Tax Policy and Maintenance Behavior

Jackson Mejia*

January 6, 2025

The user cost of capital mediates the transmission of business taxes to capital accumulation, wages, and output. This paper highlights an overlooked component of user cost—capital maintenance—that fundamentally alters the transmission of tax policy in two ways. First, tax-deductibility of maintenance attenuates the tax elasticities of aggregate outcomes. The magnitude of this mechanical tax shield effect is determined by the maintenance share of user cost. Second, if maintenance demand is elastic, then tax cuts induce firms to substitute investment for maintenance. However, the substitution effect also implies that the tax elasticity of investment is strictly larger than the tax elasticity of capital, so standard estimates of the tax elasticity of investment are uninformative about aggregate policy objectives without knowing maintenance demand. Drawing on corporate tax returns and unique microdata from Class I freight railroads, I estimate a price elasticity of maintenance demand of approximately two, with maintenance expenditures rivaling gross investment in magnitude. Using these estimates, I find that the 2017 Tax Cuts and Jobs Act increased corporate capital by 2% after ten years—just 40% of the benchmark neoclassical prediction.

*Massachusetts Institute of Technology, jpmejia@mit.edu. I am especially grateful to Jim Poterba for invaluable guidance. Additionally, Daron Acemoglu, Martin Beraja, Ricardo Caballero, Tomás Caravello, Janice Eberly, Sam Jordan-Wood, Pedro Martinez-Bruera, Ellen McGrattan, Chelsea Mitchell, Giuditta Perinelli, Iván Werning, Christian Wolf and participants in numerous seminars provided helpful comments and discussions. This material is based upon work supported by the NSF under Grant No. 1122374 and is also supported by the George and Obie Shultz Fund.

1 Introduction

Governments frequently pursue business tax reform with dual objectives: stimulating short-run economic activity and fostering long-run growth (Romer and Romer 2010). For example, President Kennedy introduced accelerated tax depreciation and an investment tax credit to "stimulate the investment needed for sustained expansion and longer-run growth," a motivation echoed by the architects of the 2017 Tax Cuts and Jobs Act (CEA 2018). These reforms are grounded in workhorse models of investment, where tax cuts reduce the user cost of capital, thereby stimulating investment which in turn leads to capital deepening and output growth. Despite six decades of declining business tax burdens and extensive empirical evidence indicating strong investment responses to tax cuts (Hassett and Hubbard 2002; Zwick and Mahon 2017), the evidence for corresponding effects on growth remains mixed.[1] This is difficult to reconcile with benchmark tax policy models, which typically imply that the tax elasticity of investment is equal to the capital elasticity and proportional to the output elasticity.

This paper presents a theoretical framework, empirical evidence, and quantitative analysis to demonstrate that a little-noticed distortion in the tax code significantly dampens the effects of tax reforms despite robust investment responses to tax policy. Capital maintenance, which consists of expenditures and activities meant to extend the life of existing capital, is fully tax-deductible, but standard models assume maintenance demand is inelastically zero. By contrast, the return on new capital is not. Building on McGrattan and Schmitz Jr. (1999), which first explicitly modeled the maintenance-investment distortion in a neoclassical model, I show that as long as the demand for maintenance is positive, the distortion's existence has three important theoretical implications for the user cost of capital, which is at the heart of many tax policy models.[2]

First, I show that the distortion creates a *tax shield effect*. Suppose we relax the standard assumption on maintenance demand so that it is inelastic but positive. In practical terms, this means that a firm purchasing a car expects to spend some fraction of the vehicle's value on oil changes, repairs, tire rotations, and so on. Hence, in the same way that depreciation is a cost of capital, so too is maintenance. However, since the return on new capital is taxed net of maintenance, capital is more tax-inelastic than if mainte-

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

2. 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 capital maintenance.

nance demand were inelastically zero. In the limiting case with no depreciation and no discounting, tax policy would be irrelevant for capital accumulation because the only cost would be tax-exempt maintenance. I show that this leads to a tax shield effect in which the the tax elasticity of user cost—and hence of capital and output—is given a haircut by the share of maintenance relative to the rest of user cost. The result implies that, all else equal, longer-lived capital is therefore more tax-inelastic than short-lived capital. This result adds nuance to House (2014) and Winberry (2021), who show that long-lived capital should be considerably more price-elastic than short-lived capital.

