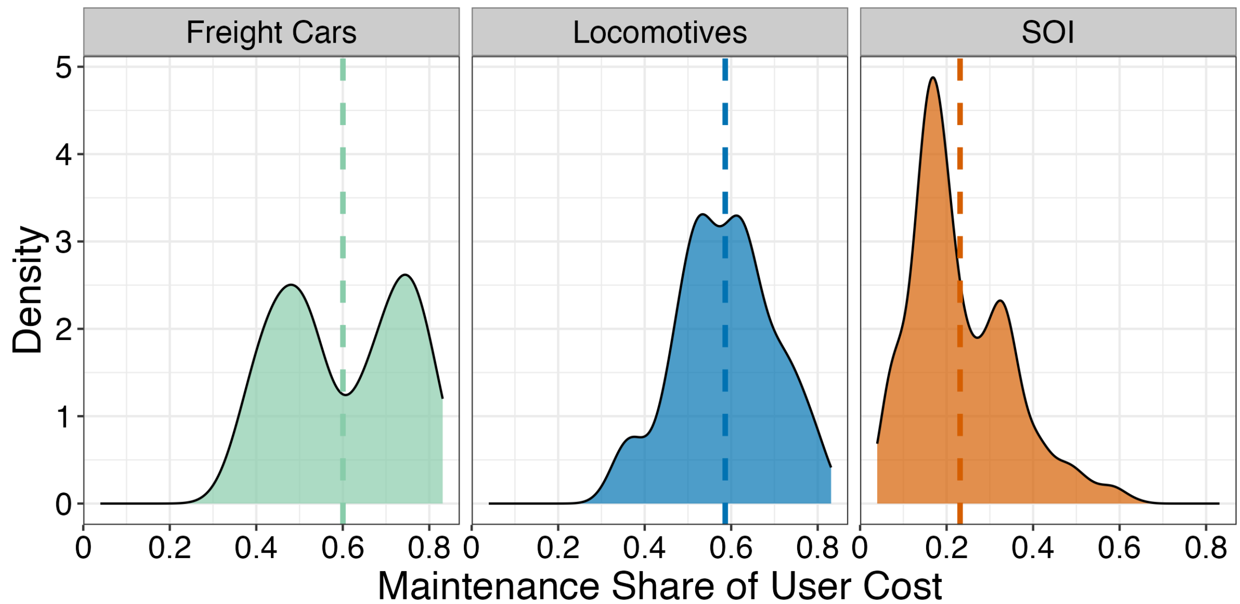
The SOI data show a maintenance share of about 25%, though this is likely a lower bound. SOI maintenance expenditures exclude internal labor costs, which appear as wages on tax forms

14. Appendix C.2 provides details on asset-level wedge construction and capital weighting.

15. The user cost formula requires a depreciation rate, which I take from BEA estimates. These estimates assume constant depreciation, which is precisely what this paper relaxes. However, the BEA rates reflect average depreciation given average maintenance behavior over the sample period, making them appropriate for roughly measuring the level of s_m at current policy.

rather than repairs. Since labor accounts for 30–45% of total maintenance costs in the railroad data, the true economy-wide maintenance share may be closer to 35–40%. Even at the conservative SOI estimate, tax incentives reduce the cost of capital by only three-quarters as much as standard models imply.

Figure 6: The Maintenance Share of User Cost



Note: Density plots for the maintenance share of user cost. Dashed lines are means: 23% (SOI), 60% (Freight Cars), 58.6% (Locomotives). See Appendix C for construction details.

The difference between the datasets reflects both measurement and economics. Railroad rolling stock is maintenance-intensive: locomotives and freight cars operate continuously, face harsh conditions, and require regular inspection and repair. The broader economy includes structures and other long-lived assets with lower maintenance requirements. For the quantitative analysis that follows, I use the SOI estimate as a conservative baseline, recognizing that the true attenuation is likely larger for equipment-intensive industries.

The maintenance share determines the capital preservation effect. But mapping investment responses to capital also requires the elasticity of maintenance demand, which I estimate next.

6 Estimating The Maintenance Demand Elasticity

The maintenance share determines the capital preservation effect. Mapping investment responses to capital also requires the elasticity of maintenance demand, which governs the investment-capital gap. This section estimates the latter using complementary evidence from railroad data (firm-level variation in relative prices) and industry data (variation in tax policy exposure). The railroad estimates provide precise identification of the elasticity but reflect partial equilibrium responses at the firm level. The industry estimates capture any within-industry general equilibrium effects but are less precise due to measurement error in maintenance and capital stocks.

6.1 Evidence from Freight Railroads

I estimate the maintenance elasticity using locomotives and freight cars owned by seven Class I railroads from 1999-2023. Let $P_{i,j,t}$ denote the firm i by asset j by year t after-tax relative price of maintenance to investment defined in Section 4. The basic regression specification estimates the maintenance elasticity of demand ω with

$$\log m_{i,j,t} = \alpha_{ij} + \lambda_t - \omega \log P_{i,j,t} + \text{Controls} + u_{i,j,t}, \tag{19}$$

where α_{ij} is a firm-by-capital type fixed effect and λ_t is a time fixed effect. The coefficient ω is identified by leveraging variation in relative prices within each firm-capital type over time, with fixed effects controlling for all time-invariant characteristics and common temporal shocks. I cluster standard errors by firm and year to account for correlation in maintenance decisions 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 OLS estimates will be biased. Unobserved firm-level supply shocks could simultaneously affect maintenance intensity and input prices. Similarly, regional economic expansions might raise both wages and freight demand, leading firms to defer maintenance to maximize utilization.

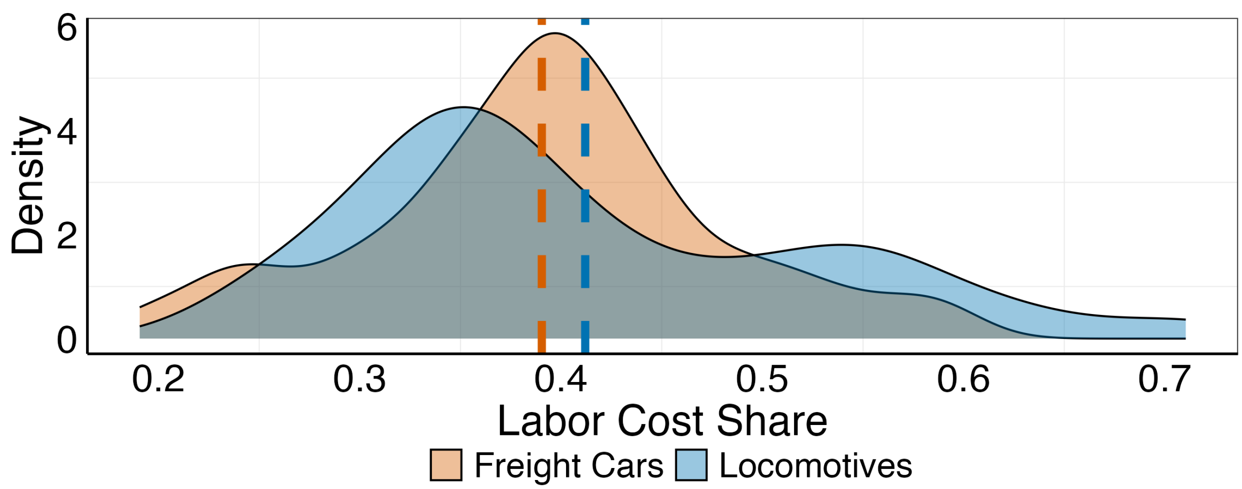
To address this endogeneity, I construct a shift-share instrument that isolates exogenous variation in maintenance costs:

$$Z_{i,j,t} = \frac{\text{Labor}_{i,j,t-2}}{\text{Internal Maintenance}_{i,j,t-2}} \sum_{s=1}^{S} \frac{\text{Rail Miles}_{i,t,s}}{\text{Rail Miles}_{i,t}} W_{s,t}. \tag{20}$$

The instrument has two components. The *shares* capture each firm's cost structure: the labor cost share of internal maintenance, lagged two years to ensure pre-determination. Firms that rely more heavily on internal labor are more exposed to wage movements. The *shifts* are state-level wage indices for maintenance occupations (BLS SOC code 49-0000), weighted by each firm's geographic footprint. These state wages reflect broad labor market conditions—tightness, cost of living, unionization—that are plausibly orthogonal to individual railroads' maintenance needs.[16]

The instrument follows the "many exogenous shifts" approach of Borusyak, Hull, and Jaravel (2024). The shifts, which occur at a broad state-level wage category across 49 states over 25 years, are numerous and plausibly orthogonal to firm-asset maintenance decisions. Railroad maintenance facilities are geographically dispersed based on network structure and historical infrastructure, not chosen to minimize current labor costs. The shares, comprised of geographic footprints and cost structures, are persistent and pre-determined. Together, these deliver variation in relative maintenance prices orthogonal to unobserved demand or supply shocks at the firm-asset level.

Figure 7: Internal Labor Cost Share for Rolling Stock



Note: The figure plots the winsorized density of labor cost shares for locomotives and freight cars from R-1 reports.

Figure 7 plots the distribution of labor cost shares by asset type, showing substantial variation both within and between firms over time. The first stage has the correct sign and exceeds the usual $F > 10$ threshold using the Montiel-Olea and Pflueger (2013) test, but the inference that follows is robust to weak instruments. Additionally, the instrument satisfies standard balance tests. Appendix Figure D.1 shows that lagged maintenance rates are not predicted by $Z_{i,j,t}$, indi-

16. Why focus on internal rather than total maintenance? This choice serves both a practical and a diagnostic purpose. Practically, external maintenance is typically contracted in advance with predetermined service agreements, often negotiated at equipment purchase. These contracts make external maintenance inflexible in the short run, so any price-driven adjustment occurs primarily through the internal margin. More importantly, the internal-external distinction provides a test of the exclusion restriction. If the instrument isolates cost-side shocks (shifting the price of in-house labor) we should observe: (i) large quantity responses for internal maintenance where firms can flex, (ii) near-zero responses for external maintenance where contracts are sticky, and (iii) firms substituting toward external when internal wages rise. By contrast, if the instrument were capturing demand shocks—such as utilization spikes that simultaneously raise maintenance needs and local wages—both internal and external quantities would move together. I show below that the data strongly support the cost-side interpretation.

cating no anticipation effects. Appendix Figure D.2 shows that labor cost shares are orthogonal to lagged maintenance rates, relative prices, and asset age, confirming that the shares are not correlated with pre-period predictors of maintenance.

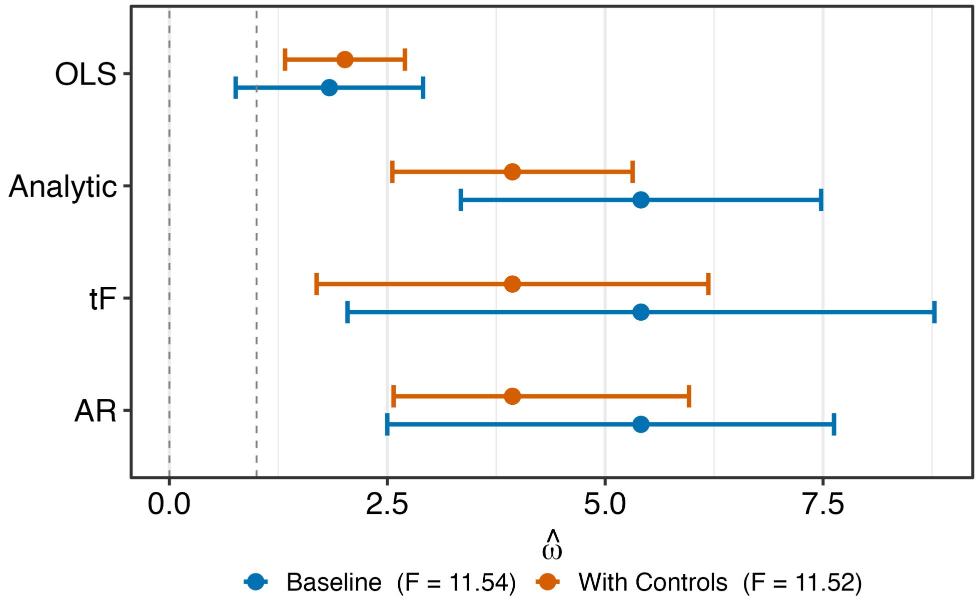
To address remaining confounders, I include several controls that target potential violations of the exclusion restriction at both the shift and unit level. At the shift level, the primary concern is that local economic conditions might simultaneously affect freight demand, wages, and maintenance intensity. For example, a regional boom could increase demand for rail services (raising utilization and deferring maintenance), tighten local labor markets (raising wages), and increase freight revenues simultaneously. To address this, I construct each firm's demand exposure as a weighted average of state-level GDP growth, using track miles in each state as weights. This variable captures how aggregate demand shocks in a railroad's service territory affect its operations, allowing me to isolate wage variation orthogonal to local business cycles.

At the unit level, I control for capital age (proxied by the ratio of net to gross book capital) because older capital requires more maintenance and may also have different exposure to local labor market condition since older equipment might be maintained at older facilities in regions with different wage dynamics. I also include firm-specific linear time trends to absorb gradual changes in firm operations, technology adoption, or management practices that might correlate with both maintenance intensity and geographic wage exposure. For example, if a firm is gradually shifting its maintenance operations to lower-wage regions over time, the firm trend absorbs this smooth reallocation, ensuring identification comes from within-firm year-to-year variation in the instrument rather than secular trends.

These controls, combined with firm-asset and time fixed effects, create a demanding specification: identification requires that conditional on a firm's persistent maintenance practices, common national shocks, smooth firm-specific trends, local demand conditions, and capital vintage, the instrument provides variation in maintenance costs orthogonal to unobserved maintenance needs.

Results. Figure 8 presents estimates of equation (19). The baseline OLS estimate yields a point estimate near 2. Instrumenting for relative prices produces a substantially larger elasticity: the TSLS point estimate is approximately 3.5. Because the instrument is only moderately strong (F $\approx$ 11), I follow Lee et al. (2022) and Lal et al. (2024) and compute 95% confidence intervals by inverting the Anderson and Rubin (1949) and tF statistics. While wider than analytic intervals, both easily reject $\omega = 0$ and $\omega = 1$. It is important to reject $\omega = 1$ so that returns to scale are decreasing in maintenance. 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).

Figure 8: R-1 maintenance demand elasticity with 95% confidence interval

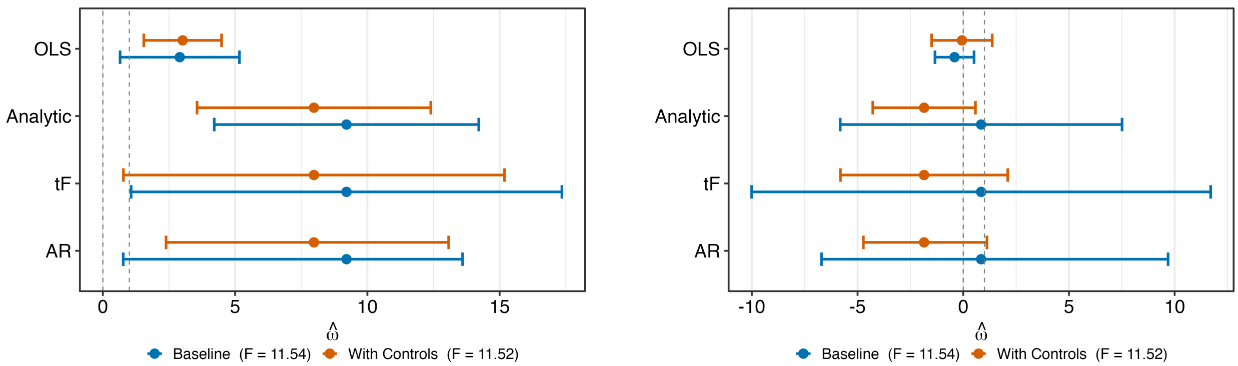


Note: This figure plots the point estimates and result for estimating (19). The blue lines contain no controls, while the orange lines control for local GDP exposure, firm-year trends, and the age of the capital stock. All standard errors are clustered by firm. The top estimate is for OLS only, while the bottom three all correspond to the instrument specified in (20). Analytic confidence intervals are from traditional Wald estimates, while the tF and AR confidence intervals result from inverting the tF (Lee et al. 2022) and Anderson and Rubin (1949) tests, respectively. The F-statistic reported in the legend is the effective F-statistic from Montiel-Olea and Pflueger (2013).

Robustness and Validation. I now present two types of evidence supporting the baseline results: first, a test of the exclusion restriction using the internal-external maintenance split; second, a summary of additional robustness checks detailed in Appendix D.1.

Internal vs. External Maintenance: Testing the Exclusion Restriction. The preceding results aggregate all maintenance into a single input. Examining internal and external maintenance separately provides a powerful test of whether the instrument isolates cost-side variation or captures correlated demand shocks. The instrument shifts the cost of internal maintenance performed by the firm's own employees through state-level wage movements. If this successfully isolates supply-side shocks, it leads to sharp predictions. Internal maintenance is flexible: firms can reallocate labor, adjust schedules, or defer maintenance when costs rise. External maintenance is typically contracted in advance with predetermined service agreements, typically negotiated at equipment purchase, and involves vendors with limited capacity. A valid cost-side shock therefore predicts: (i) large quantity responses for internal maintenance where firms can change their maintenance mix, (ii) minimal responses for external maintenance where contracts are sticky, and (iii) substitution in sourcing mix toward external maintenance when internal becomes more expensive. These predictions would not hold under alternative interpretations. If the instrument captured demand shocks, for example, regional booms simultaneously raising maintenance needs and wages, both internal and external maintenance would move together and the sourcing mix would remain stable. The asymmetry predicted by the cost-side interpretation provides a falsifiable test.

Figure 9: Maintenance demand elasticity with 95% confidence intervals



(a) Internal maintenance demand elasticity

(b) External maintenance demand elasticity

Note: Each panel plots the point estimates and results for estimating (19). The blue lines contain no controls, while the orange lines control for local GDP exposure, firm-year trends, and the age of the capital stock. All standard errors are clustered by firm. The top estimate is for OLS only, while the bottom three all correspond to the instrument specified in (20). Analytic confidence intervals are from traditional Wald estimates, while the tF and AR confidence intervals result from inverting the tF (Lee et al. 2022) and Anderson and Rubin (1949) tests, respectively. The F-statistic reported in the legend is the effective F-statistic from Montiel-Olea and Pflueger (2013).

Figures 9a and 9b re-estimate equation (19) separately for internal and external maintenance. The contrast is stark. Internal maintenance exhibits an elasticity nearly double the pooled estimate, reaching approximately 7, with confidence intervals easily rejecting both zero and unit elasticity. External maintenance shows an elasticity statistically indistinguishable from zero across all specifications.

This pattern strongly supports the exclusion restriction. The instrument generates precisely the asymmetric response a cost shifter predicts: large adjustment on the flexible internal margin, no adjustment on the sticky external margin. The pattern is difficult to reconcile with demand confounds. The internal estimate of $\omega \approx 7$ likely provides an upper bound on the structural elasticity. Any residual demand-side correlation would attenuate the elasticity toward zero, so observing such a large elasticity despite potential attenuation suggests maintenance demand is highly price-sensitive where firms have flexibility.

Additional Robustness Checks. Appendix D.1 provides extensive additional validation. I show that the first stage is strong across multiple instrument specifications (Table D.1). The appendix also presents robustness checks using physical capital stocks rather than book values (Figure D.3), alternative instruments using national wage indices (Figure D.4) and different lag structures for the labor shares (Figure D.5). Across all specifications, the large negative elasticity remains, indicating the result is not an artifact of any particular modeling choice.

I also provide checks with dynamic specifications. When controlling for lagged maintenance, the short-run elasticity is smaller, but the long-run elasticity remains at approximately 3.5 (Appendix Figure D.6), consistent with the steady-state interpretation from theory. However, local projections in Figure D.7 indicate that the response of maintenance is immediate but also displays persistence. Firms reduce upkeep on impact, and the effect deepens for two to three years before attenuating. This pattern is consistent with some adjustment frictions, such as planning lags or a stock-of-disrepair channel, that make the full reallocation of resources away from maintenance gradual rather than instantaneous.

6.2 Maintenance in the SOI

The railroad estimates reflect firm-level responses. In general equilibrium, firms may reallocate capital: when tax incentives make new capital attractive, firms cutting maintenance may sell used equipment to other firms rather than scrapping it. If buyers maintain this capital more intensively, the aggregate decline in maintenance will be smaller than the firm-level response. Appendix F.1 formalizes how this reallocation dampens the aggregate elasticity.

To estimate something closer to an aggregate elasticity, I turn to industry-level SOI data. The unit of observation—an industry-year covering 49 broadly defined industries—is sufficiently aggregated that within-industry capital reallocation is largely netted out. This assumes capital sales following tax cuts remain within industries, plausible for specialized capital (oil rigs) but less so for general-purpose capital (rental cars). Nevertheless, the SOI provides the only economy-wide evidence on maintenance and allows assessment of whether firm-level elasticities translate to the aggregate.

Identification Strategy. Identification comes from cross-sectional variation in industry exposure to tax policy changes. Industries differ in capital composition: some rely heavily on equipment eligible for accelerated depreciation, others on structures. This creates differential exposure to two major types of reforms. First, bonus depreciation varied from 0% to 100% between 2002-2023, with larger effects on equipment-intensive industries (House and Shapiro 2008; Zwick and Mahon 2017; Garrett, Ohrn, and Suárez Serrato 2020). Second, the 2017 Tax Cuts and Jobs Act increased bonus to 100% and cut the corporate rate from 35% to 21%, creating variation across industries (Kennedy et al. 2023; Chodorow-Reich et al. 2025). There is substantial evidence that both kinds of reforms boosted investment.

I estimate:

$$\log m_{i,t} = \alpha_i + \lambda_t - \omega \log\left(\frac{1-\tau_t^c}{1-\tau_t^c z_i}\right) + \text{Controls} + \eta_{i,t}, \tag{21}$$

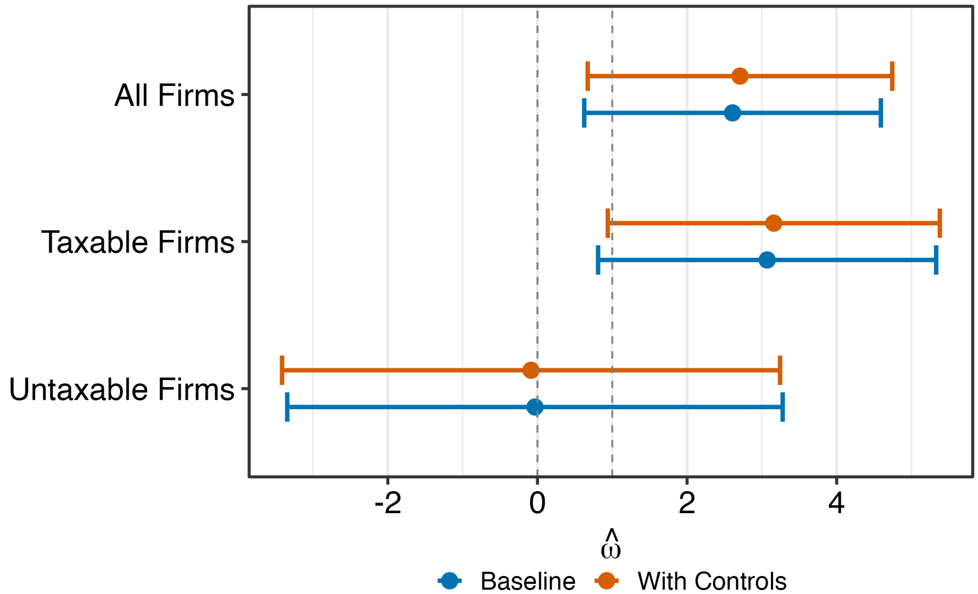
where α_i is an industry fixed effect and λ_t is a time fixed effect, and the tax term is the wedge from equation 1. z_i determines how exposed each industry is to the reform. I construct z_i by using pre-reform capital weights. This captures the economically relevant margin: firms are differentially exposed based on their existing stock of capital.[17]

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. Figure 10 shows estimates of (21) for three groups: all firms, taxable firms, and untaxable firms. The top row 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. Compared to the fully partial equilibrium R-1 coefficient, the SOI coefficient is about 80% as large, which implies some degree of within-industry dampening. The gap between the SOI and freight rail estimates suggests some reallocation between firms following tax cuts, resulting in a smaller decline in aggregate maintenance than observed at the micro level.