The second implication is not new to this paper. Suppose the demand for maintenance is elastic and positive. In that case, the demand for maintenance is determined by how expensive it is relative to investing in new capital. Policy creates a tax wedge in the decision to maintain or invest at the margin, which induces firms to overmaintain capital relative to a tax code with no wedge. Since maintenance is inextricable from depreciation, tax cuts result in higher depreciation as maintenance declines, which in turn results in a lower average age of capital because it is renewed at a higher rate. Although there are considerable differences in model details, Feldstein and Rothschild (1974), Cooley, Greenwood, and Yorukoglu (1997), and McGrattan and Schmitz Jr. (1999) emphasize this *input substitution effect*.[3] I show that, although the input substitution effect is first-order for maintenance and investment, it is second-order for capital accumulation and output. That follows because the maintenance rate and the depreciation rates are both components of the cost of capital and because tax cuts induce them to move against each other, the resulting effect is largely offsetting and therefore second-order.[4]

Even though the substitution effect is second-order for output, it has first-order implications for investment. Traditionally, economists assess the consequences of tax reforms by relating the change in investment to a model-based measure of the cost of capital like user cost or q-theory (Summers 1981). In a typical example, an economist uses cross-sectional variation in exposure to tax changes to identify the user cost elasticity of invest-

3. Feldstein and Rothschild (1974) and Cooley, Greenwood, and Yorukoglu (1997) are both models of vintage capital, but the former is in partial equilibrium and the latter is in general equilibrium. McGrattan and Schmitz Jr. (1999) employ a homogeneous capital neoclassical model with endogenous depreciation mediated by maintenance. My model is the same as that paper's, but I go beyond it to discuss the tax shield effect and the implications for empirical tax analysis.

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

ment (Goolsbee 1998a; Zwick and Mahon 2017; Kennedy et al. 2023; Chodorow-Reich et al. 2023). Since accounting for maintenance reduces the tax elasticity of user cost, it therefore follows that standard measures of the investment elasticity are biased downward because they ignore maintenance.[5] Hence, empirical estimates of the tax elasticity of investment are underestimated, while the tax elasticities of capital and output are overestimated. Under the assumption that maintenance demand is constant elasticity, I show that there is a convenient closed form for the degree of underestimation which enables us to recover how close the correspondence is between investment and capital elasticities.

The theoretical and quantitative importance of maintenance depends on its demand function, but there is little evidence on maintenance demand functions at all, let alone for the United States.[6] Some studies of maintenance rely on data from India (Kabir, Tan, and Vardishvili 2024; Kabir and Tan 2024) or Canada (Albonico, Kalyvitis, and Pappa 2014; Angelopoulou and Kalyvitis 2012), but none, to my knowledge, estimate a maintenance demand function. However, there is some indirect evidence. We know from Goolsbee (1998b) that airlines retire their airplanes more quickly when tax policy makes it favorable to buy new ones, supporting the Feldstein and Rothschild (1974) hypothesis. Similarly, Goolsbee (2004) shows that firms buy capital with lower maintenance requirements following tax cuts, where quality is proxied with the price, which is in line with the tax shield effect emphasized in this paper.[7] Moreover, casual evidence from firms (Pfeifer 2023) and households (Pinsker 2024) suggest that agents do adjust their maintenance behavior when the price of maintenance changes. But we lack direct evidence on maintenance because, like intangible expenditures, maintenance is often a hidden expenditure that goes under broader categories like costs of goods sold. Toward shedding light on maintenance demand in the United States, I bring together two datasets.

The first dataset is a representative sample of corporate tax returns from the Internal Revenue Service's Statistics of Income Division from 1998-2019. I leverage industry-level variation in exposure to exogenous tax policy changes as an instrument to identify the coefficient in a regression of the log maintenance rate on the tax term. Since the decision to maintain old capital or invest in new capital is determined at the margin by the

5. I do not address q-theory regressions because most of the modern public finance literature focuses on the user cost specification. Motahar (1992) shows that q-theory regressions are no longer theoretically justifiable if there are multiple inputs to capital production. That result applies here because maintenance is a second input into capital production.