17. One could also consider an investment-weighted scheme, as is standard in investment elasticity studies (e.g., (Zwick and Mahon 2017)). In those studies, z is constructed by taking a weighted average of recent investment flows. This captures the elasticity for recently acquired assets. However, maintenance applies to the entire installed capital base, not just recent purchases, making investment weights conceptually misaligned. Appendix Figure D.9 validates this choice: the maintenance demand elasticity is indistinguishable for an investment-weighted scheme.

Figure 10: Maintenance demand elasticity with 95% confidence interval



Note: This figure plots the point estimates and result for estimating (21). All estimates have two-way fixed effects together with linear and quadratic trends in two-digit NAICS codes. Orange lines control for the age of the capital stock. All standard errors are clustered by industry. The top estimate is for the All Firm sample, while the bottom two groups of estimates split the SOI into a taxable and an untaxable sample and re-runs (21) individually for each.

I provide further validation of the mechanism by splitting the sample into firms with positive net income ("taxable") and firms without positive income ("untaxable") firms.[18] In principle, maintenance should not move for untaxable firms and decline for taxable firms following a tax cut if the model is correct. The middle two rows and bottom two rows of Figure 10 show demand elasticity estimates together with 95% confidence intervals. The taxable firm elasticity increases to around three and becomes more statistically significant compared to the full sample. On the other hand, the untaxable elasticities are centered at zero. Thus, interpreted as either a placebo test for the theory or more broadly as reflecting reallocation, the sample split provides sound evidence in favor of the hypotheses advanced in Section 3.

Robustness and Validation. Appendix D.2 presents extensive robustness checks. Results are unchanged when ending the sample in 2013, before SOI sampling methodology changes (Figure D.8). Using BEA capital stocks instead of SOI book capital yields similar though less precise estimates (Figure D.10). As noted above, using investment-weighted $z_{i,t}$ yields $\omega \approx 0$ (Figure D.9), confirming maintenance responds to the installed base rather than recent purchases. Testing

18. The mapping is rough because some of the firms in the taxable sample have positive net operating losses, so they are not actually taxable.

for selection effects shows the elasticity is homogeneous across industries regardless of equipment intensity(Figure D.11).[19] The interaction between equipment intensity and the wedge is statistically insignificant and quantitatively small, ruling out the concern that differential bonus exposure correlates with pre-existing elasticity differences.

Local projections show maintenance responds essentially contemporaneously to policy changes (Figure D.12). Industries cut maintenance in the same year the wedge falls, with little persistence in subsequent years. This immediate adjustment contrasts with the gradual adjustment in the railroad data. It likely reflects the nature of identification: discrete policy reforms can be acted upon immediately, while cost shocks may require staggered operational adjustments. Since the SOI captures policy-relevant dynamics, subsequent quantitative exercises use the implied immediate response from these estimates.

6.3 General Equilibrium Price Effects

Appendix B.2 identifies a condition under which general equilibrium amplifies the attenuation of capital responses: $\Lambda^M > \Lambda_0$, meaning maintenance prices are more sensitive to capital accumulation than investment prices and interest rates together. When this condition holds, tax cuts that raise capital also raise the relative price of maintenance, reinforcing the substitution away from upkeep and further dampening capital accumulation.

Investment prices are largely invariant to U.S. tax policy. Although Goolsbee (1998a) showed that investment supply is upward-sloping, more recent evidence (House and Shapiro 2008; House, Mocanu, and Shapiro 2017; Basu, Kim, and Singh 2021) indicates that equipment prices did not respond to bonus depreciation during the 2000s, largely due to globalized equipment markets and foreign competition. This effectively makes $\varepsilon_{p^I,K} \approx 0$ for the policy variation I study.

Maintenance prices are more wage-sensitive. Labor accounts for 30–45% of maintenance costs in the railroad data, and wages rise following tax cuts that stimulate investment (Fuest, Peichl, and Siegloch 2018; Kennedy et al. 2023). If a tax cut raises wages by 2% while equipment prices remain flat, the relative price of maintenance increases, which is exactly the condition for GE amplification. The evidence therefore supports $\Lambda^M > \Lambda_0$.

This matters for interpreting my elasticity estimates. With upward-sloping maintenance supply, tax policy affects both quantities and prices. The regressions recover an equilibrium elasticity $\omega_{\text{eq}} = \omega/(1 + \omega/\varepsilon_s)$, where ε_s is the supply elasticity.[20] Since $\omega_{\text{eq}} < \omega$ for any finite ε_s, the esti-

19. Koby and Wolf (2020) point to important theoretical reasons to worry about heterogeneous selection effects of bonus. Low-depreciation equipment is the most effected by bonus *and* the most price-sensitive. That same concern does not appear to be important here.

20. Let demand be $m = a(Qp^M)^{-\omega}$ with $Q \equiv (1 - \tau)/(1 - \tau z)$, and inverse supply $p^M = bm^{1/\varepsilon_s}$. Substituting and differentiating with respect to $\ln Q$ yields $\omega_{\text{eq}} = \omega/(1 + \omega/\varepsilon_s)$.

mates are attenuated toward zero. In the railroad panel, any residual correlation between wages and maintenance demand biases estimates downward; the internal-external split addresses this, but some attenuation may remain. In the SOI panel, equilibrium wage increases mechanically dampen the response to policy.

The consistency of estimates across designs (approximately 3 to 3.5 in both settings) suggests the attenuation is modest. But modest or not, these are conservative lower bounds on the structural elasticity. Since the investment-capital gap depends on ω, the true divergence between investment and capital responses may be larger than my baseline estimates imply. The asymmetry between maintenance and investment prices reinforces the dampening of capital responses to tax policy beyond what partial equilibrium analysis would suggest.

7 Quantitative Implications of Maintenance Demand

The theoretical results identify four channels through which maintenance attenuates the effects of tax incentives. First, the investment-capital gap: observed investment responses overstate capital accumulation because tax cuts endogenously raise depreciation. Second, the capital preservation effect: only the non-maintenance share of user cost responds to tax incentives. Third, bias in investment regressions: standard estimates understate even the short-run investment response. Fourth, slower convergence: the maintenance model converges more slowly when calibrated to the same short-run evidence. The empirical estimates from Sections 5 and 6 provide the parameters needed to quantify all four. In this section, I first show how the investment-capital gap maps investment elasticities into capital elasticities. I then apply the OVB correction to estimates from the literature. Finally, I embed the estimated maintenance demand function into a general equilibrium model to assess the 2017 Tax Cuts and Jobs Act, where all four channels operate jointly.

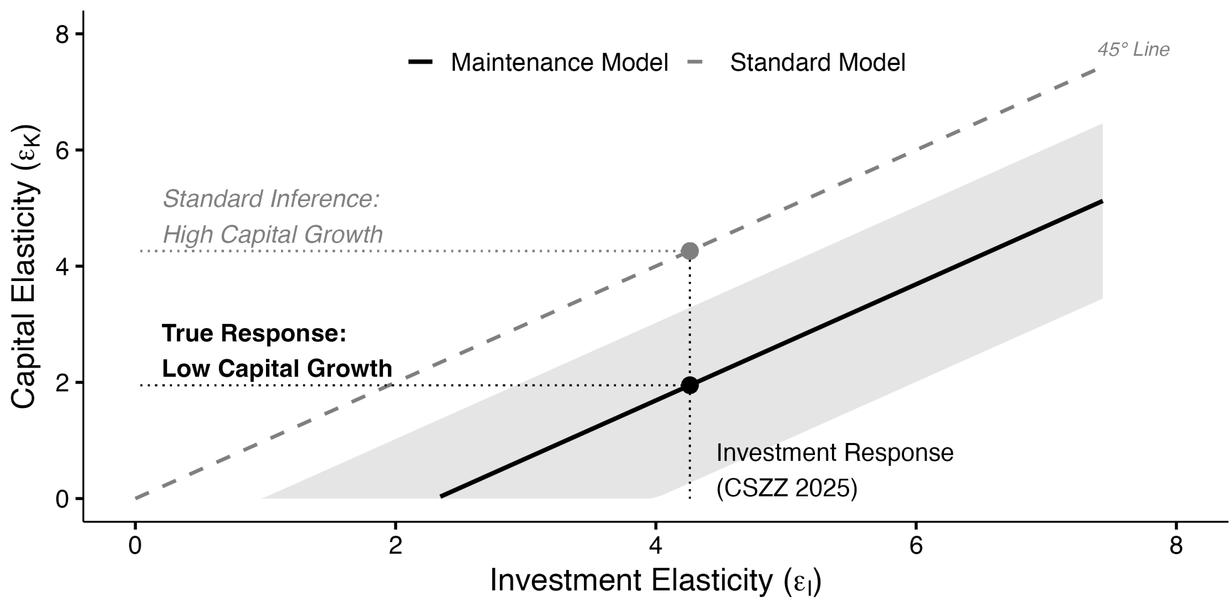
7.1 The Investment-Capital Gap

Proposition 1 establishes that $\varepsilon_{I,\tau} = \varepsilon_{\delta,\tau} + \varepsilon_{K,\tau}$: the investment response to tax policy exceeds the capital response by the depreciation elasticity. The standard identity $\varepsilon_{I,\tau} = \varepsilon_{K,\tau}$ holds only when $\varepsilon_{\delta,\tau} = 0$, which requires either perfectly inelastic maintenance demand or zero maintenance. The estimates from Section 6 reject both cases.

To quantify the gap, I use the SOI estimates of (γ, ω) and back out δ_0 to match the pre-TCJA investment-output ratio of 10.9%. At the median estimates, $\delta_0 \approx 0.08$. I construct confidence intervals by drawing from the joint distribution of (γ, ω), recalibrating δ_0 for each draw.

Figure 11 plots the result. The 45° line is the standard model where $\varepsilon_{K,\tau} = \varepsilon_{I,\tau}$. The solid line is the maintenance model. For a given investment elasticity on the horizontal axis, the vertical gap shows how much capital accumulation is overstated by standard inference. The shaded band reflects uncertainty in the maintenance parameters only. I take the investment elasticity as given rather than propagating uncertainty from that estimate, since the goal here is to show what maintenance implies for any measured investment response.

Figure 11: The Investment-Capital Elasticity Gap



Notes: The dashed line is the 45° line where $\varepsilon_{K,\tau} = \varepsilon_{I,\tau}$. The solid line plots $\varepsilon_{K,\tau} = \varepsilon_{I,\tau} - \varepsilon_{\delta,\tau}$ at the median estimates from Section 6. The shaded band is a 95% confidence interval from 5,000 draws of (γ, ω), conditional on the investment elasticity. The vertical line marks the investment elasticity from Chodorow-Reich et al. (2025).

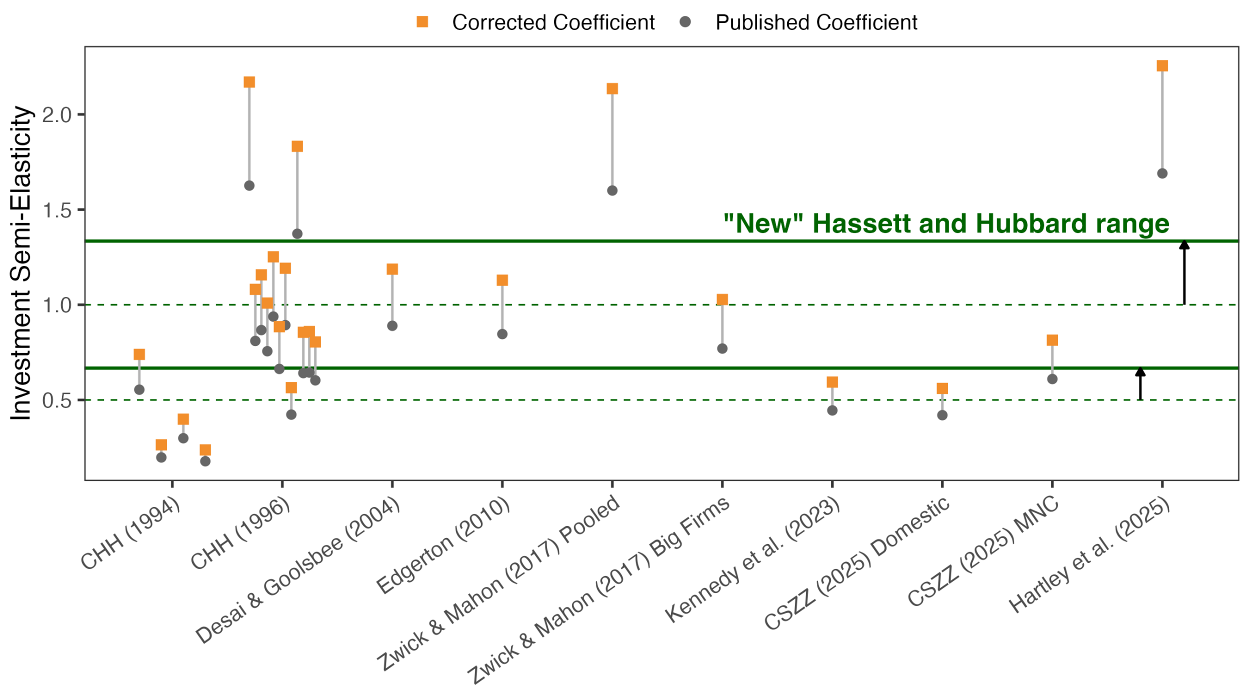
At the Chodorow-Reich et al. (2025) investment elasticity of approximately 4.3, the implied capital elasticity is only about 2, or less than half. Standard models that equate investment and capital responses would overstate capital accumulation, and the associated effects on output and wages, by a factor of two. I now embed this channel in a full model of the 2017 Tax Cuts and Jobs Act.

7.2 Correcting Existing Estimates

Proposition 4 shows that standard investment regressions understate the true short-run response because measured user cost overstates the true price change. The correction factor is $1/(1 - s_m)$: if maintenance accounts for share s_m of true user cost, the true coefficient is $1/(1 - s_m)$ times the estimated coefficient.

Under the estimates from Section 6, the correction factor is approximately 1.35. This adjustment is first-order for interpreting the empirical investment literature. Figure 12 applies Proposition 4 to a broad swathe of studies, all of which have the investment rate as the left-hand side variable. The corrected estimates are uniformly larger than published estimates. The lines in green plot what Hassett and Hubbard (2002) refer to as the "consensus range" for estimates in the literature; the correction pushes this range from roughly 0.5–1.0 to approximately 0.75–1.5.[21]

Figure 12: Corrected Investment Coefficients from the Literature



Notes: This figure applies Proposition 4 to studies from the literature using the maintenance demand function estimated in Section 6. Most estimates are taken from Chodorow-Reich, Zidar, and Zwick (2024). CHH1994 refers to Cummins, Hassett, and Hubbard (1994); CSZZ2025 refers to Chodorow-Reich et al. (2025). The correction factor is approximately 1.35.

The OVB correction is necessary but not sufficient for translating estimated coefficients into capital effects. Even after correction, three additional adjustments remain. First, the corrected coefficient is a short-run estimate; transition dynamics relate short-run to long-run investment responses, and the maintenance model converges more slowly than standard models imply (Section 3.4). Second, even long-run investment responses overstate capital accumulation because of the investment-capital gap (Section 3.2). Third, the capital preservation effect implies that the

21. As Chodorow-Reich (2025) argues, the coefficients in this figure are not strictly investment elasticities. The correction nonetheless applies because the bias operates through the same channel regardless of how the dependent variable is specified.

user cost elasticity itself is attenuated by $(1-s_m)$, reducing steady-state capital responses (Section 3.3). The following section traces these adjustments through a full model of the 2017 Tax Cuts and Jobs Act

7.3 Capital Maintenance and the 2017 Tax Cuts and Jobs Act

Having established that investment responses overstate capital accumulation, I now embed the maintenance channel in a full model to assess TCJA. Throughout this subsection, I compare the maintenance model (NGMM) to the standard model with zero maintenance (NGM, the $s_m \to 0$ limit). The model extends Section 3 to multiple sectors with adjustment costs and general equilibrium in labor markets.

Model and Calibration

There are three sectors: corporate, non-corporate, and government. The representative firm in each private sector $i \in \{c, nc\}$ produces output with identical Cobb-Douglas technology and discounts the future at rate r^k. Capital and labor shares are α_K and α_L with $\alpha_K + \alpha_L \leq 1$. One unit of labor is supplied inelastically and allocated across sectors to equalize wages. I normalize corporate productivity to one; non-corporate productivity is calibrated below. To facilitate comparison with Chodorow-Reich et al. (2025), I adopt their values for the discount rate, capital share, and labor share.

To capture dynamics, both the NGM and the NGMM include capital adjustment costs:

$$\Phi(I_t, K_t) = \frac{\phi}{2}\left(\frac{I_t}{K_t} - \delta(m_t)\right)^2 K_t. \tag{22}$$

In the NGM, $\delta(m_t) = \delta$ since maintenance is zero.[22] I set parameters so both models start from the same steady-state capital-labor ratio and sectoral capital shares, but because the models differ, some parameters like ϕ must differ as well.

Two corrections are required to take the model to TCJA. First, standard investment regressions omit maintenance from user cost, biasing coefficients toward zero. Section 7.2 derives a correction factor of approximately 1.35; I apply this to the Chodorow-Reich et al. (2025) investment elasticity throughout. Second, reconciling a large investment response with a smaller capital response requires steeper adjustment costs in the NGMM than in the NGM. Appendix B.5 derives the implied adjustment cost parameter; the key intuition is that part of the observed investment

22. This specification implies maintenance adjusts instantaneously. I use capital adjustment costs for comparability with Chodorow-Reich et al. (2025).

surge replaces capital that now depreciates faster rather than expanding the net stock, so larger frictions are needed to rationalize the same gross response.

NGMM Calibration. The maintenance demand estimates from Section 6 pin down (γ, ω). For each of 5,000 draws from their joint distribution, I calibrate δ_0 and non-corporate productivity A_{nc} to jointly match two targets: the ratio of corporate to total capital ($K_c/K = 0.7$, from Chodorow-Reich et al. 2025) and the pre-TCJA investment-output ratio (0.109, from NIPA).[23] Given these parameters, I compute the depreciation elasticity $\varepsilon_{\delta,\tau}$ using the first-order approximation in Appendix B.5. For the investment elasticity, I take the estimate from Chodorow-Reich et al. (2025) and apply the OVB correction from Section 7.2, drawing independently to propagate uncertainty from both sources. The implied adjustment cost ϕ_{NGMM} then follows from the derivations in Appendix B.5. The resulting calibration implies a maintenance share of user cost $s_m \approx 0.22$, consistent with the SOI data and the theoretical prediction that steady-state outcomes are marked down by approximately $(1 - s_m)$.

NGM Calibration. As a benchmark, I calibrate an otherwise identical model with zero maintenance. I set the constant depreciation rate δ to match the same initial steady state as the NGMM. I then calculate ϕ_{NGM} using the *unadjusted* investment elasticity from Chodorow-Reich et al. (2025). This calibrates adjustment costs as if the NGM were true, yielding a conservative difference in convergence rates between models.

Policy Reform. I set pre- and post-TCJA tax rates following Chodorow-Reich et al. (2025), assuming permanent bonus depreciation and no change in non-corporate marginal rates.[24] Corporate tax rates come from a capital-weighted average of their domestic estimates. Given the reform, aggregate output growth is

$$\frac{\Delta Y_{0,t}}{Y_0} = \sum_{i \in \{c,nc,g\}} c_i \frac{\Delta Y_{i,0,t}}{Y_{i,0}},$$

where c_i is the sectoral weight and $\Delta Y_{i,0,t}/Y_{i,0}$ is cumulative growth from year zero to t.

I propagate uncertainty from two sources: the maintenance demand function (via the variance-covariance matrix from Section 6) and the investment elasticity (via the standard errors from Chodorow-Reich et al. 2025). I hold all other parameters fixed. This differs from Chodorow-Reich et al. (2025), who propagate uncertainty across all structural parameters. I adopt the narrower approach for two reasons. First, it isolates uncertainty attributable to the maintenance channel.

23. I divide the sum of non-residential investment in equipment and structures by GDP less government expenditures in NIPA Table 1.1.5.

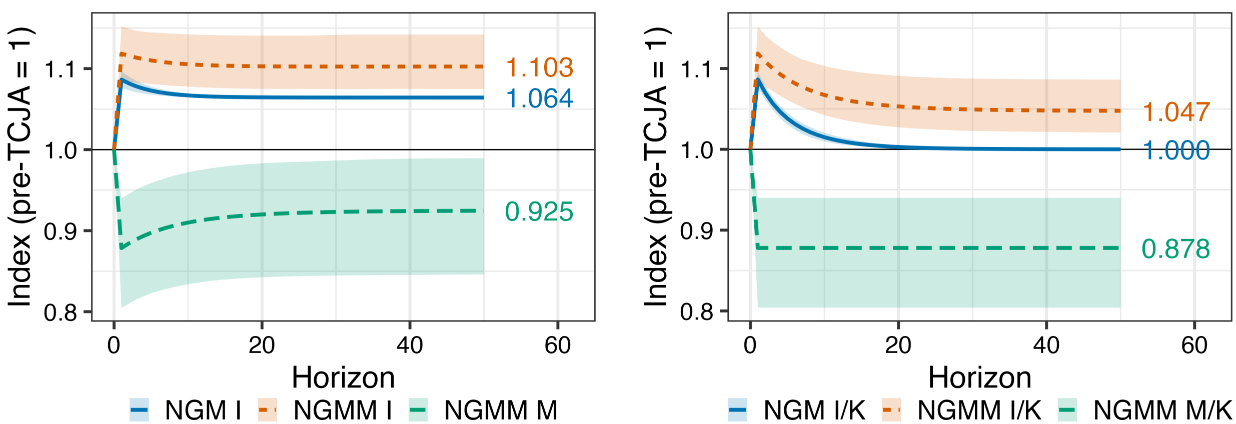
24. This is not what actually happened: bonus was temporary and non-corporate taxes fell substantially. The goal is to isolate the maintenance channel rather than score TCJA comprehensively. The exercise is best viewed as a comparison to Chodorow-Reich et al. (2025).

Second, it facilitates direct comparison: the NGM results exactly replicate theirs when uncertainty is limited to adjustment costs alone. The trade-off is that reported confidence intervals understate total uncertainty and should be interpreted as conditional on the broader calibration.

Aggregate Effects of TCJA

The Tax Cuts and Jobs Act cut corporate capital taxes by around 3.4% on average. Figure 13 plots how investment and maintenance evolved in response. The left panel shows levels; the right panel shows rates relative to capital.

Figure 13: The Effect of TCJA on Capital Inputs



(a) Investment and Maintenance Levels

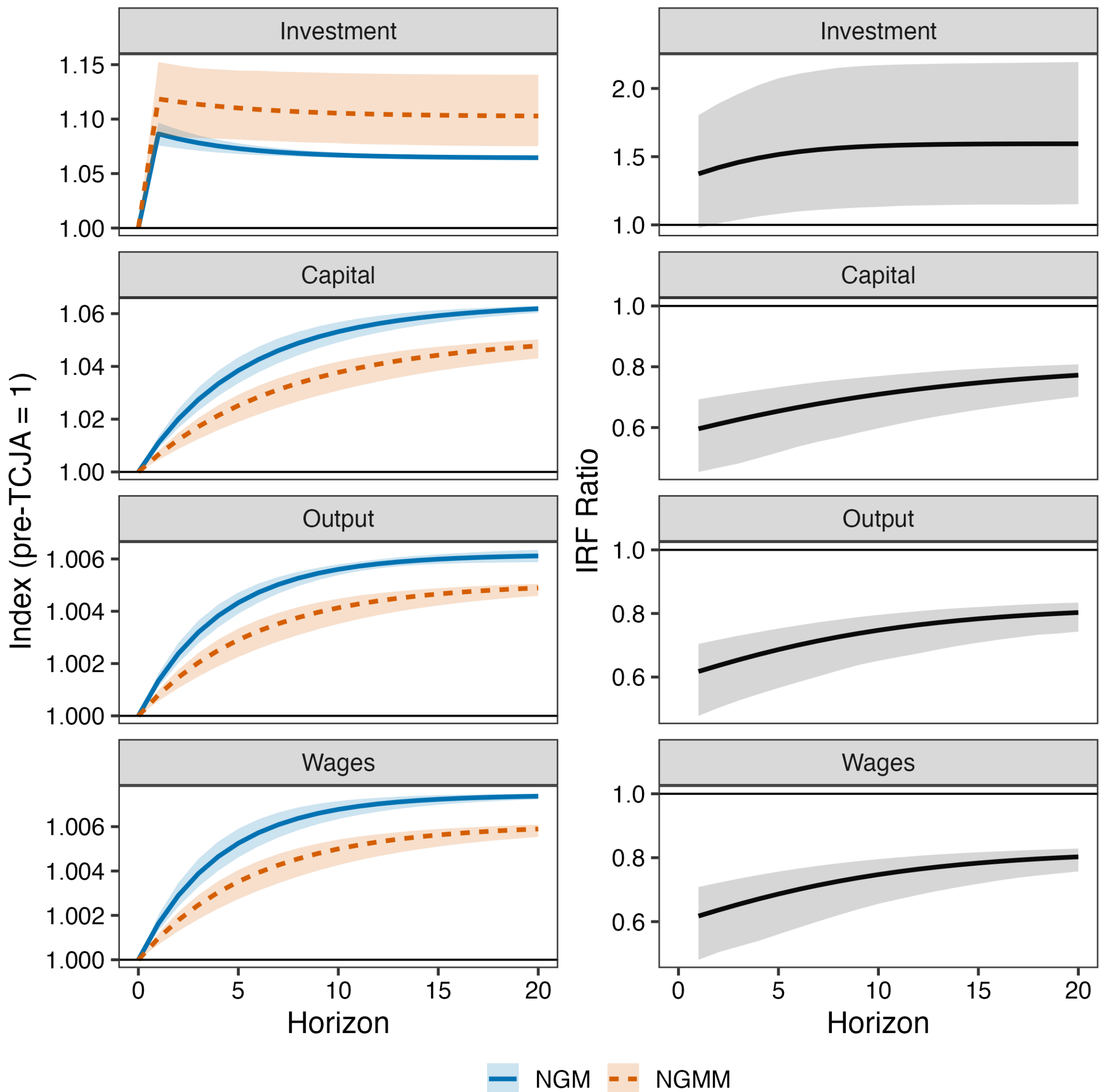
(b) Investment and Maintenance Rates

Notes: Panel (a) shows the response of domestic corporate investment and maintenance to TCJA in the NGMM (orange, with 95% CI) and the NGM (blue). Panel (b) shows corresponding changes in rates relative to capital.

In the NGM, investment rises by 6.4%. In the NGMM, the OVB-corrected investment elasticity implies a larger response: investment rises by 10.3%. But this larger gross investment response does not translate into proportionally larger capital accumulation. Maintenance falls, depreciation rises, and more of the investment flow goes toward replacement rather than expansion. The right panel shows the key distinction: in the NGMM, the investment rate rises permanently—4.7% above baseline—to offset the permanently lower maintenance rate. In the NGM, the investment rate increase is temporary, converging back to baseline as the capital stock adjusts. This is the churn-versus-growth distinction from Section 3.2: tax cuts raise the investment rate permanently, but this reflects faster replacement of a younger capital stock, not a larger capital stock.

Figure 14 plots the aggregate effects on investment, capital, output, and wages. The left panels show paths under both models; the right panels show the ratio of NGMM to NGM responses.

Figure 14: The Effect of TCJA on Aggregate Outcomes



Notes: The left panels show the response of aggregate variables to TCJA in the NGMM (orange) and the NGM (blue). The right panels plot the ratio of NGMM to NGM responses. All lines are bootstrapped with 95% confidence intervals.

Three patterns stand out. First, steady-state effects on capital, output, and wages are roughly 75–80% as large in the NGMM as in the NGM. This reflects the capital preservation effect: only the non-maintenance share of user cost responds to tax incentives. Second, investment and capital responses diverge sharply in the NGMM. In the NGM, both rise by 6.4% in steady state, replicating Chodorow-Reich et al. (2025). In the NGMM, investment rises by 10.3% while capital rises by only two-thirds that amount. The gap reflects Proposition 1: gross investment must rise to both expand the capital stock and offset faster depreciation. Third, convergence is markedly slower in the NGMM. At the ten-year horizon, which is the statutory scoring window, the NGMM capital stock has reached only about 75% of its steady-state change, compared to 85% in the NGM. This follows from the higher adjustment costs required to reconcile a large gross investment response with a smaller net capital impulse.

Together, these patterns show that all four theoretical channels operate in the quantitative model. The OVB correction recovers the true investment response from biased estimates. The investment-capital gap means gross investment overstates capital accumulation. The capital preservation effect dampens steady-state responses. And slower convergence reduces growth along the transition path.

Scoring TCJA

The quantitative difference in convergence rates matters for how we score tax reform. Government bodies like the Congressional Budget Office and the Joint Committee on Taxation publish budgetary and macroeconomic effects at a ten-year horizon. Static scores assume no behavioral changes; dynamic scores account for the extra output (and hence extra revenue) from growth effects.[25] Because convergence typically takes decades, the relevant metric is not steady-state effects but the ten-year mark along the transition path.

To score the reform, I follow Barro and Furman (2018). For both models, I adjust the CBO's static output projections using the model-implied growth path. The extra output generates additional tax revenue given the CBO's projected corporate revenue share. I express results as the percent of the bill's static cost offset by this additional revenue. If the offset is 100%, the bill pays for itself.

Table 1 presents ten-year outcomes for corporate capital accumulation, aggregate output growth, and the static-score offset.

25. See Elmendorf, Hubbard, and Williams (2024) for discussion of when and how to dynamically score tax reforms.

Table 1: Ten-Year Corporate Capital, Aggregate Output, and Scores

		$\Delta K_c/K_c$ (%)		$\Delta Y/Y$		Static-Score Offset	
		10Y	Ratio	10Y	Ratio	10Y	Ratio
GE	NGM	5.5	-	0.56	-	7.5	-
	NGMM	3.9	0.71	0.41	0.73	5.0	0.67
	NGMMP	4.1	0.75	0.44	0.79	5.3	0.71
GE w/CO	NGM	4.2	-	0.33	-	4.3	-
	NGMM	2.8	0.67	0.21	0.64	2.4	0.55
	NGMMP	2.9	0.69	0.22	0.67	2.6	0.60
PE	NGM	9.3	-	3.4	-	63.9	-
	NGMM	7.0	0.75	2.5	0.74	38.6	0.60
PE w/CO	NGM	7.6	-	2.8	-	46.9	-
	NGMM	5.2	0.73	1.9	0.71	26.4	0.56

Notes: Within each panel, the ratio is relative to the corresponding NGM model. NGMMP denotes the closure in which labor costs comprise half of maintenance costs, so tax cuts raise the relative price of maintenance beyond the direct tax effect.

Baseline Results (GE). In the baseline general equilibrium model, the NGM predicts corporate capital rises by 5.5% and aggregate output by 0.56% over ten years, offsetting 7.5% of the static cost. The NGMM predicts capital rises by 3.9% and output by 0.41%, offsetting only 5%. The bill does not pay for itself under either model. The ratios are stable across outcomes: NGMM responses are approximately 67–73% as large as NGM responses, reflecting the theoretical structure in which the maintenance share marks down all aggregates proportionally.

Endogenous Maintenance Prices (NGMMP). The third row within each panel allows the pre-tax price of maintenance to rise with wages, as discussed in Section 6.3. I assume labor comprises half of maintenance costs and compute the induced wage increase from output expansion. The quantitative difference from baseline NGMM is minimal: ratios increase only from 0.67–0.73 to 0.69–0.79. Wage endogeneity matters for interpreting elasticity estimates but has limited impact on policy counterfactuals.

Crowding Out (GE w/CO). The second panel incorporates fiscal crowding out. I compute the 2027 debt-GDP ratio implied by TCJA's fiscal cost and endogenous revenue feedback, then use Neveu and Schafer (2024) to calculate the resulting increase in real interest rates. Higher rates reduce private investment. Crowding out affects both models but exacerbates the difference: the NGMM offset falls to 2.4% while the NGM falls to 4.3%. The larger proportional reduction in the NGMM reflects its slower initial growth. Because capital accumulates more gradually, debt accumulates faster over the scoring window. The ratio of NGMM to NGM responses falls from 0.67–0.73 to 0.55–0.67 with crowding out. Starting from a $17 trillion baseline, the predicted difference in corporate capital between models is approximately $240 billion.

Partial Equilibrium (PE). The final panels assume perfectly elastic labor supply. Aggregate outcomes are substantially larger. The NGM offset rises to 63.9%, but the ratio of NGMM to NGM responses remains similar, ranging from 0.60 to 0.75. This stability reinforces that the maintenance channel operates through the capital preservation effect and the investment-capital gap, both of which persist regardless of labor supply assumptions.

Interpretation. Given how little of the static cost is offset by either model, investment-driven growth provides minimal self-financing for capital tax cuts. The maintenance channel reduces an already-small revenue feedback by approximately one-third. This does not render dynamic scoring irrelevant; dynamic scores inform distributional analysis, validate mechanisms, and guide fiscal timing. But for reforms targeting investment incentives, the growth-induced revenue feedback may be too small to substantially alter fiscal projections.[26]

The broader lesson extends beyond TCJA. The NGM results replicate Chodorow-Reich et al. (2025), so the haircuts I obtain apply to their analysis. But the mechanism generalizes: in richer models where capital accumulation responds to user cost reductions (Sedlacek and Sterk 2019; Zeida 2022), maintenance would similarly dampen responses. The channel operates through capital preservation and the investment-capital gap regardless of other frictions.

8 Concluding Remarks

In this paper, I establish that capital maintenance is a first-order margin for understanding how tax incentives transmit to aggregate outcomes. Using novel data from freight railroad filings and corporate tax returns, I show that maintenance demand is large and elastic. A calibrated model of the 2017 Tax Cuts and Jobs Act implies that accounting for maintenance reduces ten-year capital,

26. The scoring exercise covers only domestic corporate provisions. Other margins may matter; the static score for permanent bonus comes from Barro and Furman (2018).

output, and revenue effects by roughly one-quarter to one-third relative to standard models. Two mechanisms drive this result: a scale effect operating through the level of maintenance, which attenuates user cost elasticities and biases standard regression estimates; and a substitution effect operating through its elasticity, which breaks the equivalence between investment and capital responses and slows convergence to steady state. The core intuition is churn versus growth: because tax cuts raise depreciation through reduced maintenance, gross investment overstates net capital accumulation. Investment subsidies promote capital turnover, not necessarily capital expansion.

These findings extend beyond TCJA to any policy that changes the relative price of new capital versus maintenance. They also raise questions for national accounting: maintenance is treated as intermediate consumption while investment is final demand, but the substitution between them is endogenous to policy. Similarly, depreciation rates are treated as fixed, but if maintenance affects capital longevity, measured net capital stocks may overstate true accumulation when tax policy discourages upkeep. 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 begin accounting for maintenance is too big to ignore.

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Appendices

A Institutional Background

Once classified as an expenditure that must be capitalized, assets are slotted into one of eight lives under rules governed by the Modified Asset Cost Recovery System (MACRS)—three, five, seven, ten, fifteen, twenty, 27.5, or 39 years—which govern how quickly they may be depreciated; shorter class lives yield faster deductions and larger present-value tax benefits. Given a class life of T years and a discount rate r^k, the net present value of a dollar of deductions for a capital investment is

$$z = \sum_{t=0}^{T} \left(\frac{1}{1 + r^k} \right)^t d_t,$$

where d_t is the allowable deduction by the IRS in period t. Table A.1 shows typical assets and associated present value of deductions z for each class category, and Table A.2 works out the year-by-year tax consequences of spending a marginal dollar investing in a new seven-year asset versus maintaining an existing one.

Table A.1: MACRS Asset Lives and NPV of Depreciation Allowances z at a 6% discount rate

MACRS Asset Life (Years)	**Representative Examples**	z
3	Racehorses; special tools	0.9467
5	Automobiles; computers; office machinery	0.9038
7	Furniture; fixtures; general-purpose equipment; locomotives[27]	0.8645
10	Appliances; vessels; barges	0.8108
15	Land improvements; sewage treatment facilities; telephone poles	0.6942
20	Farm buildings; municipal sewers	0.6219
27.5	Residential rental property	0.5001
39	Nonresidential real property (commercial buildings)	0.3958

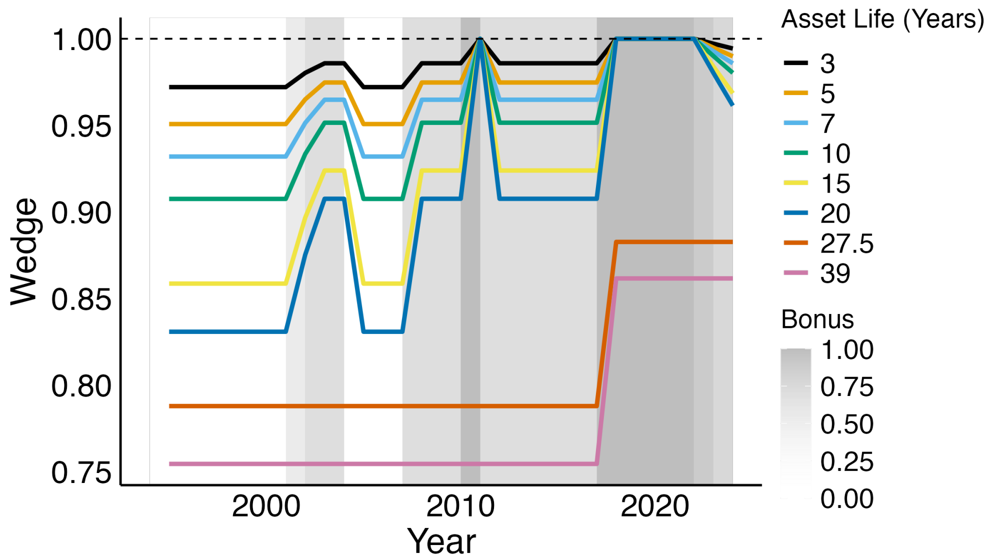
Table A.2: The Tax Treatment of Investment and Maintenance for a Seven-Year Asset

Year:	0	1	2	3	4	5	6	7	Total	z
Investment										
Deductions (000s)	142.9	244.9	174.9	124.9	89.3	89.2	89.3	44.6	1,000	
Tax benefit ($\tau = 35\%$)	50.0	85.7	61.2	43.7	31.3	31.2	31.3	15.6	350	0.86
Tax Benefit (PV)	50.0	80.9	54.5	36.7	24.8	23.3	22.0	10.4	302.6	
Maintenance										
Deductions (000s)	1,000	0	0	0	0	0	0	0	1,000	
Tax benefit ($\tau = 35\%$)	350	0	0	0	0	0	0	0	350	1.00
Tax Benefit (PV)	350	0	0	0	0	0	0	0	350	

Notes: This table adapts Table 1 from Zwick and Mahon (2017) to a seven-year MACRS schedule (8-year life with half-year convention and 200% declining balance until straightline becomes optimal). It includes year-by-year deductions, tax benefits, and present values using a 6% discount rate, and reports z, the PV factor per dollar of tax benefit.

Figure A.1 plots the wedge since 1995 for all MACRS assets. The wedge is largest for long-lived assets and with 100% bonus, the wedge vanishes for qualifying assets. Of course, some firms may elect not to claim bonus if they are not taxable because the deductions are worthless to them (Kitchen and Knittel 2011). Regardless, the wedge has varied considerably between asset types over time.

Figure A.1: The Maintenance-Investment Wedge for MACRS Assets



Notes: The wedge is defined in the main text as the ratio $(1-\tau)/(1-\tau\tilde{z})$, where $\tilde{z}$ is the net present value of depreciation allowances after accounting for bonus depreciation. I set the discount rate as $r = 0.06$.

B Model Derivations

This appendix contains proofs and additional results and discussion for the theoretical results in Section 3. Throughout, the NGM is the $s_m \to 0$ limit of the NGMM, with $\Psi^{NGM} = \lim_{s_m \to 0} \Psi^{NGMM}$.

B.1 Proofs

Proof of Lemma 1

The optimal maintenance condition $-\delta'(m^*) = \rho$ where $\rho \equiv \frac{p^M}{p^I}(1-\tau)$ implicitly defines m^* as a function of parameters. Define $G(m, \rho) \equiv -\delta'(m) - \rho$. At the optimum, $G(m^*, \rho) = 0$. By the implicit function theorem:

$$\frac{\partial m^*}{\partial \rho} = -\frac{\partial G/\partial \rho}{\partial G/\partial m} = -\frac{-1}{-\delta''(m^*)} = \frac{-1}{\delta''(m^*)} < 0$$

For part (i), $\frac{\partial \rho}{\partial p^M} = \frac{1-\tau}{p^I} > 0$, so $\frac{\partial m^*}{\partial p^M} = \frac{\partial m^*}{\partial \rho} \cdot \frac{\partial \rho}{\partial p^M} < 0$. For part (ii), $\frac{\partial \rho}{\partial p^I} = -\frac{p^M(1-\tau)}{(p^I)^2} < 0$, so $\frac{\partial m^*}{\partial p^I} > 0$. For part (iii), $\frac{\partial \rho}{\partial (1-\tau)} = \frac{p^M}{p^I} > 0$, so $\frac{\partial m^*}{\partial (1-\tau)} < 0$. □

Proof of Proposition 1

In steady state, $K_{t+1} = K_t = K$. From the accumulation equation, $K = (1 - \delta(m^*))K + I$, which implies $I = \delta(m^*)K$. Taking logs and differentiating with respect to $\log \tau$ yields the decomposition $\varepsilon_{I,\tau} = \varepsilon_{\delta,\tau} + \varepsilon_{K,\tau}$.

For the signs, note that by Lemma 1(iii), investment incentives reduce maintenance: $\partial m^*/\partial(1-\tau) < 0$. Since $\delta'(m) < 0$ by Assumption 2(i), lower m^* raises $\delta(m^*)$. An investment incentive decreases τ (raises $1-\tau$), so δ increases, meaning $\varepsilon_{\delta,\tau} < 0$. Lower user cost also raises capital, so $\varepsilon_{K,\tau} < 0$. Since both elasticities are negative, $|\varepsilon_{I,\tau}| = |\varepsilon_{\delta,\tau}| + |\varepsilon_{K,\tau}| > |\varepsilon_{K,\tau}|$. □

Proof of Proposition 2

The proof relies on the envelope theorem. The optimized user cost is $\Psi^{NGMM} = \Psi(m^*(x), x)$ where x represents any parameter and $m^*(x)$ is optimal maintenance. By the chain rule:

$$\frac{d\Psi^{NGMM}}{dx} = \left.\frac{\partial \Psi}{\partial m}\right|_{m=m^*} \cdot \frac{\partial m^*}{\partial x} + \left.\frac{\partial \Psi}{\partial x}\right|_{m=m^*}$$

At the optimum, $\frac{\partial \Psi}{\partial m}|_{m=m^*} = 0$ by the first-order condition, so $\frac{d\Psi^{NGMM}}{dx} = \frac{\partial \Psi}{\partial x}|_{m=m^*}$.

Computing each partial derivative of $\Psi(m) = \frac{p^I(r+\delta(m))}{1-\tau} + p^M m$: for τ, $\frac{\partial \Psi}{\partial \tau}|_{m=m^*} = \frac{p^I(r+\delta(m^*))}{(1-\tau)^2}$, which equals $\frac{\partial \Psi^{NGM}}{\partial \tau}$ when $\bar{\delta} = \delta(m^*)$. The same equality holds for derivatives with respect to r and p^I. For p^M, $\frac{\partial \Psi}{\partial p^M}|_{m=m^*} = m^*$.

To convert to elasticities, note that for any $x \in \{\tau, r, p^I\}$, $\frac{\partial \Psi^{NGMM}}{\partial x} = \frac{\partial \Psi^{NGM}}{\partial x}$. Since $\varepsilon_{\Psi,x} = \frac{\partial \Psi}{\partial x} \cdot \frac{x}{\Psi}$:

$$\frac{\varepsilon_{\Psi^{NGMM},x}}{\varepsilon_{\Psi^{NGM},x}} = \frac{\Psi^{NGM}}{\Psi^{NGMM}} = 1 - s_m$$

Therefore $\varepsilon_{\Psi^{NGMM},x} = (1 - s_m)\varepsilon_{\Psi^{NGM},x}$. For the maintenance price elasticity: $\varepsilon_{\Psi^{NGMM},p^M} = m^* \cdot \frac{p^M}{\Psi^{NGMM}} = \frac{p^M m^*}{\Psi^{NGMM}} = s_m$. □

B.2 General Equilibrium

To analyze general equilibrium, I extend the partial equilibrium model to include labor. Production is $F(K_t, L_t)$ where L_t is labor.