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

7. Asset prices rise when maintenance costs are higher. Lower quality capital goods, which require more maintenance because they are less durable, are therefore cheaper.

relative price and the tax term determines that relative price, this regression yields the elasticity of demand for maintenance, which I estimate is statistically significant between two and four. The strategy, which has its roots in the investment literature (Garrett, Ohrn, and Suárez Serrato 2020; Zwick and Mahon 2017) relies on the fact that industries vary in their capital composition and because capital is differentially taxed, industries are differentially exposed to tax policy. I validate the approach with a placebo test, analyzing a subsample of non-taxable firms that, by definition, should not adjust their maintenance rates in response to tax term changes. Consistent with theory, such firms do not adjust maintenance in response to tax reform.

Second, I construct a novel dataset on the maintenance and investment activities of Class I freight railroads using their R-1 financial filings. Large railroads are required to file heavily audited financial statements with the Surface Transportation Board. I digitize and put together a panel of maintenance, investment, capital, and relative prices from 1999-2023 using those filings, which are akin to 10-Ks filed with the SEC by corporations, but they are more detailed and hence provide a unique window into the firm.[8] For example, I observe maintenance broken down by capital type and the extent of maintenance done internally versus purchased externally and the cost shares of both labor and materials for internal maintenance. Using that information, I construct an after-tax relative price of maintenance to investment specific to every firm and capital type. I leverage variation in cost shares of maintenance inputs across capital types and firms to get variation in exposure to aggregate materials and labor prices. With that Bartik-style instrument, I show that the elasticity of demand for maintenance is statistically significant between two and three and therefore corresponds closely to the tax return estimate. The approach stands up to scrutiny from a number of robustness checks, including a unique measure of a *physical* maintenance rate.

Each dataset has its own advantages and disadvantages, but together they tell a unified story. In both the SOI and the R-1 data, maintenance is about as large as gross investment in physical capital. Moreover, both yield a demand elasticity around two. Together, these observations roundly contradict the null hypothesis of inelastically zero maintenance demand in workhorse models. This accords with analyses of housing maintenance, which consistently show that households spend significant resources maintaining houses, which has important implications for asset prices (Knight and Sirmans 1996; Harding, Rosenthal, and Sirmans 2007; Hernandez and Trupkin 2021).[9]

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

9. 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

I wrap up by quantifying the relevance of elastically positive capital maintenance demand in the context of the 2017 Tax Cuts and Jobs Act (TCJA).[10] The objective is not only to quantify TCJA, but to understand the relative importance of building in maintenance to quantitative tax policy models. Depending on the question, researchers may choose to alter the benchmark Hall and Jorgenson (1967) model with a variety of complications such as explicit demographics (PWBM 2019), heterogeneous capital (Barro and Furman 2018), heterogeneous firms (Sedlacek and Sterk 2019; Zeida 2022), lumpy adjustment (Winberry 2021), or global tax considerations (Chodorow-Reich et al. 2023). At the heart of every tax model, however, is capital accumulation, and the essential question is the extent to which explicitly modeling capital maintenance adds value quantitatively.

My starting point is the domestic block of the workhorse neoclassical growth model (NGM) from Chodorow-Reich et al. (2023), which is the seminal assessment of the general equilibrium effects of TCJA. I build in a maintenance demand function using a conservative estimate from the Statistics of Income. This model, which I call the NGMM, features a tax elasticity of capital which limits to the NGM as maintenance demand goes to zero. In partial equilibrium, domestic corporate capital rises by about 11% in the NGM and by 6.8% in the NGMM. The NGM estimate compares favorably with similar partial equilibrium estimates in Chodorow-Reich et al. (2023) and Barro and Furman (2018). To get general equilibrium estimates, I assume that labor supply is perfectly inelastic—consistent with balanced growth preferences—and there is a non-corporate sector which does not face a tax change. Rationing labor across sectors moderates the increase in capital, leading corporate capital to rise in the NGM by 6.6%, consistent with leading general equilibrium estimates (Chodorow-Reich et al. 2023; Sedlacek and Sterk 2019; Zeida 2022)., and in the NGMM by 3.9%. Thus, the tax elasticity of capital is sixty percent as large in the NGMM as the NGM.

There are two useful ways to contextualize the finding. First, the neoclassical model with Cobb-Douglas production predicts a tax elasticity of capital given by $-1/(1-\alpha)$, where α is the profit elasticity. The NGMM tax elasticity of capital is therefore equivalent to an NGM with a profit elasticity α reduced from a standard value of 0.67 to 0.45, or cutting the profit elasticity by one third. Second, the *general equilibrium* tax elasticity of capital in the NGM is equivalent to the *partial equilibrium* tax elasticity of capital in

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.