Assumption 4 (Production Technology)**.** *The production function $F : \mathbb{R}^2_+ \to \mathbb{R}_+$ is twice continuously differentiable with $F_K > 0$, $F_L > 0$, $F_{KK} < 0$, and $F_{LL} < 0$.*

The firm's after-tax dividends become:

$$d_t = (1 - \tau^c)\left[F(K_t, L_t) - p^M_t M_t - w_t L_t\right] - (1 - \tau^c z - c)p^I_t I_t \qquad \text{(A.1)}$$

where w_t is the wage. The firm's first-order conditions now include labor demand:

$$F_L(K_t, L_t) = w_t \tag{A.2}$$

$$\begin{aligned}(1 - \tau_t^c z_t - c_t)p_t^I = \frac{1}{1 + r_{t+1}} \Big\{ &(1 - \tau_{t+1}^c)F_K(K_{t+1}, L_{t+1}) \\ &+ (1 - \tau_{t+1}^c z_{t+1} - c_{t+1})p_{t+1}^I \big[1 - \delta(m_{t+1}) + \delta'(m_{t+1})m_{t+1}\big] \Big\}\end{aligned} \tag{A.3}$$

$$(1 - \tau_t^c)p_t^M = (1 - \tau_t^c z_t - c_t)p_t^I \big[-\delta'(m_t)\big] \tag{A.4}$$

The maintenance and capital conditions are unchanged from the partial equilibrium analysis; labor demand (A.2) governs the wage response to capital accumulation.

Throughout this appendix, I compare the maintenance model (NGMM) to a standard neoclassical model without maintenance (NGM). The NGM is the $s_m \to 0$ limit of the NGMM: maintenance costs are negligible, so user cost reduces to the Hall-Jorgenson formula $\Psi^{NGM} \equiv \frac{p^I(r+\delta)}{1-\tau} = \lim_{s_m \to 0} \Psi^{NGMM}$.

The capital preservation effect is a partial equilibrium result: it characterizes how user cost responds to tax policy holding prices fixed. But the effects that matter for policy occur in general equilibrium, where capital accumulation feeds back through factor markets. When capital demand rises, interest rates may adjust, wages increase, and input prices change. This appendix shows the $(1 - s_m)$ attenuation survives—and under the most empirically relevant conditions, general equilibrium amplifies it.

Assumption 5 (GE Closure)**.** *The general equilibrium is characterized by:*

(i) A GE-adjusted marginal product $\tilde{F}_K(K)$ with elasticity $\tilde{\varepsilon}_{F_K} \equiv \frac{d \log \tilde{F}_K}{d \log K} < 0$, incorporating diminishing returns and labor market clearing.

(ii) Reduced-form price-capital elasticities $\varepsilon_{r,K}$, $\varepsilon_{p^I,K}$, and $\varepsilon_{p^M,K}$.

(iii) The function $\tilde{F}_K$ is identical across models: maintenance affects the cost of capital services but not the production technology.

(iv) Stability: $\tilde{\varepsilon}_{F_K} - \Lambda < 0$ where Λ is the relevant price feedback.

To state the results, I first derive the user cost elasticities with respect to prices. From the Hall-Jorgenson formula $\Psi^{NGM} = \frac{p^I(r+\bar{\delta})}{1-\tau}$:

$$\varepsilon_{\Psi^{NGM},r} = \frac{r}{r + \bar{\delta}}, \qquad \varepsilon_{\Psi^{NGM},p^I} = 1$$

Define the GE price feedback in the standard model as the effect of capital accumulation on user cost through prices:

$$\Lambda_0 \equiv \varepsilon_{\Psi^{NGM},r} \cdot \varepsilon_{r,K} + \varepsilon_{\Psi^{NGM},p^I} \cdot \varepsilon_{p^I,K} = \frac{r}{r+\bar{\delta}}\varepsilon_{r,K} + \varepsilon_{p^I,K}$$

The first term captures crowding out: when capital rises, interest rates may rise, increasing user cost. The second term captures investment goods price effects.

For the maintenance model, define:

$$\Lambda^M \equiv \varepsilon_{p^M,K}$$

This is the elasticity of maintenance prices with respect to capital. The user cost elasticity $\varepsilon_{\Psi^{NGMM},p^M} = s_m$ from Proposition 2 will appear separately in the formulas below. I compare steady states before and after a permanent tax change, with hats denoting log-deviations.

Proposition 6 (GE Response Ratio)**.** *Under Assumptions 4–5, the steady-state capital responses to a tax shock $\hat{\tau}$ are:*

$$\hat{K}^{NGM} = \frac{\varepsilon_{\Psi^{NGM},\tau}}{\tilde{\varepsilon}_{F_K} - \Lambda_0}\hat{\tau}, \qquad \hat{K}^{NGMM} = \frac{(1-s_m)\varepsilon_{\Psi^{NGM},\tau}}{\tilde{\varepsilon}_{F_K} - (1-s_m)\Lambda_0 - s_m\Lambda^M}\hat{\tau}$$

The ratio is:

$$\frac{\hat{K}^{NGMM}}{\hat{K}^{NGM}} = (1-s_m) \cdot \frac{\tilde{\varepsilon}_{F_K} - \Lambda_0}{\tilde{\varepsilon}_{F_K} - (1-s_m)\Lambda_0 - s_m\Lambda^M} \tag{A.5}$$

Proof. The standard user cost is $\Psi^{NGM} = \frac{p^I(r+\bar{\delta})}{1-\tau}$. Taking logs gives $\log \Psi^{NGM} = \log p^I + \log(r+\bar{\delta}) - \log(1-\tau)$, so differentiating:

$$\hat{\Psi}^{NGM} = \hat{p}^I + \frac{r}{r+\bar{\delta}}\hat{r} + \frac{\tau}{1-\tau}\hat{\tau}$$

where I use $\frac{d\log(r+\bar{\delta})}{d\log r} = \frac{r}{r+\bar{\delta}}$ and $\frac{d\log(1-\tau)}{d\log\tau} = -\frac{\tau}{1-\tau}$. The user cost elasticities are therefore $\varepsilon_{\Psi^{NGM},p^I} = 1$, $\varepsilon_{\Psi^{NGM},r} = \frac{r}{r+\bar{\delta}}$, and $\varepsilon_{\Psi^{NGM},\tau} = \frac{\tau}{1-\tau}$.

Substituting the price responses $\hat{r} = \varepsilon_{r,K}\hat{K}$ and $\hat{p}^I = \varepsilon_{p^I,K}\hat{K}$ from Assumption 5:

$$\hat{\Psi}^{NGM} = \frac{\tau}{1-\tau}\hat{\tau} + \left(\frac{r}{r+\bar{\delta}}\varepsilon_{r,K} + \varepsilon_{p^I,K}\right)\hat{K} = \varepsilon_{\Psi^{NGM},\tau}\hat{\tau} + \Lambda_0\hat{K}$$

where $\Lambda_0 \equiv \frac{r}{r+\bar{\delta}}\varepsilon_{r,K} + \varepsilon_{p^I,K}$. The equilibrium condition $\tilde{F}_K(K) = \Psi$ log-linearizes to $\tilde{\varepsilon}_{F_K}\hat{K} = \hat{\Psi}$. Substituting and solving:

$$\hat{K}^{NGM} = \frac{\varepsilon_{\Psi^{NGM},\tau}}{\tilde{\varepsilon}_{F_K} - \Lambda_0}\hat{\tau}$$

For the maintenance model, Proposition 2 establishes that the derivatives of Ψ^{NGMM} with respect to (r, p^I, τ) equal those of Ψ^{NGM}. Since $\Psi^{NGM} = (1 - s_m)\Psi^{NGMM}$, the elasticities satisfy $\varepsilon_{\Psi^{NGMM},x} = (1 - s_m)\varepsilon_{\Psi^{NGM},x}$ for $x \in \{r, p^I, \tau\}$, and $\varepsilon_{\Psi^{NGMM},p^M} = s_m$. Log-linearizing:

$$\hat{\Psi}^{NGMM} = (1 - s_m)\frac{\tau}{1-\tau}\hat{\tau} + (1 - s_m)\frac{r}{r+\delta}\hat{r} + (1 - s_m)\hat{p}^I + s_m\hat{p}^M$$

where $\delta = \delta(m^*) = \bar{\delta}$ at the common steady state. Substituting price responses $\hat{r} = \varepsilon_{r,K}\hat{K}$, $\hat{p}^I = \varepsilon_{p^I,K}\hat{K}$, and $\hat{p}^M = \varepsilon_{p^M,K}\hat{K}$:

$$\hat{\Psi}^{NGMM} = (1 - s_m)\varepsilon_{\Psi^{NGM},\tau}\hat{\tau} + \left[(1 - s_m)\Lambda_0 + s_m\Lambda^M\right]\hat{K}$$

where $\Lambda^M \equiv \varepsilon_{p^M,K}$. Substituting into the equilibrium condition and solving:

$$\hat{K}^{NGMM} = \frac{(1 - s_m)\varepsilon_{\Psi^{NGM},\tau}}{\tilde{\varepsilon}_{F_K} - (1 - s_m)\Lambda_0 - s_m\Lambda^M}\hat{\tau}$$

Taking the ratio yields (A.5). □

The numerator of the maintenance model is $(1 - s_m)$ times the standard model—the capital preservation effect from Proposition 2 carries through to general equilibrium. The denominators reflect general equilibrium adjustment: $\tilde{\varepsilon}_{F_K}$ captures real crowding out through diminishing returns and labor markets, while the Λ terms capture price feedbacks. The coefficient $(1 - s_m)$ on Λ_0 in the maintenance model's denominator reflects that only the investment component of user cost responds to interest rates and investment prices. The coefficient s_m on Λ^M reflects that maintenance prices affect only the maintenance component.

Why does $\tilde{\varepsilon}_{F_K}$ appear identically in both models? Because it works through the production technology, which maintenance does not affect. At any capital stock K, output is $F(K, L)$ regardless of how that capital was maintained. Diminishing returns and labor market adjustment therefore scale both models' responses equally, and $\tilde{\varepsilon}_{F_K}$ cancels when taking ratios. What remains is differential price exposure: the standard model faces Λ_0, while the maintenance model faces a weighted average $(1 - s_m)\Lambda_0 + s_m\Lambda^M$.

Proposition 7 (GE Attenuation). *Under Assumptions 4–5:*

$$\frac{\hat{K}^{NGMM}}{\hat{K}^{NGM}} = 1 - s_m \qquad \Longleftrightarrow \qquad \Lambda^M = \Lambda_0 \tag{A.6}$$

Proof. For the forward direction, suppose $\frac{\hat{K}^{NGMM}}{\hat{K}^{NGM}} = 1 - s_m$. By Proposition 6:

$$(1 - s_m) \cdot \frac{\tilde{\varepsilon}_{F_K} - \Lambda_0}{\tilde{\varepsilon}_{F_K} - (1 - s_m)\Lambda_0 - s_m\Lambda^M} = 1 - s_m$$

Dividing by $(1 - s_m) > 0$ and cross-multiplying gives $\tilde{\varepsilon}_{F_K} - \Lambda_0 = \tilde{\varepsilon}_{F_K} - (1 - s_m)\Lambda_0 - s_m\Lambda^M$, which simplifies to $-s_m\Lambda_0 = -s_m\Lambda^M$, hence $\Lambda_0 = \Lambda^M$.

For the reverse direction, suppose $\Lambda^M = \Lambda_0$. The denominator of Proposition 6 becomes $\tilde{\varepsilon}_{F_K} - (1 - s_m)\Lambda_0 - s_m\Lambda_0 = \tilde{\varepsilon}_{F_K} - \Lambda_0$, so the ratio equals $(1 - s_m) \cdot \frac{\tilde{\varepsilon}_{F_K} - \Lambda_0}{\tilde{\varepsilon}_{F_K} - \Lambda_0} = 1 - s_m$. □

When maintenance prices respond to capital accumulation the same way as the combination of interest rates and investment goods prices (weighted by their user cost elasticities), the ratio equals $(1 - s_m)$ exactly.

Two economic forces determine whether this condition holds. The first is interest rate insensitivity. The maintenance component $\Psi^M = p^M m^*$ does not depend on the interest rate, so when capital accumulates and interest rates rise, only share $(1 - s_m)$ of the maintenance model's user cost is affected. The maintenance model is less exposed to crowding out than the standard model.

The second force is wage sensitivity. Maintenance is labor-intensive—repairs require technicians, upkeep requires workers. When capital accumulates and wages rise, maintenance prices rise more than investment goods prices if maintenance is more labor-intensive. The maintenance model is more exposed to wage-driven cost increases than the standard model.

The condition $\Lambda^M = \Lambda_0$ holds when these forces offset. In a small open economy where interest rates and input prices are pinned globally, neither force operates and the condition holds trivially. The empirically relevant case is likely an open economy where investment goods are traded globally but maintenance services are local. House and Shapiro (2008) and House, Mocanu, and Shapiro (2017) find that investment goods prices did not respond to tax policy changes during the 2000s, largely due to foreign competition—suggesting $\varepsilon_{p^I,K} \approx 0$. Interest rate crowding out depends on how tax cuts are financed: deficit-financed cuts may raise interest rates (Engen and Hubbard 2004; Neveu and Schafer 2024), though the magnitude is debated. But maintenance requires domestic labor and cannot be imported. Fuest, Peichl, and Siegloch (2018) and Kennedy et al. (2023) document that wages rise following corporate tax cuts, implying $\varepsilon_{p^M,K} > 0$. If interest rate crowding out is modest and maintenance prices are wage-sensitive, then $\Lambda^M > \Lambda_0$, and the ratio falls below $(1 - s_m)$: general equilibrium amplifies the attenuation. In most empirically plausible scenarios, $(1-s_m)$ is either exact or a conservative upper bound. The partial equilibrium results are robust.

With a concave production function and complementarity between capital and labor, the responses of output and wages inherit the $(1 - s_m)$ attenuation. A smaller capital response means less output and lower wages in equilibrium. To illustrate, consider Cobb-Douglas production $Y = K^\alpha L^{1-\alpha}$. The elasticities of capital, output, and wages with respect to user cost are $\varepsilon_{K,\tau} = \frac{1}{1-\alpha}\varepsilon_\Psi$ and $\varepsilon_Y = \varepsilon_w = \frac{\alpha}{1-\alpha}\varepsilon_\Psi$. Since $\varepsilon_\Psi^{NGMM} = (1 - s_m)\varepsilon_\Psi^{NGM}$, the same $(1 - s_m)$ markdown applies to all three. The maintenance margin dampens the real effects of investment incentives across all aggregates.

Additional Results

The following results characterize how the response ratio deviates from $(1 - s_m)$ when $\Lambda^M \neq \Lambda_0$.

Corollary 1 (Special Cases). *Under Assumptions 4–5: (a) if $\Lambda_0 = \Lambda^M = 0$, the ratio equals $1 - s_m$; (b) if $\varepsilon_{p^I,K} = \Lambda^M = 0$, then*

$$\frac{\hat{K}^{NGMM}}{\hat{K}^{NGM}} = (1 - s_m) \cdot \frac{\tilde{\varepsilon}_{F_K} - \frac{r}{r+\delta}\varepsilon_{r,K}}{\tilde{\varepsilon}_{F_K} - (1 - s_m)\frac{r}{r+\delta}\varepsilon_{r,K}}$$

(c) if $\varepsilon_{r,K} = \varepsilon_{p^I,K} = 0$, then

$$\frac{\hat{K}^{NGMM}}{\hat{K}^{NGM}} = (1 - s_m) \cdot \frac{\tilde{\varepsilon}_{F_K}}{\tilde{\varepsilon}_{F_K} - s_m\Lambda^M}$$

Proof. Part (a) follows from Proposition 7. Parts (b) and (c) follow by substitution into Proposition 6. □

Proposition 8 (Deviation from $(1 - s_m)$). *Define $R \equiv \frac{\hat{K}^{NGMM}}{\hat{K}^{NGM}}$. Under Assumptions 4–5: (a) if $\Lambda^M > \Lambda_0$, then $R < 1 - s_m$; (b) if $\Lambda^M < \Lambda_0$, then $R > 1 - s_m$; (c) if $\Lambda^M = \Lambda_0$, then $R = 1 - s_m$.*

Proof. Define $N \equiv \tilde{\varepsilon}_{F_K} - \Lambda_0$ and $D \equiv \tilde{\varepsilon}_{F_K} - (1 - s_m)\Lambda_0 - s_m\Lambda^M$. By Assumption 5(iv), $N < 0$ and $D < 0$. By Proposition 6, $R = (1-s_m)\cdot\frac{N}{D}$. Since $D - N = s_m(\Lambda_0 - \Lambda^M)$, if $\Lambda^M > \Lambda_0$ then $D < N < 0$, so $|D| > |N|$ and $R < 1 - s_m$. The other cases follow analogously. □

Proposition 9 (First-Order Approximation). *For $|\Lambda_0|, |\Lambda^M| \ll |\tilde{\varepsilon}_{F_K}|$:*

$$R \approx (1 - s_m)\left(1 + \frac{s_m(\Lambda^M - \Lambda_0)}{\tilde{\varepsilon}_{F_K}}\right)$$

Proof. From Proposition 6, factor out $\tilde{\varepsilon}_{F_K}$ and apply the approximation $\frac{1-a}{1-b} \approx 1 - a + b$ for small a, b. □

B.3 The Tax Elasticity of Investment

In steady state, investment is given by $I = \delta(m)K$. Defining investment explicitly in terms of the tax wedge $(1 - \tau)$:

$$I(1 - \tau) = \delta(m(1 - \tau)) \cdot K(1 - \tau, m(1 - \tau), \delta(m(1 - \tau))) \tag{A.7}$$

Taking logs and differentiating:

$$\begin{aligned} \varepsilon_{I,\tau} &= \frac{d\ln I}{d\ln(1 - \tau)} = \frac{d\ln\delta}{d\ln(1 - \tau)} + \frac{d\ln K}{d\ln(1 - \tau)} \\ &= \varepsilon_{\delta,\tau} + \varepsilon_{K,\tau} \end{aligned} \tag{A.8}$$

I now derive explicit expressions for each component using the constant-elasticity depreciation technology:

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

and Cobb-Douglas production $F(K) = K^\alpha$.

Depreciation elasticity. Substituting optimal maintenance $m^* = \gamma(1-\tau)^{-\omega}$ into the depreciation technology yields:

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

Taking the derivative with respect to $(1-\tau)$:

$$\frac{\partial \delta}{\partial(1-\tau)} = \gamma\omega(1-\tau)^{-\omega}$$

Evaluating at $\tau \approx 0$:

$$\varepsilon_{\delta,\tau} = \frac{\partial \ln \delta}{\partial \ln(1-\tau)} = \frac{\gamma\omega}{\delta_0 + \frac{\gamma\omega}{1-\omega}} \tag{A.9}$$

Capital elasticity. With Cobb-Douglas production, the capital stock satisfies:

$$K = \left(\frac{\alpha}{\Psi}\right)^{\frac{1}{1-\alpha}}$$

where $\Psi = \frac{r^k + \delta(m^*)}{1-\tau} + m^*$ is the user cost. Taking logs and differentiating:

$$\varepsilon_{K,\tau} = \frac{d \ln K}{d \ln(1-\tau)} = \frac{-1}{1-\alpha} \cdot \varepsilon_\Psi$$

where $\varepsilon_\Psi = \frac{d \ln \Psi}{d \ln(1-\tau)}$ is the user cost elasticity. By Proposition 2, $\varepsilon_\Psi = -(1-s_m)\frac{1}{1-\tau}$, so evaluating at $\tau \approx 0$:

$$\varepsilon_{K,\tau} = \frac{1-s_m}{1-\alpha} \tag{A.10}$$

where $s_m = \frac{m^*}{\Psi}$ is the maintenance share of user cost.

Investment elasticity. Combining (A.9) and (A.10):

$$\varepsilon_{I,\tau} = \varepsilon_{\delta,\tau} + \varepsilon_{K,\tau} = \frac{\gamma\omega}{\delta_0 + \frac{\gamma\omega}{1-\omega}} + \frac{1-s_m}{1-\alpha} \tag{A.11}$$

Both terms are positive: investment increases in response to higher $(1-\tau)$ both because capital expands ($\varepsilon_{K,\tau} > 0$) and because depreciation rises as firms substitute away from maintenance

($\varepsilon_{\delta,\tau} > 0$). The investment-capital gap from Proposition 1 is precisely $\varepsilon_{\delta,\tau}$.

Balanced Growth

Note that with balanced growth, the steady state investment condition is

$$I = (\delta(m) + n + g)K,$$

where n and g are exogenous rates of population and productivity growth. In that case, the gap would simply become

$$\varepsilon_{I,\tau} = \varepsilon_{\delta,\tau}\left(\frac{\delta(m)}{\delta(m) + n + g}\right) + \varepsilon_{K,\tau}$$

B.4 Omitted Variable Bias in Investment Regressions

This appendix proves Proposition 4 and applies the correction to estimates from the literature.

Proof of Proposition 4

The correctly specified regression uses the full user cost $\Psi = \Psi^I + \Psi^M$:

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

Standard regressions use only $\Psi^I = \frac{r^k+\delta}{1-\tau}$, omitting the maintenance component. The coefficient β represents the short-run investment response to a change in user cost; the omission biases this short-run estimate toward zero.

Under the constant-elasticity functional form, optimal maintenance is $m^* = \gamma(1-\tau)^{-\omega}$ and depreciation is $\delta(m^*) = \delta_0 + \frac{\gamma\omega}{1-\omega}(1-\tau)^{1-\omega}$. The omitted term is the difference between the true and standard log user costs. Taking a first-order approximation around $\tau \approx 0$:

$$\begin{aligned}
\text{Omitted Term} &= \log\left(\frac{r^k + \delta_0 + \frac{\gamma}{1-\omega}(1-\tau)^{1-\omega}}{1-\tau} + m^*\right) - \log\left(\frac{r^k + \delta}{1-\tau}\right) \\
&\approx \log\left(\frac{r^k + \delta_0 + \frac{\gamma}{1-\omega}(1-(1-\omega)\tau)}{r^k + \delta}\right) \\
&= \log\left(\frac{r^k + \delta_0 + \frac{\gamma}{1-\omega}}{r^k + \delta}\left(1 - \frac{\gamma\tau}{r^k + \delta_0 + \frac{\gamma}{1-\omega}}\right)\right) \\
&\approx -\frac{\gamma\tau}{r^k + \delta_0 + \frac{\gamma}{1-\omega}},
\end{aligned}$$

where constant terms are absorbed by fixed effects.

Applying the omitted variable bias formula:

$$\begin{aligned}
\text{Bias} &= \beta \cdot \frac{\text{Cov}\left(\log\left(\frac{r^k+\delta}{1-\tau}\right), -\frac{\gamma\tau}{r^k+\delta_0+\frac{\gamma}{1-\omega}}\right)}{\text{Var}\left(\log\left(\frac{r^k+\delta}{1-\tau}\right)\right)} \\
&\approx -\beta \cdot \frac{\text{Cov}\left(\tau, \frac{\gamma\tau}{r^k+\delta_0+\frac{\gamma}{1-\omega}}\right)}{\text{Var}(\tau)} \\
&= -\beta \cdot \frac{\gamma}{r^k+\delta_0+\frac{\gamma}{1-\omega}}.
\end{aligned}$$

Since $\hat{\beta} = \beta + \text{Bias}$, rearranging yields:

$$\beta = \frac{\hat{\beta}}{1 - \frac{\gamma}{r^k+\delta_0+\frac{\gamma}{1-\omega}}}. \tag{A.13}$$

Under the functional form assumptions, the denominator equals $(1 - s_m)$ evaluated at the steady state, yielding the expression in Proposition 4. The correction factor depends only on the relationship between the included and omitted terms on the right-hand side, not on the left-hand side variable $f(\cdot)$. □

B.5 Adjustment Costs and Dynamic Scoring

Throughout this appendix, the standard model (NGM) is the $s_m \to 0$ limit of the maintenance model (NGMM), with $\Psi^{NGM} = \lim_{s_m \to 0} \Psi^{NGMM}$.