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

the NGMM. Therefore, if reducing the capital share by one third or accounting for general equilibrium effects is considered critical in tax policy analysis, then accounting for maintenance should be regarded as equally important.

Finally, I map the general equilibrium path of domestic corporate capital following passage of TCJA. Following Chodorow-Reich et al. (2023), I calibrate capital adjustment costs by relying on a short-run estimate of the tax elasticity of investment. My maintenance demand function suggests that the tax elasticity of investment from user cost regressions should be increased by a factor of 1.5. This implies that, for example, the Hassett and Hubbard (2002) consensus range of 0.5-1.0 should be increased to 0.75-1.5. Adjusting up the Chodorow-Reich et al. (2023) estimate of the tax elasticity by that factor results in an increase in the domestic corporate capital of 2% after ten years, which is 40% as much as the NGM predicts.

Roadmap. In Section 2, I develop a theoretical framework to analyze capital maintenance. Sections 3 and 4 introduce data for and estimate maintenance functions. In Section 5, I show why accounting for maintenance matters for tax policy analysis in the context of the 2017 Tax Cuts and Jobs Act. Section 6 concludes.

2 A Simple Model of Capital Maintenance

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

2.1 The Benchmark Neoclassical Model

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

$$d_t = (1 - \tau_t^c)\,(F(K_t, L_t) - w_t L_t) - (1 - c_t - z_t \tau_t^c)\, p_t^x X_t. \tag{1}$$

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

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

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

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

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

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

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

Tax cuts increase the after-tax return on capital, which spurs new investment, increases capital, and in general equilibrium raises output and wages to a degree determined by complementarity between capital and labor. Although one can add a number of complications like convex adjustment costs (Summers 1981), lumpy adjustment (Winberry 2021), demographics (Altig et al. 2001), or firm dynamics Zeida (2022), the core of the transmission mechanism remains the same.

As a simple example, suppose output is given by $Y = K^\alpha$. Changes in user cost propagate through to capital and output via

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

Since investment is the only input to capital, the tax elasticity of capital is equal to the tax elasticity of investment, so the latter is a sufficient statistic for the macroeconomic effects of tax policy. The elasticity equivalence motivates a large empirical literature analyzing the effects of tax policy reforms on investment; if we know how much investment changed, that is a sufficient statistic for the effects on capital, output, and wages.

2.2 Introducing Maintenance to the NGM

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

$$d_t = (1-\tau_t^c)\left(F(K_t, L_t) - w_t L_t - p_t^m M_t\right) - (1 - c_t - \tau_t^c z_t)\, p_t^x X_t.$$

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

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

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

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

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

As long as $-\delta'(m) > 0$, the decision to maintain is economic rather than technical. Corporate and investment tax reforms therefore result in changes in the demand for maintenance and hence the depreciation rate of existing capital.[11] Moreover, the extent to

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

which tax reforms induce firms to substitute maintenance for investment depends on the concavity of the depreciation technology. If maintenance enters linearly in (5) and, as is a standard assumption, investment does too, then they are perfect substitutes. Intuitively, if there is more curvature in $\delta(m_t)$, then maintenance does not have to work hard to change the depreciation rate, which in turn means that the firm would not alter its demand for maintenance very much following a change in the incentive to maintain capital. That conclusion establishes that there is an inverse relationship between the elasticity of demand for maintenance and the maintenance elasticity of depreciation. Inverting $-\delta'(m)$ yields the demand for the maintenance rate.

Incorporating maintenance leads to an additional element in the user cost of capital, namely that an additional unit of capital must be maintained at price p^m. In steady state, with a concave production function $F(K)$, firms invest until the marginal product of capital equals the user cost Ψ:

$$F_K = \Psi = \frac{p^x(1 - c - \tau^c z)}{1 - \tau^c}\left(r^k + \delta(m)\right) + p^m m, \tag{7}$$

where r^k is the discount rate and m is the optimally chosen maintenance rate given the relative price. (7) is a generalization of (2).