The investment-capital gap established in Proposition 1 has direct implications for transition dynamics. Because the NGMM features a higher long-run investment elasticity than the NGM—investment must both expand capital and replace faster depreciation—matching the same observed short-run investment response requires slower convergence to steady state. This section proves that result in general and then quantifies the magnitude using the standard quadratic specification.

Proof of Proposition 3

The proof proceeds in three steps: (i) establish that long-run investment elasticities are higher in the NGMM, (ii) characterize transition paths under convex adjustment costs, and (iii) show that calibrating to the same short-run elasticity implies slower convergence.

Step 1: Long-run investment elasticities. In steady state, investment replaces depreciated capital: $I = \delta(m)K$. Taking logs and differentiating with respect to the tax term yields

$$\begin{aligned} \varepsilon_{I,\tau}^{LR,NGM} &= \varepsilon_{K,\tau} \\ \varepsilon_{I,\tau}^{LR,NGMM} &= \varepsilon_{\delta,\tau} + \varepsilon_{K,\tau} \end{aligned}$$

where I use the fact that δ is fixed in the NGM. By Proposition 1, $\varepsilon_{\delta,\tau} > 0$ when maintenance demand is elastic, so $\varepsilon_{I,\tau}^{LR,NGMM} > \varepsilon_{I,\tau}^{LR,NGM}$.

Step 2: Transition paths. With smooth, strictly convex adjustment costs, the economy converges monotonically to steady state. For the class of adjustment cost specifications commonly used in the tax literature—including quadratic costs in the investment rate—the transition path for the investment elasticity takes the form

$$\varepsilon_{I,\tau}(t) = \varepsilon_{I,\tau}^{LR}\left[1 - (1-\theta)e^{-\lambda t}\right] \tag{A.14}$$

where $\lambda > 0$ is the convergence rate and $\theta \in (0,1)$ is the impact response as a fraction of the long-run response.[28] Both θ and λ depend on the adjustment cost parameter ϕ: higher adjustment costs reduce the impact response and slow convergence. The key property is that θ and λ are co-monotonic in ϕ—specifications with larger impact jumps also converge faster.

Step 3: Calibration and convergence rates. Suppose both models are calibrated to match the same observed short-run investment elasticity $\hat{\varepsilon}_I^{SR}$ at horizon T:

$$\begin{aligned} \hat{\varepsilon}_I^{SR} &= \varepsilon_{I,\tau}^{LR,NGM}\left[1 - (1-\theta^{NGM})e^{-\lambda^{NGM}T}\right] \\ \hat{\varepsilon}_I^{SR} &= \varepsilon_{I,\tau}^{LR,NGMM}\left[1 - (1-\theta^{NGMM})e^{-\lambda^{NGMM}T}\right] \end{aligned}$$

Rearranging each expression:

$$(1-\theta)e^{-\lambda T} = 1 - \frac{\hat{\varepsilon}_I^{SR}}{\varepsilon_{I,\tau}^{LR}} \tag{A.15}$$

Since $\varepsilon_{I,\tau}^{LR,NGMM} > \varepsilon_{I,\tau}^{LR,NGM}$, the right-hand side is larger for the NGMM:

$$(1-\theta^{NGMM})e^{-\lambda^{NGMM}T} > (1-\theta^{NGM})e^{-\lambda^{NGM}T} \tag{A.16}$$

28. This functional form is exact for linearized dynamics around steady state with quadratic adjustment costs. More generally, any smooth convex specification generates monotonic convergence that can be approximated by (A.14) locally.

The left-hand side $(1-\theta)e^{-\lambda T}$ is monotonically decreasing in both θ and λ. By co-monotonicity, a higher value of this expression implies lower θ and lower λ. Therefore $\lambda^{NGMM} < \lambda^{NGM}$: the NGMM converges more slowly. □

The intuition is straightforward. Both models start from the same initial steady state and display the same short-run investment response. But the NGMM must reach a higher long-run investment level (to cover both capital expansion and higher depreciation). With the same starting point, the same short-run response, and a higher destination, the NGMM must be traveling more slowly along the transition path.

Example with Quadratic Adjustment Costs

To quantify the difference in convergence rates, consider the standard quadratic adjustment cost specification from Summers (1981) and Koby and Wolf (2020). A firm chooses sequences of investment, maintenance, labor, and capital to maximize the present value of after-tax profits:

$$\max_{I_t, M_t, L_t, K_{t+1}} \sum_{t=0}^{\infty} \left(\frac{1}{1+r^k}\right)^t \Bigg\{ (1-\tau_t^c)\left(F(K_t, L_t) - w_t L_t - \frac{\phi}{2}\left(\frac{I_t}{K_t} - \delta(m_t)\right)^2 K_t - p_t^M M_t\right) \\ - (1 - c_t - z_t\tau_t^c) p_t^I I_t \Bigg\} \quad \text{s.t.} \quad K_{t+1} = (1-\delta(m_t))K_t + I_t. \tag{A.17}$$

The parameter ϕ governs how costly it is to deviate from replacement investment $\delta(m_t)K_t$. Higher ϕ means slower adjustment. Note that this specification implies maintenance adjusts instantaneously—I rely on capital adjustment costs because it allows for easier comparison with Chodorow-Reich et al. (2025), who use the same specification.

Letting q_t denote the shadow value of capital, the first-order conditions for investment and maintenance are:

$$(1-\tau_t^c)\phi\left(\frac{I_t}{K_t} - \delta(m_t)\right) = q_t - (1 - c_t - z_t\tau_t^c)p_t^I \tag{A.18}$$

$$-\delta'(m_t) = \frac{1-\tau_t^c}{1 - c_t - z_t\tau_t^c}\frac{p_t^M}{p_t^I}. \tag{A.19}$$

The maintenance condition is static and identical to the model without adjustment costs. The investment condition shows that the gap between the investment rate and the depreciation rate is proportional to the gap between the shadow value q_t and the after-tax purchase price.

Define $i \equiv I_t/K_t$. Rearranging the investment FOC:

$$i = \frac{(1-c-z\tau^c)p^I - \kappa}{(1-\tau^c)\phi} + \delta(m). \tag{A.20}$$

In steady state, $i = \delta(m)$, so the investment rate equals the depreciation rate. Taking derivatives and expressing in elasticity form:

$$|\varepsilon_{I,\tau}| \equiv \left|\frac{\partial \ln i}{\partial \ln q}\right| = \frac{(1 - c - z\tau^c)p^I}{i(1-\tau^c)\phi} + |\varepsilon_{\delta,\tau}| \tag{A.21}$$

where $|\varepsilon_{\delta,\tau}| \equiv |\frac{\partial \ln \delta}{\partial \ln q}|$ is the elasticity of depreciation with respect to the shadow value of capital. The key insight is that the observed investment elasticity has two components: the direct effect through the adjustment cost channel, and the indirect effect through endogenous depreciation. Only the first component represents the adjustment friction; the second is a consequence of elastic maintenance demand.

Solving for the adjustment cost parameter, evaluated locally around a zero marginal tax rate ($(1 - c - z\tau^c)p^I = q \approx 1$) and using the steady-state condition $i = \delta(m)$:

$$\phi^{NGMM} = \frac{1}{\delta(m)} \cdot \frac{1}{|\hat{\varepsilon}_I| - |\hat{\varepsilon}_\delta|}. \tag{A.22}$$

When maintenance demand is perfectly inelastic, $|\varepsilon_{\delta,\tau}| = 0$ and this collapses to

$$\phi^{NGM} = \frac{1}{\delta} \cdot \frac{1}{|\hat{\varepsilon}_I|}. \tag{A.23}$$

Since $|\hat{\varepsilon}_\delta| > 0$ whenever maintenance demand is elastic, we have $\phi^{NGMM} > \phi^{NGM}$: the maintenance model requires larger adjustment costs to rationalize the same observed investment response.

To quantify the difference, suppose the empirical investment elasticity is $|\hat{\varepsilon}_I| = 5$ (consistent with estimates in Section 7.3) and the depreciation elasticity is $|\hat{\varepsilon}_\delta| = 1.5$ (implied by the maintenance demand estimates). Then:

$$\frac{\phi^{NGMM}}{\phi^{NGM}} = \frac{|\hat{\varepsilon}_I|}{|\hat{\varepsilon}_I| - |\hat{\varepsilon}_\delta|} = \frac{5}{5 - 1.5} \approx 1.43.$$

Adjustment costs are roughly 40% larger in the maintenance model. In the calibrated model of Section 7.3, this translates to meaningfully slower convergence: at the ten-year horizon, the NGMM capital stock reaches only about 75% of its steady-state change, compared to roughly 85% in the NGM. The combination of a smaller destination and a slower path produces dynamic scores substantially closer to static scores than conventional models suggest.

Implications for Dynamic Scoring

Slower convergence to a smaller steady state has direct implications for scoring tax reform. By statute, the Congressional Budget Office (CBO) scores tax reforms over ten-year windows, computing both a static score (assuming no behavioral changes) and a dynamic score (accounting for revenue feedback from growth effects). Since model convergence typically takes far longer than ten years, the transition path critically affects dynamic scores.

Corollary 2 (Dynamic Scoring)**.** *Consider a permanent tax cut scored over a ten-year window. Because the NGMM features slower convergence and a smaller steady-state capital stock than the NGM, the NGMM generates strictly less additional output and tax revenue over the scoring window. The dynamic score is therefore closer to the static score.*

This establishes that the maintenance channel substantially reduces estimated revenue feedback from investment incentives. Although economists emphasize the importance of dynamic scoring (Barro and Furman 2018; Elmendorf, Hubbard, and Williams 2024), incorporating the maintenance margin produces revenue projections closer to static scoring.

C Data

C.1 R-1 Data Construction

Data Sources and Digitization

Class I freight railroads must file annual R-1 reports with the Surface Transportation Board (STB) under 49 CFR §1241. These reports follow the Uniform System of Accounts for Railroad Companies, which differs meaningfully from Generally Accepted Accounting Principles (GAAP). For example, railroads often use composite depreciation rates—group rates applied to classes of similar assets—which must be approved ex ante by the STB.

I hand-collected and digitized R-1 reports for all Class I railroads from 1999-2023. Reports are available directly from the STB website for years after 2012. For earlier years (1999-2011), I used Amazon Textract to extract the relevant data from PDF scans of physical filings. Each report is independently audited by major accounting firms (e.g., KPMG, PwC, Deloitte) and then reviewed by the STB, providing high data quality.

The reports contain dozens of detailed schedules. For this paper, I extract data from:

- **Schedule 410:** All components of maintenance expenditures come from Line 202 (Locomotives) and Line 221 (Freight Cars). This schedule also breaks down maintenance costs by materials, labor, and purchased services.

- **Schedules 330 and 335:** Investment expenditures and capital stocks for locomotives and freight cars
- **Schedule 702:** Miles of track by state (used for constructing geographic exposure weights)
- **Schedule 710:** Detailed capital inventories by asset type
- **Wage Form A&B:** Hourly wage rates for maintenance workers by occupation and firm

Sample Construction

My sample includes seven Class I railroads:

1. Burlington Northern & Santa Fe Railway (BNSF)
2. CSX Transportation
3. Norfolk Southern Railway (NS)
4. Union Pacific Railroad (UP)
5. Kansas City Southern Railway (KCS)
6. Soo Line Railroad (SOO)
7. Grand Trunk Western Railroad (GT)

These firms are geographically dispersed. Burlington Northern and Union Pacific dominate the western United States, with extensive networks covering the Great Plains and West Coast. CSX and Norfolk Southern operate primarily on the eastern seaboard and in the South. The Soo Line, Kansas City Southern, and Grand Trunk (operated by Canadian National Railway) have networks concentrated in the Midwest, with Kansas City Southern also serving the Southwest and Mexico.

The industry was highly fragmented prior to the Staggers Rail Act of 1980, which deregulated much of the industry. Throughout the 1980s and 1990s, extensive consolidation occurred through mergers and acquisitions. By the late 1990s, the industry had stabilized into the current seven-firm structure. I begin my sample in 1999 because: (1) the industry structure was stable by then, (2) some data elements in Schedule 410 are unavailable or inconsistent before this period, and (3) maintenance behavior may differ systematically during periods of anticipated merger activity. I end the sample in 2023 because Canadian Pacific Railway formally took control of both the Soo Line and Kansas City Southern by 2024, fundamentally altering the competitive structure. Including post-merger years would conflate firm-level maintenance decisions with merger-related reorganization.

Institutional Background: The R-1 Reporting Requirement. The R-1 reporting requirement originates from the Interstate Commerce Commission (ICC), the predecessor to the STB. Prior to the 1990s, the ICC extensively used R-1 reports to regulate rate-setting through cost-of-service regulation. While the STB still maintains regulatory oversight and occasionally intervenes in rate disputes, its role has diminished substantially since deregulation. The detailed reporting requirements remain in place primarily for regulatory monitoring and dispute resolution, though the data are rarely used for academic research.

Maintenance Rate Construction

The primary maintenance rate is:

$$m_{i,j,t} = \frac{\text{Maintenance Expenditures}_{i,j,t}}{\text{Beginning Book Capital}_{i,j,t}}, \tag{A.24}$$

where i indexes firms, j indexes asset types (locomotives or freight cars), and t indexes years.

Maintenance expenditures come directly from Schedule 410, Line 202 for locomotives and Line 221 for freight cars. These lines capture all repair and maintenance activities and are broken down into whether the expenditures were for labor, materials, or external services. Beginning book capital is the prior year's ending value from Schedules 330 and 335. This timing ensures maintenance in year t responds to the capital stock at the start of year t, consistent with the theoretical model. I construct three alternative measures to check robustness:

Physical Maintenance Rate. To control for inflation and asset quality changes, I construct:

$$m^{\text{phys}}_{i,j,t} = \begin{cases} \frac{\text{Maintenance Expenditures}_{i,j,t}}{\text{Total Horsepower}_{i,j,t}} & \text{if } j = \text{locomotives} \\ \frac{\text{Maintenance Expenditures}_{i,j,t}}{\text{Total Freight Ton Capacity}_{i,j,t}} & \text{if } j = \text{freight cars} \end{cases} \tag{A.25}$$

Horsepower and freight ton capacity come from Schedule 710, which reports quantities and physical characteristics of equipment.

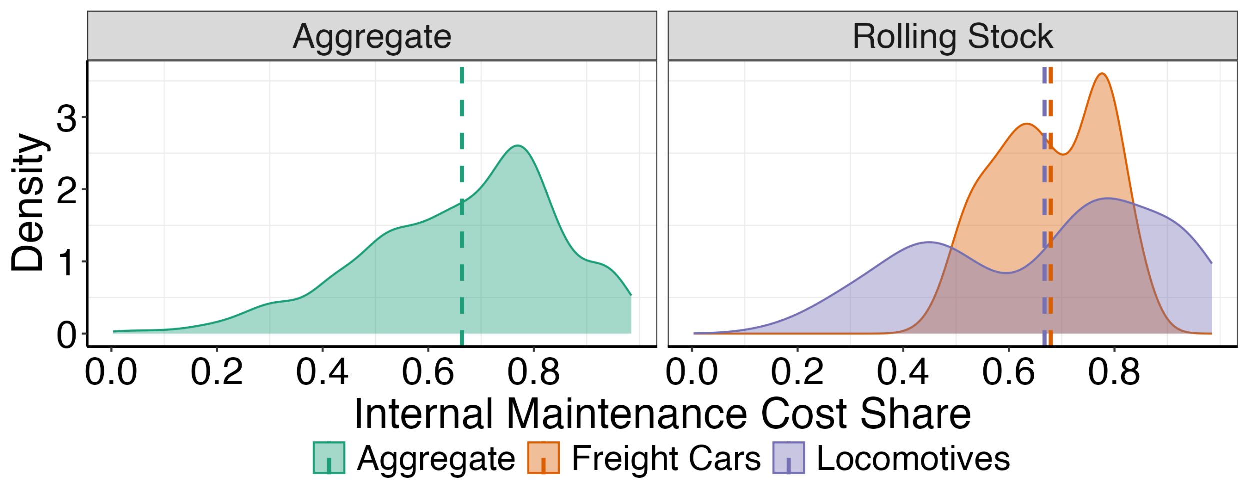
Internal vs. External Maintenance. Schedule 410 breaks down maintenance costs into three components:

- Materials costs (e.g., replacement parts, lubricants, consumables)
- Labor costs (wages and benefits for railroad employees performing maintenance)
- Purchased services (maintenance contracted to outside vendors)

I define **internal maintenance** as the sum of materials and labor costs, and **external maintenance** as purchased services. This distinction is crucial for identification. Internal maintenance costs vary with local labor market conditions and firm-specific wage policies, while external maintenance costs reflect national market prices for specialized services. If maintenance demand is elastic, the adjustment will occur primarily through the internal margin in the short run, as external maintenance often involves predetermined contracts.

There is significant variability across firms in their internal maintenance practices. On average, approximately 65% of total maintenance is performed internally. However, this share varies considerably: some firms like Norfolk Southern perform nearly all locomotive maintenance in-house, while similarly sized competitors like CSX outsource around 70% of locomotive maintenance. Freight car maintenance tends to have less variability, perhaps because locomotives are more technically complex and require specialized expertise.

Figure C.1: 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. For 2007, 2012, and 2017, I subtract payments to NAICS 811 from total maintenance expenditures after applying a labor cost correction. 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.

Relative Price Construction

The after-tax relative price is:

$$P_{i,j,t} = \frac{p^M_{i,j,t}}{p^I_{j,t}} \frac{1 - \tau_{i,t}}{1 - \tau_{i,t} z_t}. \tag{A.26}$$

I construct each component as follows:

Investment Price ($p^I_{j,t}$). The investment price varies by asset type but not by firm. I use BLS Producer Price Indices:

Freight Cars: Through 2016, I use BLS series PCU3365103365103Z ("Producer Price Index by Industry: Railroad Rolling Stock Manufacturing: Passenger and Freight Train Cars, New (Excluding Parts)"). For subsequent years, I splice this series with WPU14440102 ("Wholesale Price Index: Passenger and Freight Train Cars, New (Excluding Parts)"). The two series have a correlation of 0.98 in the overlapping period.

Locomotives: Through 2018, I use BLS series WDU1441 ("Wholesale Price Index: Locomotives"). The BLS discontinued this series in 2019 without a direct replacement. For 2019-2023, I construct a locomotive-specific price index by decomposing the broader rolling stock price index (WPU144) using investment shares from the R-1 data. Specifically, I calculate the locomotive share of total rolling stock investment for each year and construct a Tornqvist index that separates locomotive price movements from freight car price movements.

Maintenance Price ($p^M_{i,j,t}$). The pre-tax maintenance price is a firm-asset-time specific weighted average of input prices:

$$p^M_{i,j,t} = \alpha^{\text{labor}}_{i,j,t-1} \cdot w_{i,t} + \alpha^{\text{materials}}_{i,j,t-1} \cdot p^{\text{mat}}_t + \alpha^{\text{services}}_{i,j,t-1} \cdot p^{\text{serv}}_t, \tag{A.27}$$

where:

- $\alpha^{\text{labor}}_{i,j,t-1}$, $\alpha^{\text{materials}}_{i,j,t-1}$, and $\alpha^{\text{services}}_{i,j,t-1}$ are lagged cost shares for labor, materials, and purchased services from Schedule 410. I use lagged shares to avoid mechanical correlation between prices and quantities.

- $w_{i,t}$ is the firm-specific average hourly wage for rolling stock maintenance workers from Wage Form A&B filed with the STB. This form reports detailed wage information by occupation and skill level.

- p^{mat}_t is BLS series PCU33651033651054 ("Producer Price Index by Industry: Railroad Rolling Stock Manufacturing: Railway Maintenance of Way Equipment and Parts, Parts for All Railcars, and Other Railway Vehicles")

- p^{serv}_t is the Producer Price Index for equipment maintenance and repair services (BLS series PCU8111, available from 2007 forward)

For the external services component before 2007, I use the PPI for automotive repair and maintenance (BLS series PCU8111) as a proxy. This series is highly correlated (correlation =

0.94) with the equipment maintenance series in the overlapping period (2007-2023) and captures similar labor and parts cost pressures facing maintenance service providers.

The external cost component assumes a constant markup over time for maintenance services purchased from vendors. This is a simplifying assumption, but variation in external maintenance prices comes primarily from underlying input costs (parts and labor) rather than time-varying markups.

Tax Parameters. I construct firm-specific statutory tax rates ($\tau_{i,t}$) as:

$$\tau_{i,t} = \tau_t^{\text{federal}} + \tau_{i,t}^{\text{state}} - \tau_t^{\text{federal}} \cdot \tau_{i,t}^{\text{state}}, \tag{A.28}$$

where τ_t^{federal} is the federal corporate tax rate (35% before 2018, 21% thereafter) and $\tau_{i,t}^{\text{state}}$ is a revenue-weighted average state corporate tax rate.

The state component is calculated using the geographic distribution of each railroad's operations. Schedule 702 reports track miles by state for each firm. I use these track miles as weights to construct a firm-specific exposure to state corporate tax rates:

$$\tau_{i,t}^{\text{state}} = \sum_s \left(\frac{\text{Track Miles}_{i,s,t}}{\text{Total Track Miles}_{i,t}} \right) \cdot \tau_{s,t}^{\text{state}}, \tag{A.29}$$

where $\tau_{s,t}^{\text{state}}$ is the statutory corporate tax rate in state s at time t. I obtain state tax rates by extending the dataset of Suárez Serrato and Zidar (2016) through 2023.

The present value of depreciation allowances (z_t) varies over time due to changes in bonus depreciation and MACRS schedules. Following House and Shapiro (2008), I calculate:

- Both locomotives and freight cars are classified as MACRS 7-year property
- Bonus depreciation rates
- Discount rate: $r^k = 0.0713$ (industry average for NAICS 48 from Gormsen and Huber (2022))

Because the IRS places both asset types in the same depreciation class, z_t does not vary between locomotives and freight cars. However, there is firm-level variation in the effective tax rate through the state tax component.

Additional Control Variables

Local GDP Exposure. I construct a firm-specific measure of exposure to local demand shocks using:

$$\Delta \log Y_{i,t} = \sum_s \left(\frac{\text{Track Miles}_{i,s,t}}{\text{Total Track Miles}_{i,t}} \right) \cdot \Delta \log \text{GDP}_{s,t}, \tag{A.30}$$

where $\Delta \log \text{GDP}_{s,t}$ is the log change in gross state product from the Bureau of Economic Analysis. This measure captures how aggregate demand shocks in a railroad's service territory might affect maintenance decisions.

Local Wage Index. I construct a firm-specific maintenance wage index using Bureau of Labor Statistics data on wages by state in the Installation, Maintenance, and Repair Occupation (SOC Code 49-0000):

$$W_{i,t} = \sum_s \left(\frac{\text{Track Miles}_{i,s,t}}{\text{Total Track Miles}_{i,t}} \right) \cdot \frac{w_{s,t}}{w_{s,1999}}, \tag{A.31}$$

where $w_{s,t}$ is the average wage in state s at time t, normalized to 1999 = 1. This provides an alternative measure of maintenance labor costs that is not firm-specific and can serve as an instrument for firm-level wage variation.

Maintenance Share of User Cost. Following the definition in Section 3, I calculate:

$$s_{m,i,j,t} = \frac{(1-\tau_{i,t}) \cdot p^M_{i,j,t} \cdot m_{i,j,t}}{(1-\tau_{i,t} z_t) \cdot p^I_{j,t} \cdot (r^k + \delta_j) + (1-\tau_{i,t}) \cdot p^M_{i,j,t} \cdot m_{i,j,t}}. \tag{A.32}$$

The depreciation rate δ_j is assumed constant across firms but varies by asset type:

- Locomotives: $\delta = 0.04$ (4% annual depreciation)
- Freight cars: $\delta = 0.03$ (3% annual depreciation)

These rates are industry standards for freight railroads and are consistent with the depreciation rates railroads report to the STB for composite depreciation calculations. The discount rate is $r^k = 0.0713$ as noted above.

Summary Statistics

Tables C.1 and C.2 present summary statistics for the R-1 sample, separately for locomotives and freight cars.

Table C.1: Summary Statistics: R-1 Data (Locomotives)

Variable	Mean	10th Pctl	Median	90th Pctl	N
Year	2011.19	2001.10	2011.00	2021.00	172
$m_{i,j,t}$ (Total)	0.17	0.07	0.14	0.30	172
$m_{i,j,t}$ (Internal)	0.11	0.04	0.09	0.19	172
$m_{i,j,t}$ (External)	0.06	0.00	0.05	0.11	172
$m_{i,j,t}$ (Physical)	0.03	0.02	0.02	0.04	172
$\log M_{i,j,t}$	11.99	10.35	12.37	13.41	172
$\log I_{i,j,t}$	11.34	9.19	11.94	13.31	172
Investment Rate	0.15	0.02	0.10	0.28	172
$P_{i,j,t}$	1.11	1.00	1.10	1.25	172
Capital Age	1.48	1.24	1.51	1.69	172
Local GDP Exposure	1.99	-0.21	2.13	4.09	172
$z_{i,j,t}$	0.56	0.36	0.50	0.83	172
Labor Cost Share (lag)	0.41	0.29	0.37	0.57	172
Local Wage Index	1.33	1.08	1.32	1.64	172
Effective Tax Rate	1.04	1.00	1.04	1.09	172
Maintenance Share (s_m)	0.59	0.45	0.59	0.74	172

Notes: Sample covers 7 firms over 25 years (1999-2023), with some missing observations. Maintenance and investment rates are scaled as shares of beginning-of-period book capital.

Table C.2: Summary Statistics: R-1 Data (Freight Cars)

Variable	Mean	10th Pctl	Median	90th Pctl	N
Year	2011.19	2001.10	2011.00	2021.00	172
$m_{i,j,t}$ (Total)	0.22	0.08	0.16	0.45	172
$m_{i,j,t}$ (Internal)	0.15	0.05	0.10	0.34	172
$m_{i,j,t}$ (External)	0.07	0.02	0.05	0.12	172
$m_{i,j,t}$ (Physical)	0.03	0.02	0.03	0.06	172
$\log M_{i,j,t}$	11.70	10.35	11.92	13.03	172
$\log I_{i,j,t}$	9.33	6.02	10.56	12.21	172
Investment Rate	0.08	0.00	0.05	0.19	172
$P_{i,j,t}$	0.90	0.77	0.88	1.04	172
Capital Age	1.59	1.18	1.62	1.93	172
Local GDP Exposure	1.99	-0.21	2.13	4.09	172
$z_{i,j,t}$	0.52	0.36	0.53	0.67	172
Labor Cost Share (lag)	0.39	0.26	0.39	0.51	172
Local Wage Index	1.33	1.08	1.32	1.64	172
Effective Tax Rate	1.04	1.00	1.04	1.09	172
Maintenance Share (s_m)	0.60	0.41	0.60	0.78	172

Notes: Sample covers 7 firms over 25 years (1999-2023), with some missing observations. Maintenance and investment rates are scaled as shares of beginning-of-period book capital.

C.2 SOI Data Construction

Data Sources and Sample Construction

The Statistics of Income (SOI) is published annually by the Internal Revenue Service and aggregates corporate tax return data into industry-level samples. The SOI uses a stratified sampling procedure that oversamples large corporations and then applies weights to make the sample representative of the full corporate population. Corporations report maintenance expenditures (labeled "repairs and maintenance") and book capital as line items on their tax forms (Form 1120), which the SOI aggregates across firms within industries.

I use the SOI Corporate Sample files from 1999-2019. The data are publicly available at the industry level but not at the firm level. Each observation is an industry-year cell, with all dollar amounts representing weighted aggregates across firms in that industry. The SOI reports data at varying levels of aggregation, roughly corresponding to 2-3 digit NAICS codes. However, the number of SOI industries fluctuates over time as the IRS adjusts its classification scheme. In 2014, for example, the SOI changed from a "major" to a "minor" industry scheme.

To maintain consistency across years, I map SOI industries to Bureau of Economic Analysis (BEA) industry definitions, which are more stable over time. Specifically, I use the 49-industry classification from the BEA's Fixed Asset Tables. This mapping is not one-to-one—some SOI industries must be aggregated—but it ensures definitional consistency across my sample period. I exclude several categories the financial industry and passthrough entitities from the analysis, focusing only on corporate filings. The resulting sample consists of 49 industries observed annually from 1999-2019, yielding up to 1,029 industry-year observations. Some industry-year cells have missing data, resulting in a final sample of approximately 1,116 observations.

I use the BEA industry definition rather than the raw SOI definition for three reasons. First, I combine SOI data with BEA data in some specifications (e.g., using BEA depreciation rates, capital composition weights, and price deflators). Using a consistent industry definition facilitates this merging. Second, the BEA definition is more aggregated than the SOI definition. This aggregation arguably better captures general equilibrium effects: when national tax policy changes, firms can reallocate capital within broadly defined industries, and the BEA aggregation level implicitly nets out this within-industry reallocation. Third, the BEA classification is stable over time, whereas the SOI classification changes periodically, creating artificial breaks in the panel.

Taxable vs. Untaxable Firms. For some analyses, I separate the sample into taxable and untaxable firms. I define **taxable firms** as those with positive net income in a given year, and **untaxable firms** as those without positive net income. The SOI reports both categories separately.

This classification is imperfect. Some firms in the "taxable" category may not actually face positive tax liability because they have accumulated net operating losses (NOLs) from prior years that they can carry forward to offset current income. Conversely, some "untaxable" firms may face some tax liability through alternative minimum tax provisions or other mechanisms. Despite these limitations, the taxable/untaxable split provides a useful approximation: taxable firms face stronger incentives to respond to tax policy changes than untaxable firms.

Variable Construction

Maintenance Rate. The maintenance rate is defined as the ratio of the maintenance and repairs line item to lagged book capital:

$$m_{i,t} = \frac{\text{Repairs and Maintenance}_{i,t}}{\text{Book Capital}_{i,t-1}}, \tag{A.33}$$

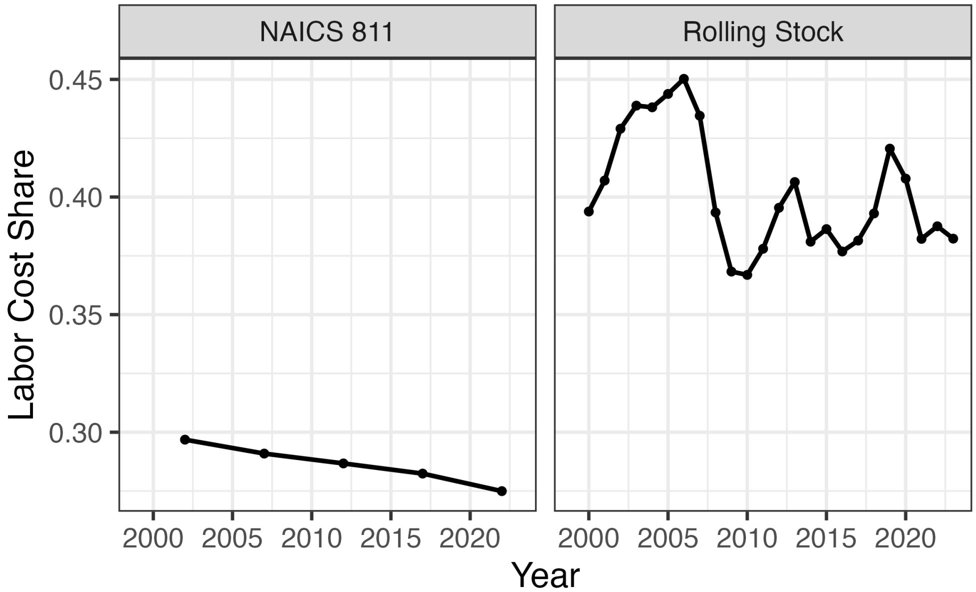
where i indexes industries and t indexes years.

The SOI maintenance measure is noisier than the R-1 measure for two important reasons:

First, labor costs are likely understated. On corporate tax forms, labor expenditures are reported as a separate line item (wages and salaries). As a result, the repairs and maintenance line primarily reflects spending on materials and external maintenance services purchased from vendors. Internal maintenance performed by the firm's own employees—which can be substantial—is not fully captured. Additionally, some materials costs may be classified under cost of goods sold rather than the maintenance line item, further understating true maintenance expenditures.

In the R-1 railroad panel, internal labor accounts for about 40 percent of total maintenance expenditures on both freight cars and locomotives (Figure 7). There is not a corresponding aggregate labor cost share, but Appendix Figure C.2 plots the ratio of labor costs to total receipts for the maintenance and repair sector using the Economic Census from 2002-2022. The labor share is consistently 30%. Thus, materials and parts are usually around 60-70% of maintenance expenditures. 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.

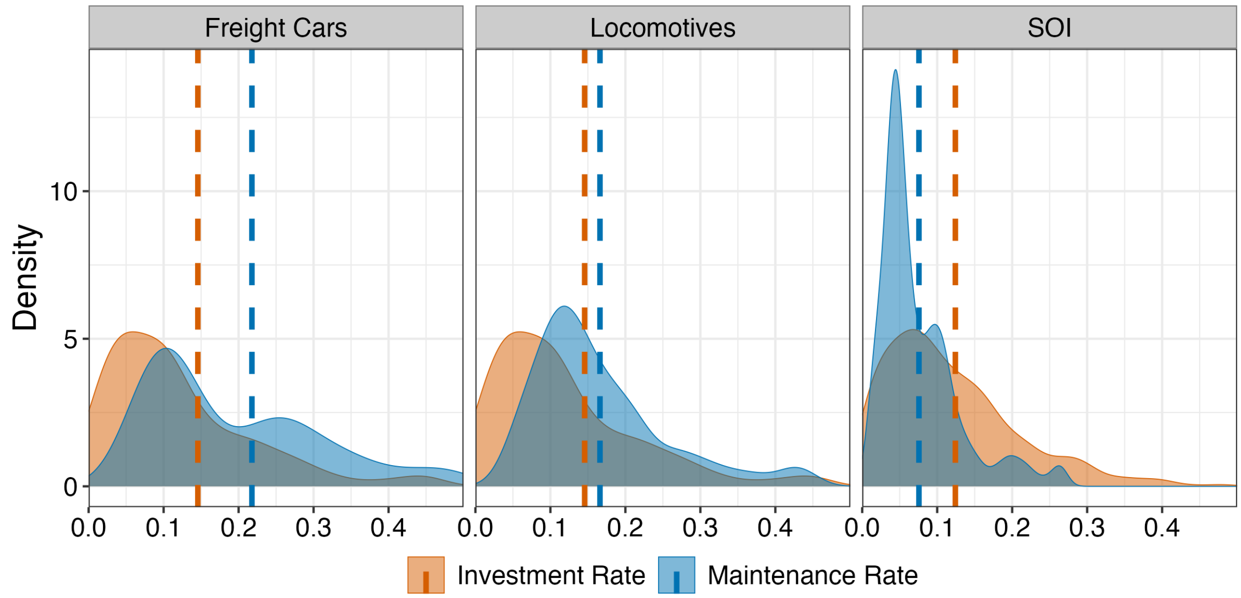
Figure C.2: Aggregate Internal Labor Cost Share



Notes: The share is computed by dividing labor costs by total internal maintenance costs. The left panel 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. The right panel is the average for all rolling stock in the R-1 data.

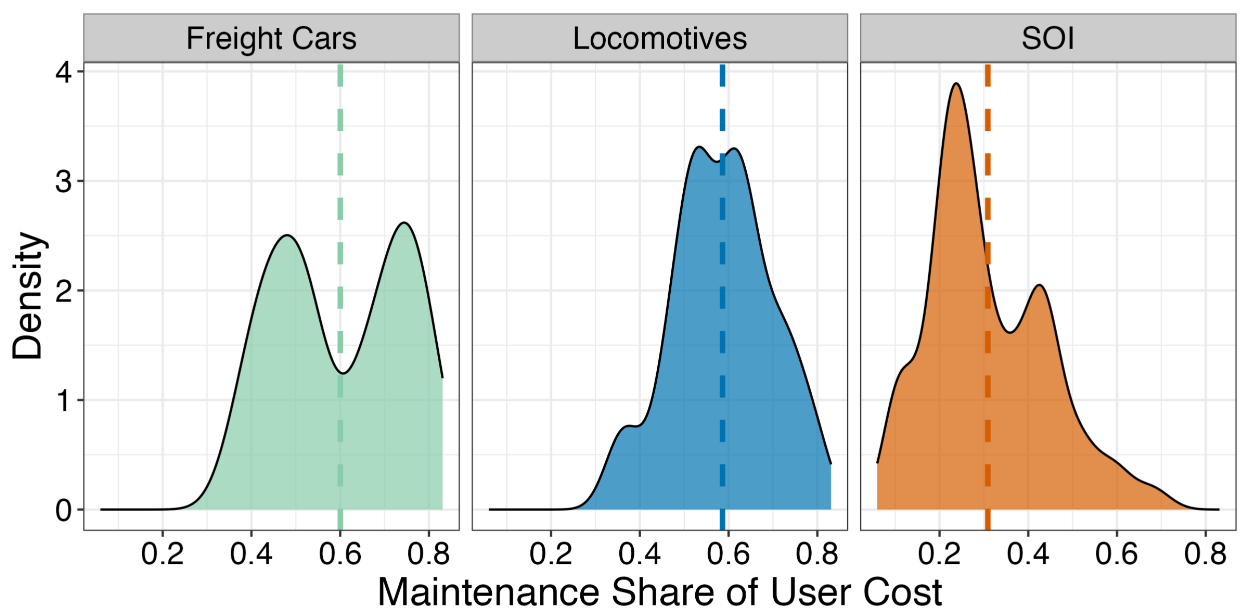
The Equipment Maintenance and Repair sector (NAICS 811) suggests that labor accounts for 30-45% of total maintenance costs. If this labor share applies broadly, then reported SOI maintenance may understate true maintenance by a factor of roughly 1.4. In robustness checks, I construct an "adjusted" maintenance rate by dividing reported maintenance by 0.65 to approximate total maintenance inclusive of labor. The elasticity results are invariant to this measure, but the *level* results in the main text are necessarily conservative because they are a lower bound.

Figure C.3: Density plots for maintenance and gross investment rates (adjusted)



Note: Each density plot is constructed with beginning of period book capital in the denominator. The dashed lines are mean maintenance and investment rates. From left to right, the mean maintenance rates are 7.9%, 21.8%, and 16.6%. The corresponding investment rates are 13.8%, 7.9%, and 14.6%. The SOI maintenance rate is adjusted for missing labor and materials costs.

Figure C.4: Density plots for the maintenance share of user cost (adjusted)



Note: Each density plot is constructed with beginning of period book capital in the denominator. The dashed lines are mean maintenance shares. Across the SOI, freight cars, and locomotives, the mean maintenance shares are 30%, 60%, and 58.6%. The maintenance rate is adjusted for labor costs.

Second, the capital stock denominator uses tax depreciation. The SOI constructs book capital using firms' reported accumulated depreciation, which follows tax depreciation schedules rather than economic depreciation. Tax depreciation can be accelerated (especially during bonus depreciation periods), causing book capital to understate true economic capital. This introduces measurement error in the denominator, which may attenuate estimated elasticities. Despite these measurement issues, SOI maintenance rates are comparable to those observed in aggregate Canadian *survey* data, which is constructed by Statistics Canada.

Investment Rate. The net investment rate is:

$$\frac{I_{i,t}}{K_{i,t}} = \frac{\text{Gross Investment}_{i,t} - \text{Tax Depreciation}_{i,t}}{\text{Book Capital}_{i,t-1}}. \tag{A.34}$$

Capital Age. I proxy for capital age using the ratio of gross to net book capital:

$$\text{Capital Age}_{i,t} = \frac{\text{Gross Book Capital}_{i,t}}{\text{Net Book Capital}_{i,t}}. \tag{A.35}$$

Higher values indicate older capital (more accumulated depreciation relative to gross value). This measure is imperfect because it reflects tax depreciation schedules rather than true physical age, but it provides a useful control for capital vintage effects.

I winsorize maintenance rates, investment rates, and capital age at the 2nd and 98th percentiles to reduce the influence of outliers and measurement error.

Policy Wedge Construction

The key source of identification in the SOI data is variation in the policy wedge:

$$\text{Wedge}_{i,t} = \frac{1 - \tau_t}{1 - \tau_t z_{i,t}}, \tag{A.36}$$

where τ_t is the statutory federal corporate tax rate (35% before 2018, 21% thereafter) and $z_{i,t}$ is the net present value of depreciation allowances for industry i at time t.

I construct $z_{i,t}$ in three steps:

Step 1: Asset-Level Present Value of Depreciation. For every asset type j with MACRS class life T, I compute the baseline present value of depreciation allowances as:

$$z_{i,j} = \sum_{t=0}^{T} \left(\frac{1}{1 + r_i^k} \right)^t d_t, \tag{A.37}$$

where d_t is the depreciation rate in year t under the applicable MACRS schedule (e.g., 200% declining balance for 5-year property, 150% declining balance for 15-year property, straight-line for structures), and r_i^k is the industry-specific discount rate.

I obtain industry-specific discount rates from Gormsen and Huber (2022), who estimate firm-level costs of capital using equity returns and leverage. I map their firm-level estimates to BEA industries and take a time-series average within each industry.

Step 2: Adjusting for Bonus Depreciation. Time-series variation in $z_{i,j,t}$ comes from changes in bonus depreciation policy. Let θ_t denote the bonus depreciation rate (the percentage of asset cost that can be immediately expensed). Then:

$$z_{i,j,t} = \theta_t + (1 - \theta_t) z_{i,j}, \tag{A.38}$$

where θ_t only applies to eligible assets (primarily equipment). Structures are generally ineligible for bonus depreciation. My sample ends before the TCJA bonus provisions began phasing out.

Step 3: Aggregating to Industry-Level Wedges. To construct the industry-specific $z_{i,t}$, I aggregate across the 36 detailed asset categories in the BEA's Fixed Asset Tables using capital-weighted shares:

$$z_{i,t} = \sum_{j=1}^{36} \alpha_{i,j} \cdot z_{i,j,t}, \tag{A.39}$$

where $\alpha_{i,j}$ is the share of asset type j in industry i's total capital stock. I map the 36 BEA assets to their corresponding MACRS depreciation classes using the concordance from House and Shapiro (2008).

Capital Weights and Exogeneity. A key consideration is which years to use for constructing the capital weights $\alpha_{i,j}$. Using contemporaneous weights would introduce endogeneity: if tax policy affects investment, it also affects capital composition, which would feed back into the construction of $z_{i,t}$.

To maintain exogeneity while preserving relevance, I use two different weighting periods:

- **1998-2001 weights** for all years 1999-2017: These years had no variation in tax policy (no bonus depreciation, stable MACRS schedules), so capital weights are pre-determined relative to subsequent policy changes.

- **2014-2017 weights** for years 2018-2019: These years also had stable policy (50% bonus ramping down to zero), making them pre-determined relative to the TCJA changes in 2018.

This approach balances two objectives: maintaining exogeneity (using pre-policy weights) while ensuring relevance (using weights not too far in the past from the policy change). The 2017 TCJA represented a major structural break (corporate rate cut from 35% to 21% plus 100% bonus), so using 2014-2017 weights better captures the capital composition relevant to that reform.

Industries with more equipment-intensive capital structures (higher shares of short-lived assets eligible for bonus depreciation) experience larger changes in $z_{i,t}$ when bonus depreciation rates change. Figure 5 in the main text shows substantial cross-industry variation in the wedge over time, with equipment-intensive industries like manufacturing experiencing larger policy-driven changes than structures-intensive industries like utilities or real estate.

Maintenance Share of User Cost

Following the definition in Section 3, I calculate the maintenance share of user cost as:

$$s_{m,i,t} = \frac{(1-\tau_t^c) \cdot p_t^M \cdot m_{i,t}}{(1-\tau_t^c z_{i,t}) \cdot p_t^I \cdot (r_i^k + \delta_i) + (1-\tau_t^c) \cdot p_t^M \cdot m_{i,t}}, \tag{A.40}$$

where:

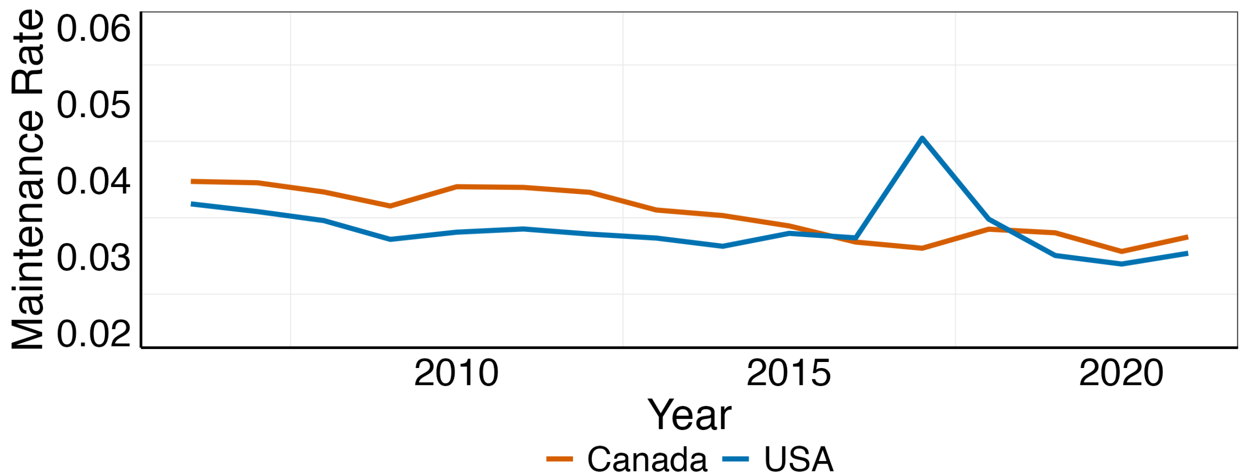
- r_i^k is the industry-average discount rate from Gormsen and Huber (2022)
- δ_i is a capital-weighted industry-average depreciation rate constructed from the BEA Fixed Asset Tables. For each industry, I compute $\delta_i = \sum_j \alpha_{i,j}\delta_j$, where δ_j is the BEA's estimate of economic depreciation for asset type j.
- p_t^I is the implicit price deflator for fixed investment from the BEA National Income and Product Accounts (NIPA Table 1.1.4)
- p_t^M is the Producer Price Index for equipment maintenance and repair services (BLS series PCU8111). For years before 2007 when this series is unavailable, I use the PPI for automotive repair and maintenance as a proxy.

Table C.3 also reports an "adjusted" maintenance share that accounts for the labor understatement issue discussed above. This is calculated by dividing reported maintenance by 0.65 before computing the share, under the assumption that labor accounts for approximately 35% of total maintenance costs.

Comparison to Canadian Data

To validate the SOI maintenance rates, I compare them to aggregate maintenance data from Canada. The Canadian data compiled by Statistics Canada are from survey data on maintenance expenditures combined with an estimated aggregate economic capital stock. Figure C.5 plots the aggregate maintenance rate (total maintenance divided by total book capital) for both the U.S. SOI sample and Canadian data.

Figure C.5: American vs. Canadian Maintenance Rates



Note: This figure plots the maintenance rate (net of govenrnment capital and maintenance) from Statistics Canada against the SOI maintenance rate.

The two series track each other closely, with mean maintenance rates of 4.8% (U.S.) and 5.1% (Canada). Both exhibit similar cyclical patterns, rising during recessions (when investment falls but maintenance continues) and declining during booms. This similarity suggests that despite measurement issues, the SOI provides a reasonable proxy for economy-wide maintenance behavior.

Summary Statistics

Table C.3 presents summary statistics for the SOI sample, separately for all firms, taxable firms, and untaxable firms.

Table C.3: Summary Statistics: SOI Data

Variable	Mean	10th Pctl	Median	90th Pctl	N
All Firms					
Year	2009.95	2001.00	2010.00	2019.00	1116
$m_{i,t}$	0.05	0.02	0.04	0.09	1116
Investment Rate	0.06	-0.14	0.06	0.23	1116
Wedge	0.83	0.76	0.82	0.92	1116
Maintenance Share (s_m)	0.22	0.09	0.19	0.38	1116
s_m (Adjusted)	0.30	0.13	0.27	0.48	1116
Capital Age	2.21	1.66	2.15	2.80	1116
Taxable Firms					
Year	2009.04	2000.00	2009.00	2019.00	1114
$m_{i,t}$	0.05	0.02	0.04	0.10	1114
Investment Rate	0.11	-0.47	0.05	0.61	1114
Wedge	0.83	0.76	0.82	0.92	1114
Maintenance Share (s_m)	0.23	0.09	0.21	0.42	1114
s_m (Adjusted)	0.31	0.13	0.29	0.53	1114
Capital Age	2.25	1.69	2.19	2.93	1114
Untaxable Firms					
Year	2009.05	2000.00	2009.00	2019.00	1113
$m_{i,t}$	0.05	0.01	0.04	0.09	1113
Investment Rate	0.13	-0.40	0.02	0.83	1113
Wedge	0.83	0.76	0.82	0.92	1113
Maintenance Share (s_m)	0.23	0.07	0.20	0.43	1113
s_m (Adjusted)	0.30	0.11	0.28	0.54	1113
Capital Age	2.12	1.52	2.06	2.75	1113

Notes: Sample covers 49 industries over 21 years (1999-2019). Maintenance and investment rates are winsorized at 2nd and 98th percentiles. "Adjusted" maintenance share divides reported maintenance by 0.65 to approximate total maintenance inclusive of labor costs. Wedge is $\frac{1-\tau_t}{1-\tau_t z_{i,t}}$.

D Empirical Robustness and Identification Details

This appendix provides detailed validation of identification strategies, robustness checks, and supplementary analyses for the maintenance demand estimates in Section 6.

D.1 R-1 Estimates

Extended Motivation for Shift-Share Design

The shift-share instrument in equation (20) is designed to approximate an idealized experiment in which maintenance input costs are shifted by forces outside individual firms' control. To motivate this approach more fully, consider a hypothetical experiment in which a central planner randomly assigns shifts to national or state-level labor markets. For instance, imagine national wage negotiations or state-level policies that randomly alter prevailing wage indices for maintenance occupations. In such a setting, these cost changes would be as good as randomly assigned from the perspective of individual firms, ensuring that resulting changes in maintenance input prices are not driven by firm-level or region-specific unobserved conditions.

The instrument approximates this ideal by using state-level input cost indices as "shifts" and employing firm- and capital-type-specific cost shares as "shares." This design choice deserves elaboration on two dimensions: the exogeneity of shifts and the pre-determination of shares.

Why State-Level Wages Are Plausibly Exogenous. The wage indices $W_{s,t}$ come from BLS data on Installation, Maintenance, and Repair occupations (SOC 49-0000) at the state level. These wages reflect broad economic conditions in each state: labor market tightness, cost of living adjustments, state-level unionization rates, and prevailing wage regulations. Importantly, railroad maintenance facilities are geographically dispersed across their service territories based on network structure and historical infrastructure investments made decades ago.

For example, Union Pacific has major maintenance facilities in Omaha (historical headquarters), North Platte (geographic midpoint of the system), and various division points determined by operational considerations like crew change requirements and locomotive fueling needs. These locations were not chosen to minimize current labor costs—indeed, many were established in the 19th century. The geographic footprint is therefore predetermined relative to current wage movements, making the weighted average of state wages plausibly orthogonal to firm-specific maintenance decisions.

Connection to Borusyak, Hull, and Jaravel (2024) The instrument follows what Borusyak, Hull, and Jaravel (2024) term the "many exogenous shifts" approach rather than the "exogenous shares" approach. The distinction is important for understanding the identification assumption. In the exogenous shares approach, identification relies on the shares being exogenous—for example, a firm's initial capital composition or geographic footprint being uncorrelated with future growth opportunities. The shifts can be endogenous because they are differentially weighted by exogenous shares.

In the many exogenous shifts approach, identification relies on having numerous shifts that are individually exogenous to the outcome of interest. The shares can be endogenous because the law of large numbers ensures that endogeneity in shares averages out across many independent shifts. My design follows this approach. The shifts are numerous and individually plausible exogenous to firm-asset-level maintenance decisions. State labor markets are large relative to any individual railroad's employment in that state, so reverse causality is implausible. The shares—geographic footprints and internal cost structures—are persistent but not necessarily exogenous in the strict sense. However, with many plausibly exogenous shifts, the design delivers valid identification.

First Stage Results

Table D.1 presents first-stage results for the baseline instrument and alternative specifications. The first stage is strong across all specifications, with F-statistics ranging from 10.5 to 11.5. The coefficient on the instrument is positive and statistically significant in all cases, indicating that increases in the instrument raise the relative price of maintenance as expected. The baseline specification (column 1) yields a coefficient of 0.165. Adding controls (column 2) leaves the first stage essentially unchanged, suggesting the instrument is not confounded by local demand conditions, capital age, or firm-specific trends. Either varying the lag structure of labor shares or using a national wage index rather than state-level indices weighted by geography yields a slightly smaller but still strong first stage.

Table D.1: First-Stage Regressions for Varying Instruments

	(1)	(2)	(3)	(4)	(5)	(6)
$Z_{i,j,t}$	0.165**	0.173**	0.002**	0.002**	0.156***	0.164**
	(0.049)	(0.051)	(0.000)	(0.000)	(0.041)	(0.045)
Capital Age		−0.012		−0.026		−0.020
		(0.032)		(0.028)		(0.031)
GDP Exposure		−0.004*		−0.002		−0.003
		(0.002)		(0.003)		(0.002)
Num.Obs.	340	340	314	314	326	326
Effective F-stat	11.54	11.52	14.32	13.27	10.16	9.74
Firm Trends	N	Y	N	Y	N	Y
Instrument Type	Baseline	Baseline	Shares Lagged 3 Years	Shares Lagged 3 Years	National Wage Index	National Wage Index

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

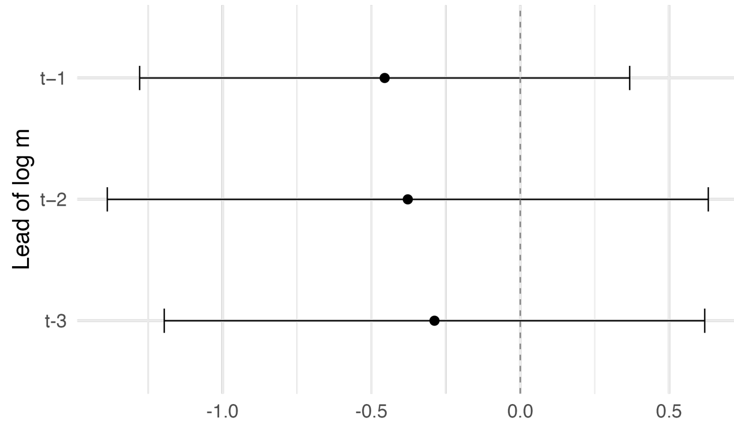
Notes: This table estimates the first stage of regressions for the main freight rail specification in (19). The first two columns use the baseline instrument described in the main text, with second adding firm-specific trends and controls for local demand shocks and capital age. The second columns are the same instrument, but with the labor share lagged three years instead of two. The final two columns use a national wage index, which is the employment cost index for workers in maintenance and repair (FRED item CIU2020000430000I). Standard errors are clustered by firm. The effective F-stat is from Montiel-Olea and Pflueger (2013).

Validation Tests

The instrument must satisfy two conditions for valid identification. First, it should not predict past maintenance rates (no anticipation). Second, the shares component should be orthogonal to pre-period determinants of maintenance (balance).

Pre-Trends. Figure D.1 tests whether lagged maintenance rates predict the instrument. If firms anticipate future wage shocks and adjust maintenance in advance, lagged maintenance should predict $Z_{i,j,t}$. I regress $Z_{i,j,t}$ on lags of log $m_{i,j,t}$, controlling for firm-asset and time fixed effects.

Figure D.1: Lead tests of the log maintenance rate on $Z_{i,j,t}$

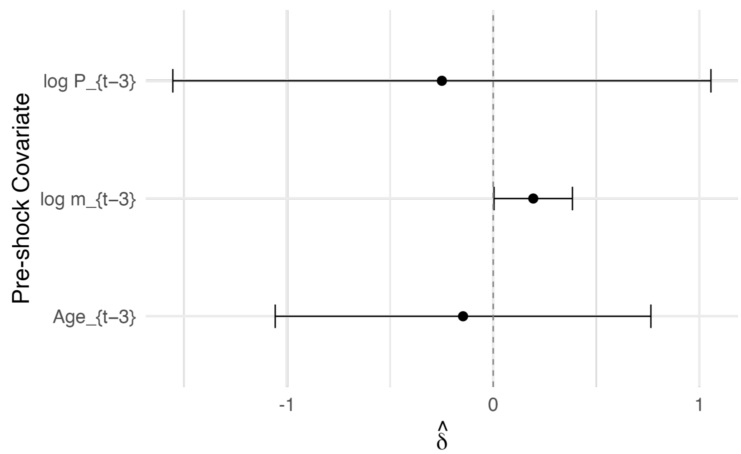


Note: This figure plots coefficients from regressing a pre-shock maintenance rate on the instrument $Z_{i,j,t}$ after controlling for firm-year trends, year fixed effects, and firm-asset fixed effects. Standard errors are clustered by industry.

None of the lagged maintenance coefficients are statistically significant or economically meaningful. This indicates firms do not anticipate future wage shocks, supporting the exclusion restriction.

Balance. Figure D.2 tests whether the labor share—the potentially endogenous component of the instrument—is correlated with pre-period observables. I regress the labor share on lagged maintenance rates, lagged relative prices, and lagged capital age. None of the coefficients are statistically significant. This confirms that the labor share—though potentially endogenous in principle—is not systematically correlated with observable determinants of maintenance, supporting the pre-determination assumption.

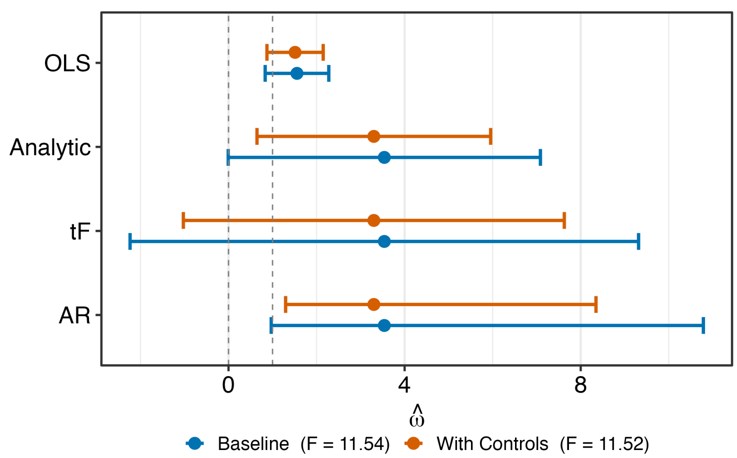
Figure D.2: Balance tests on pre-shock outcomes



Note: This figure plots coefficients from regressing the variable on the y-axis against the instrument $Z_{i,j,t}$ after controlling for firm-asset and year fixed effects and firm trends. Standard errors are clustered by firm.

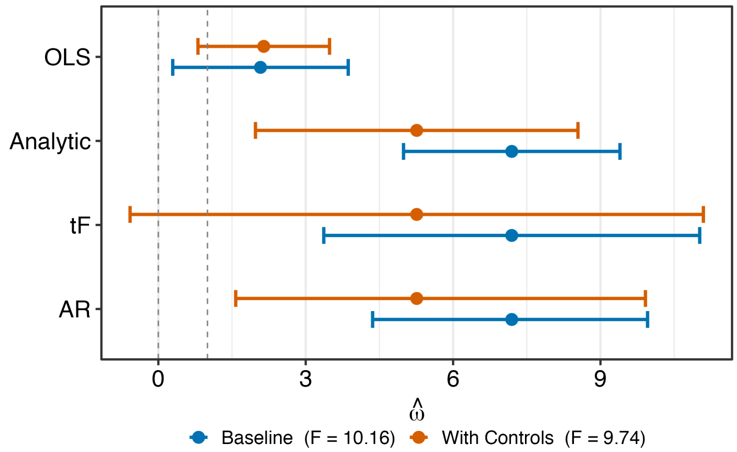
Robustness Checks

Figure D.3: Maintenance demand elasticity with 95% confidence interval (Physical Capital)



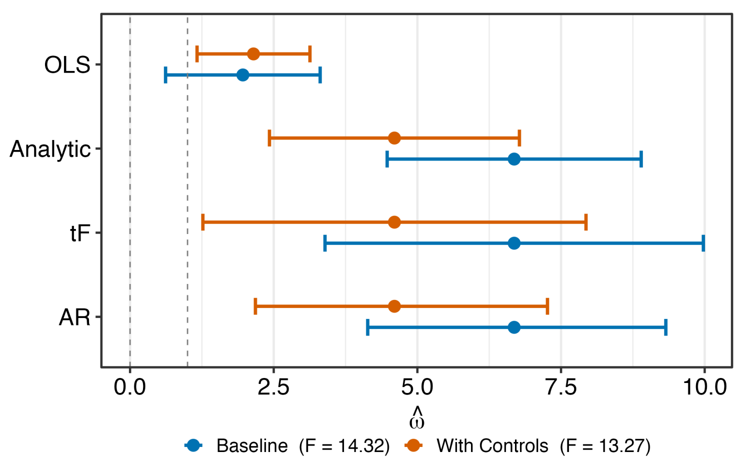
Note: This figure plots the point estimates and result for estimating (19), except I replace the maintenance rate with a physical measure of the capital stock. The blue lines contain no controls, while the orange lines control for local GDP exposure, firm-year trends, and the age of the capital stock. All standard errors are clustered by firm. The top estimate is for OLS only, while the bottom three all correspond to the instrument specified in (20). Analytic confidence intervals are from traditional Wald estimates, while the tF and AR confidence intervals result from inverting the tF (Lee et al. 2022) and Anderson and Rubin (1949) tests, respectively. The F-statistic reported in the legend is the effective F-statistic from Montiel-Olea and Pflueger (2013).

Figure D.4: Maintenance demand elasticity with 95% confidence interval (National Instrument)



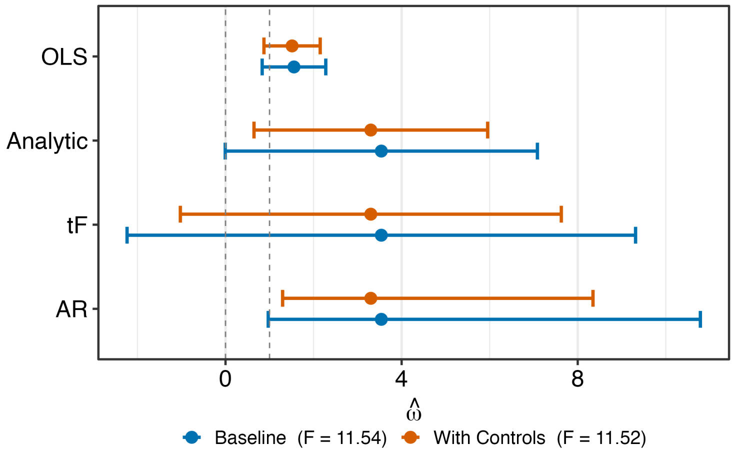
Note: This figure plots the point estimates and result for estimating (19). The blue lines contain no controls, while the orange lines control for local GDP exposure, firm-year trends, and the age of the capital stock. All standard errors are clustered by firm. The top estimate is for OLS only, while the bottom three all correspond to the instrument specified in (20), except that I use a national measure of the wage index so there is no weighting by state.. Analytic confidence intervals are from traditional Wald estimates, while the tF and AR confidence intervals result from inverting the tF (Lee et al. 2022) and Anderson and Rubin (1949) tests, respectively. The F-statistic reported in the legend is the effective F-statistic from Montiel-Olea and Pflueger (2013).

Figure D.5: Maintenance demand elasticity with 95% confidence interval (Thrice-Lagged Instrument)



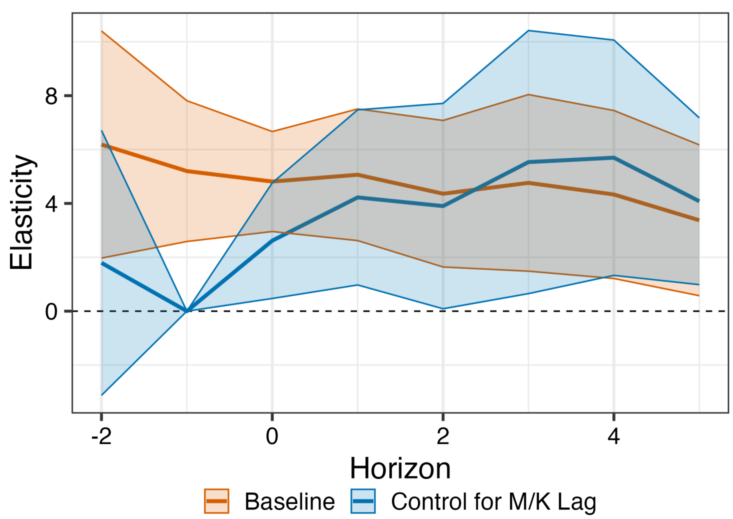
Note: This figure plots the point estimates and result for estimating (19). The blue lines contain no controls, while the orange lines control for local GDP exposure, firm-year trends, and the age of the capital stock. All standard errors are clustered by firm. The top estimate is for OLS only, while the bottom three all correspond to the instrument specified in (20), except that I use three lags of the shares rather than two. Analytic confidence intervals are from traditional Wald estimates, while the tF and AR confidence intervals result from inverting the tF (Lee et al. 2022) and Anderson and Rubin (1949) tests, respectively. The F-statistic reported in the legend is the effective F-statistic from Montiel-Olea and Pflueger (2013).

Figure D.6: Maintenance demand elasticity with 95% confidence interval (Controls for Lagged Maintenance)



Note: This figure plots the point estimates and result for estimating (19). The blue lines control for lagged maintenance, while the orange lines add controls for local GDP exposure, firm-year trends, and the age of the capital stock. All standard errors are clustered by firm. The top estimate is for OLS only, while the bottom three all correspond to the instrument specified in (20), except that I use three lags of the shares rather than two. Analytic confidence intervals are from traditional Wald estimates, while the tF and AR confidence intervals result from inverting the tF (Lee et al. 2022) and Anderson and Rubin (1949) tests, respectively. The F-statistic reported in the legend is the effective F-statistic from Montiel-Olea and Pflueger (2013).

Figure D.7: Local Projection of Relative Price Shocks on the Maintenance Rate (R-1)



Note: This figure plots the IV coefficients ω_h from the local projection

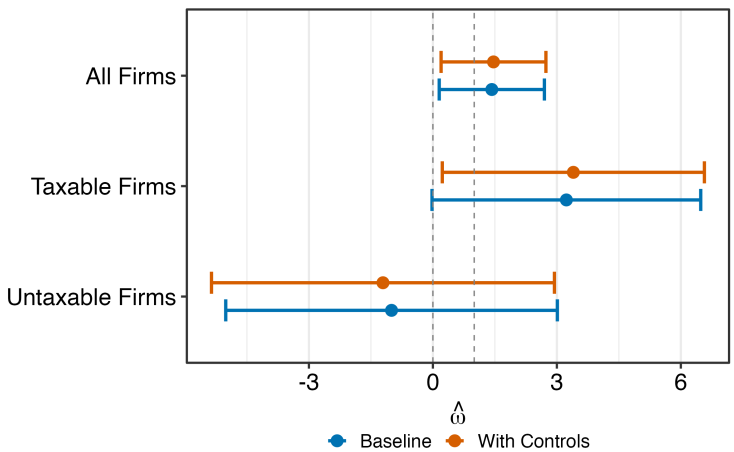
$$\log m_{i,j,t+h} = \alpha_{ij} + \lambda_t - \omega_h \log P_{i,j,t} + \text{Controls} + u_{i,j,t+h}.$$

The line in blue controls for the lagged maintenance rate, while the line in orange does not.

D.2 SOI Robustness Checks

SOI Sampling Changes. In 2013, the IRS changed the number of industries sampled in the SOI. Some industries became too small to report maintenance separately, potentially introducing measurement error. Figure D.8 shows results are unchanged when ending the sample in 2013 rather than 2019.

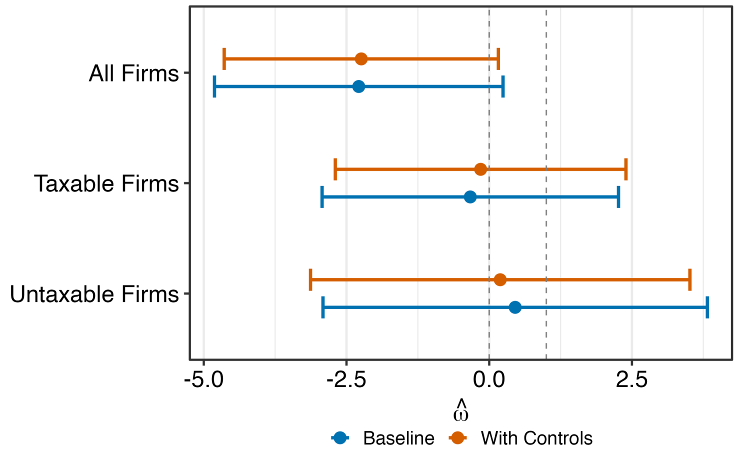
Figure D.8: Maintenance demand elasticity with 95% confidence interval



Note: This figure plots the point estimates and result for estimating (21), except it limits the data to pre-2014. All estimates have two-way fixed effects together with linear and quadratic trends in two-digit NAICS codes. Orange lines control for the age of the capital stock. All standard errors are clustered by industry. The top estimate is for the All Firm sample, while the bottom two groups of estimates split the SOI into a taxable and an untaxable sample.

Investment Weights (Placebo Test). Figure C.10 re-estimates equation (21) using investment-weighted $z_{i,t}$ rather than capital-weighted. The elasticity collapses to near zero and is statistically insignificant across all specifications. This confirms that maintenance responds to the user cost of the installed capital base, not recent investment flows.

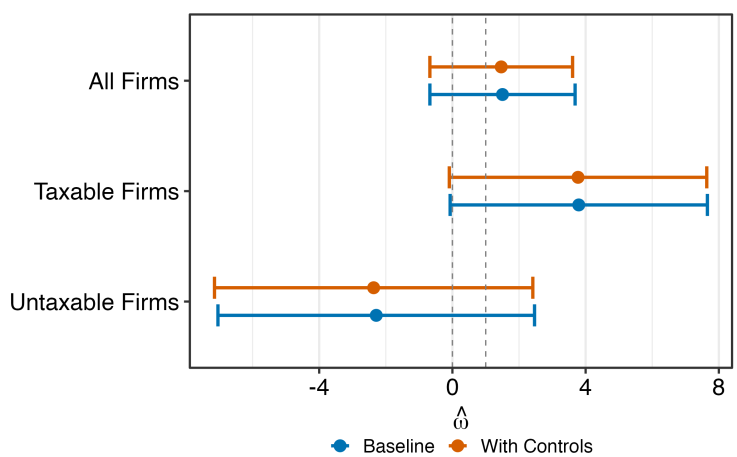
Figure D.9: Maintenance demand elasticity with 95% confidence interval



Note: This figure plots the point estimates and result for estimating (21), uses investment weights. All estimates have two-way fixed effects together with linear and quadratic trends in two-digit NAICS codes. Orange lines control for the age of the capital stock. All standard errors are clustered by industry. The top estimate is for the All Firm sample, while the bottom two groups of estimates split the SOI into a taxable and an untaxable sample.

BEA Capital Stocks. The baseline SOI analysis uses capital stocks constructed from tax depreciation reported in corporate returns. This may introduce measurement error if tax and economic depreciation diverge. Figure D.10 uses BEA capital stocks instead, which are constructed using economic depreciation rates and investment flows. Results are similar though less precise.

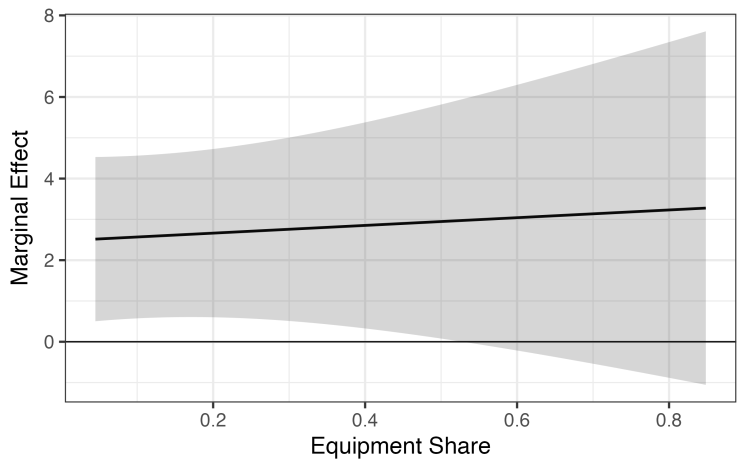
Figure D.10: Maintenance demand elasticity with 95% confidence interval



Note: This figure plots the point estimates and result for estimating (21), except it uses the BEA capital stock in the denominator. All estimates have two-way fixed effects together with linear and quadratic trends in two-digit NAICS codes. Orange lines control for the age of the capital stock. All standard errors are clustered by industry. The top estimate is for the All Firm sample, while the bottom two groups of estimates split the SOI into a taxable and an untaxable sample.

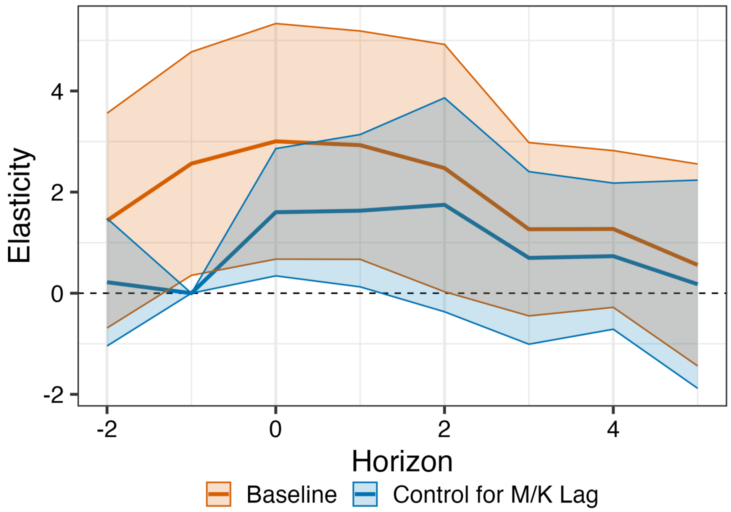
No Selection by Equipment Intensity. Koby and Wolf (2020) raise concerns that bonus depreciation identification may be confounded by selection: equipment-intensive industries may have inherently different elasticities than structures-intensive industries. If true, differential exposure to bonus would be correlated with pre-existing elasticity heterogeneity, biasing estimates. To test this, I add an interaction between the equipment-capital ratio and the wedge term to equation (21). If the elasticity varies by equipment intensity, the interaction should be significant. Figure D.11 shows the interaction is small and statistically insignificant, indicating the elasticity is homogeneous across industries. This rules out selection effects.

Figure D.11: Marginal Effect of Wedge on Maintenance Rate by Equipment Share



Note: Marginal (absolute-value) maintenance-wedge elasticity by equipment-capital ratio. The black line plots $\left|\partial \log m / \partial \log(\{wedge\})\right|$ against each industry's average equipment-capital ratio. Shaded bands are 95% confidence intervals.

Figure D.12: Local Projection of Relative Price Shocks on the Maintenance Rate (SOI)



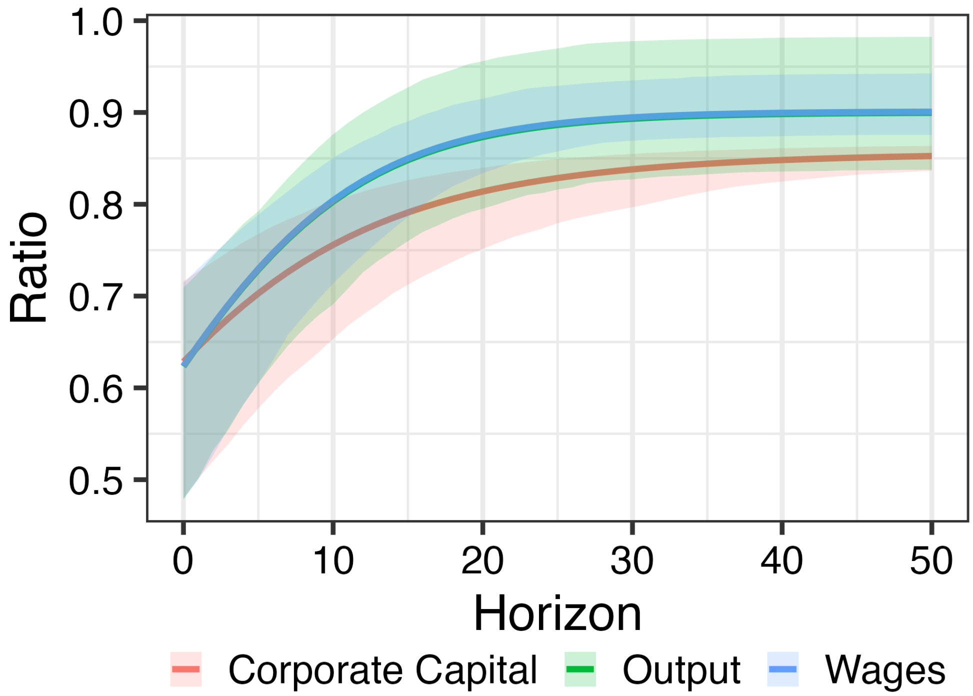
Note: This figure plots the coefficients ω_h from the regression

$$\log m_{i,t+h} = \alpha_i + \lambda_t - \omega_h \log\left(\frac{1-\tau_t^c}{1-\tau_t^c z_{i,t}}\right) + \text{Controls} + \eta_{i,t+h}.$$

The path in blue controls for the lagged maintenance rate. Both specifications control for industry trends and correspond to the SOI sample with all types of firms.

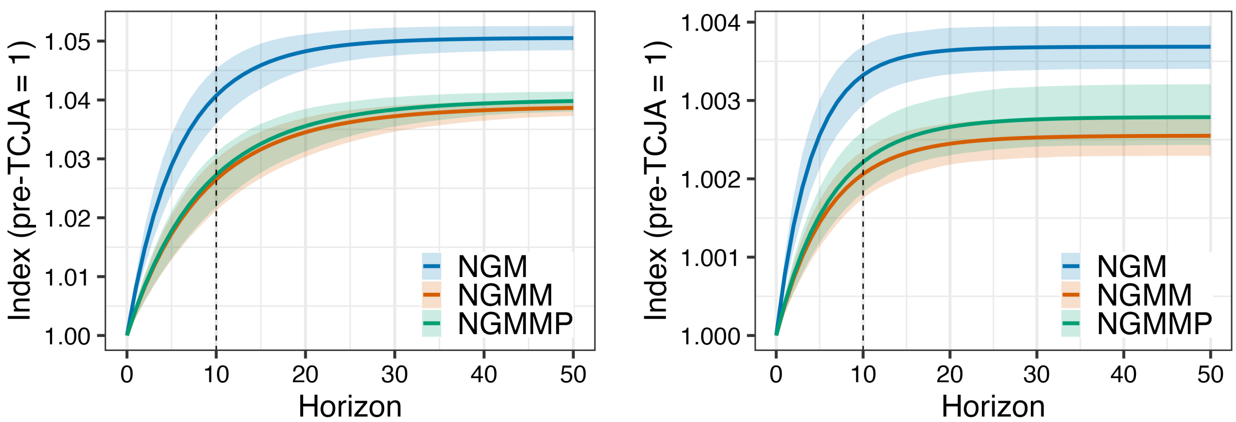
E Quantification

Figure E.1: NGMMP-NGM Ratio of Aggregates



Notes: The NGM corporate capital, output, and wages are exactly as in the main text. The NGMMP is an extension of the baseline NGMM which specifies that the price of maintenance rises with wages. I assume that wages are half the cost of maintenance.

Figure E.2: The Effect of TCJA on Corporate Capital and Aggregate Output with Crowding Out

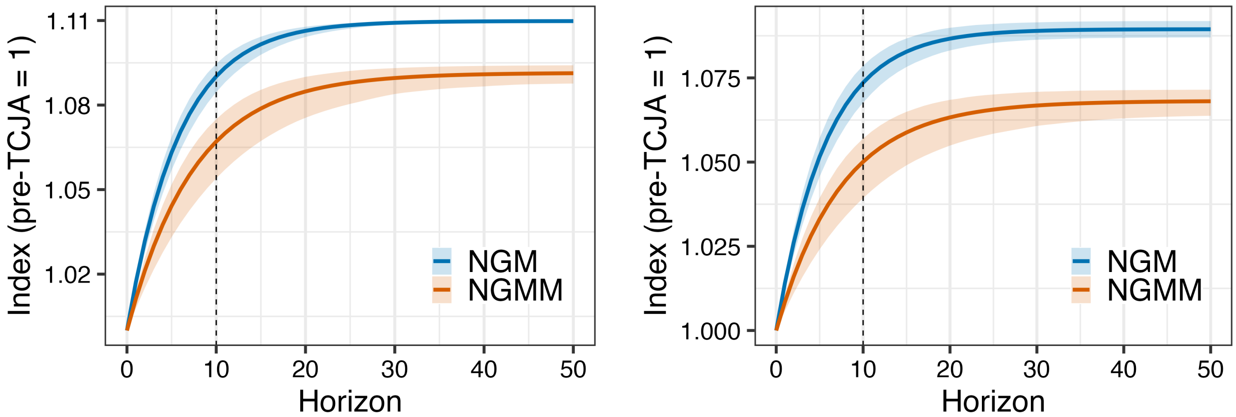


(a) Paths of Corporate Capital

(b) Paths of Output

Notes: Panel (a) shows the response of capital to the TCJA in the NGMM (orange line) and the NGM (blue line), and the NGMMP (green line), and Panel (b) plots the corresponding IRFs for aggregate output. To account for crowding out, we translate the 2027 debt-output ratio into an increase in discount rates using the static score of each model. The increase in debt-output corresponds to an increase in discount rates drawn from Neveu and Schafer (2024). A one percentage point increase in the debt-GDP ratio corresponds to a 2.2 percentage point increase in the discount rate (SE = 1.0). All lines are bootstrapped with a 95% confidence interval accounting for uncertainty in maintenance demand and crowding out.

Figure E.3: The Effect of TCJA on Corporate Capital in Partial Equilibrium



(a) Baseline

(b) Crowding Out

Notes: Panel (a) shows the response of corporate capital to the TCJA in the NGMM (orange line) and the NGM (blue line), and Panel (b) plots the corresponding IRFs with crowding out. To account for crowding out, we translate the 2027 debt-output ratio into an increase in discount rates using the static score of each model. The increase in debt-output corresponds to an increase in discount rates drawn from Neveu and Schafer (2024). A one percentage point increase in the debt-GDP ratio corresponds to a 2.2 percentage point increase in the discount rate (SE = 1.0). All lines are bootstrapped with a 95% confidence interval accounting for uncertainty in maintenance demand and crowding out.

F Model Extensions

F.1 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 must 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

$$K' = \Big[1 - \delta(m)\Big](1 - s)K + I. \tag{A.41}$$

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

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

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:

$$\begin{aligned} V^T(K) = \max_{m,s,K'} \Bigg\{ &(1 - \tau^c)\Big[F(K) - p^m\, mK + q\, s\, K - G(s)\Big] \\ &- \big(1 - c - \tau^c z\big)p^I\Big(K' - [1 - \delta(m)](1 - s)K\Big) + \frac{V^*(K')}{1 + r^k}\Bigg\}, \end{aligned} \tag{A.42}$$

where

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

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

$$\textbf{Investment:}\quad \frac{V^{*'}(K')}{1 + r^k} = \big(1 - c - \tau^c z\big)p^I, \tag{A.43}$$

$$\textbf{Maintenance:}\quad -\delta'(m) = \frac{1 - \tau^c}{1 - c - \tau^c z}\frac{p^m}{p^I\,(1 - s)}, \tag{A.44}$$

$$\textbf{Sales:}\quad (1 - \tau^c)\Big[q - G'(s)\Big] = \big(1 - c - \tau^c z\big)p^I\,[1 - \delta(m)]. \tag{A.45}$$

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

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

Given those cash flows, we get the following recursive formulation for a firm choosing K', s, M:

$$\begin{aligned} V^U(K) = \max_{m,s,K'} \Bigg\{ & F(K) - p^m\, mK + q\,s\,K - G(s) \\ & - (1-\tau^c\tilde{z})(p^I + b)\Big(K' - [1-\delta(m)](1-s)K\Big) + \frac{V^*(K')}{1+r^k} \Bigg\}. \end{aligned} \tag{A.46}$$

The type U FOCs are:

$$\textbf{Investment:} \quad \frac{V^{*'}(K')}{1+r^k} = (1-\tau^c\tilde{z})(p^I + b), \tag{A.47}$$

$$\textbf{Maintenance:} \quad -\delta'(m) = \frac{p^m}{(1-\tau^c\tilde{z})(p^I + b)(1-s)}, \tag{A.48}$$

$$\textbf{Sales:} \quad q - G'(s) = (1-\tau^c\tilde{z})(p^I + b)\,[1-\delta(m)]. \tag{A.49}$$

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

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

while for untaxed firms we have

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

The combined envelope condition is

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

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,

$$K' = \left[1 - \delta(m^{\theta})\right](1 - s)K + I,$$

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:

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

where $\mu(K)$ and $\nu(K)$ are the distributions of capital among taxable and untaxed firms.

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 untaxed firms to buy it, i.e.,

$$\frac{(1-c-\tau^c z)p^I\,[1-\delta(m^T)]}{1-\tau^c} < q < (1-\tau^c\tilde{z})(p^I+b)[1-\delta(m^U)].$$

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.

F.2 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 unnecessarily 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

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

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:

$$(1-\tau_t^c z_t)p_t^I = \frac{1}{1+r^k}\Bigg\{(1-\tau_{t+1}^c)\, F_K(K_{t+1}) + (1-\tau_{t+1}^c z_{t+1})\, p_{t+1}^I\Big[1-\delta\big(m_{I,t+1}, m_{E,t+1}\big) \\ + p_{t+1}^{M,I} m_{I,t+1} + p_{t+1}^{M,E} m_{E,t+1}\Big]\Bigg\}, \tag{A.50}$$

which in steady state simplifies to

$$F_K = p^I(1-\tau^c z)\left(\frac{r^k + \delta(m_I, m_E)}{1-\tau^c}\right) + p^{M,I} m_I + p^{M,E} m_E, \tag{A.51}$$

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

$$-\delta_1(t)\, g_L(t) = \frac{(1-\tau_t^c)w_t}{(1-\tau_t^c z_t)p_t^I}. \tag{A.52}$$

Similarly, optimal materials is given by

$$-\delta_1(t)\, g_M(t) = \frac{(1-\tau_t^c)p_t^X}{(1-\tau_t^c z_t)p_t^I}, \tag{A.53}$$

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

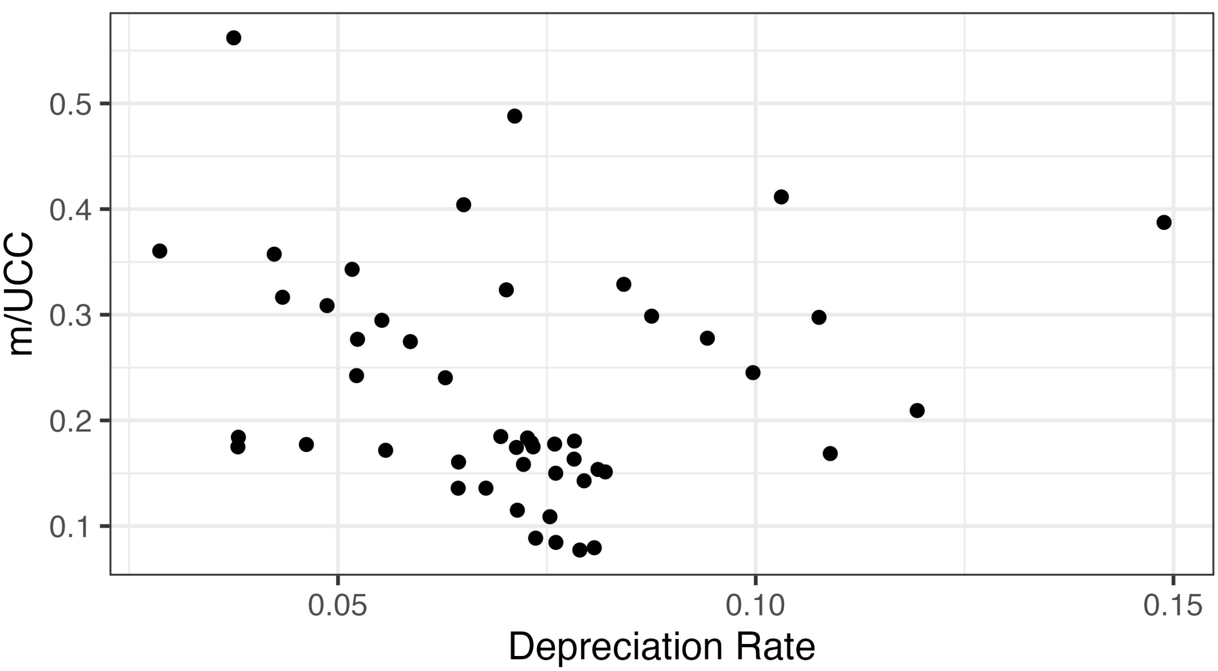
$$\frac{g_L(t)}{g_M(t)} = \frac{w_t}{p_t^X}. \tag{A.54}$$

On the other hand, external maintenance choice is given by

$$-\delta_2(t) = \frac{(1-\tau_t^c)\Big[1 + C_1(t)\Big] + \frac{1}{1+r^k}(1-\tau_{t+1}^c)\, C_2(t+1)}{(1-\tau_t^c z_t)p_t^I}. \tag{A.55}$$

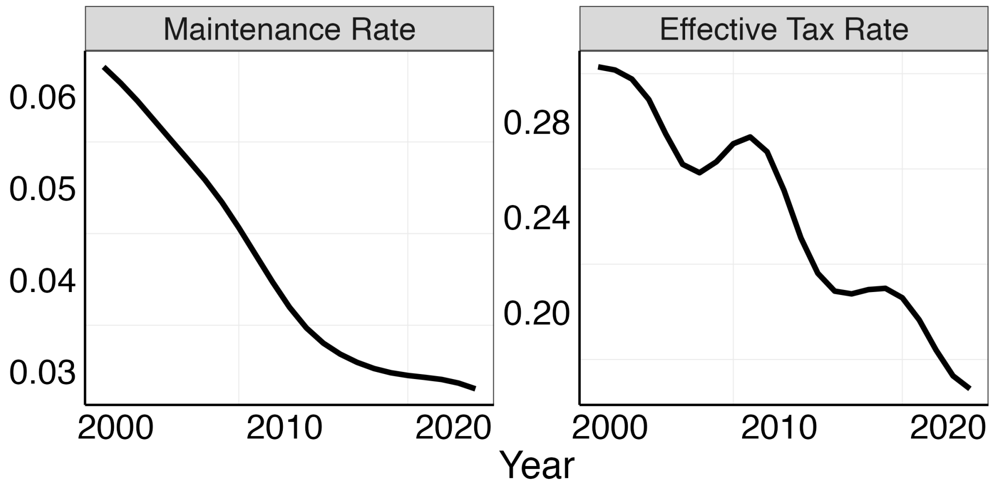
G Additional Figures and Tables

Figure G.1: The industry maintenance share of user cost is decreasing in the depreciation rate



Note: Each point is the time series average of maintenance shares and depreciation rates within an industry.

Figure G.2: 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.