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

$$\boxed{\frac{\Delta\Psi}{\Psi} = \frac{1}{\Psi}\left[\frac{1}{1-\tau'}\left(\frac{\Delta\tau\left(r^k + \delta(m)\right)}{1-\tau} + \Delta\delta(m)\right) + \Delta m\right].} \tag{8}$$

Proposition 1. *In the maintenance model, the sensitivity of the user cost of capital to a tax change is strictly smaller than in the benchmark Hall–Jorgenson model.*

The proportional change in (8) is strictly smaller than (3) because a share of the user cost is insulated from tax policy in the maintenance model. The reduced sensitivity of user cost has direct implications for capital and output.

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

This corollary follows directly from combining Proposition 1 and (4). Consequently, the tax elasticities of user cost, capital, and output are correspondingly smaller with main-

fact that p^x has declined.

tenance. However, the transmission of tax policy is different from the standard model in two ways: a tax shield effect and a substitution effect.[12]

Tax Shield Effect

The tax shield effect follows from the fact that maintenance is tax-deductible irrespective of whether depreciation has any curvature. To isolate the tax shield effect, suppose maintenance demand is perfectly inelastic but positive. In this case, $\Delta\delta(m) = \Delta m = 0$, so the proportional change in user cost is

$$\frac{\Delta\Psi}{\Psi} = \frac{\Delta\tau}{1-\tau'}\left(1 - \frac{(1-\tau)m}{r^k + \delta + (1-\tau)m}\right).$$

Thus, the benchmark change in user cost is marked down by the maintenance share of pre-tax user cost. If the (inelastic) maintenance rate is large relative to the rest of user cost, then the proportional change in user cost is smaller. Even without endogenous maintenance, tax deductions reduce taxable income, creating a "shield" that lowers overall tax liabilities. This is, as far as I know, is a novel argument that introduces some nuance to an interesting point made by House (2014) about the price elasticity of long-lived capital. House observes that because long-lived capital has a low depreciation rate, it is more price-elastic than short-lived capital. However, positive demand for maintenance implies that short-lived capital is *less* price-elastic because maintenance becomes a larger share of user cost. This channel would not exist if there were not a maintenance-investment tax distortion. In the limiting case where maintenance dominates the user cost expression, capital—and hence output—does not change at all in response to tax reform. Therefore, positive but inelastic demand for maintenance is sufficient to substantially attenuate the effectiveness of tax policy.

The magnitude of the maintenance rate, which is captured by the tax shield effect, also matters for selecting between lumpy models of investment because they typically rely on a maintenance parameter to keep the drift rate of the capital stock down. The larger this parameter is, the more closely lumpy models resemble smooth models of investment like the neoclassical one. In both Bachmann, Caballero, and Engel (2013) and McKay and Wieland (2021), the calibrated level of required maintenance is around 30% of the investment rate. If the tax shield effect is larger, then the Khan and Thomas (2008) view

12. Note that this model implicitly assumes that firms take both maintenance and investment prices as given, *i.e.*, that p^m and p^x do not respond to policy. Although Goolsbee (1998a) shows that investment good prices respond to tax changes, House and Shapiro (2008), House, Mocanu, and Shapiro (2017), and Basu, Kim, and Singh (2021) show that investment good prices did not respond to tax policy changes during the 2000s. They attribute this largely to increased foreign competition in the supply of investment goods.

that aggregate investment can be modeled as smooth is borne out. That matters because it means that policy interventions like capital tax cuts are more effective at stimulating new investment and less constrained by investment timing. However, the macroeconomic implications are different because the larger the tax shield effect is, the less it matters for capital accumulation despite the more elastic investment response.

Input Substitution Effect

The second way maintenance alters user cost is through the change in demand for maintenance induced by the tax reform, which feeds through into an opposing change in depreciation. This substitution effect, through which the composition of capital production is changed by investment substituting for maintenance, is second-order. To see why, note that the total derivative of user cost with respect to τ is

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

But by the first-order condition at the optimum $m^*(\tau)$, we have

$$\frac{\partial \Psi}{\partial m}\big(\tau, m^*(\tau)\big) \;=\; 0.$$

Therefore, the input substitution effect, which is emphasized by McGrattan and Schmitz Jr. (1999), is second-order. Consequently, it is also second-order for the transmission of user cost into macroeconomic variables like capital, output, and wages. By definition, the substitution effect is not second-order for the composition of capital inputs and depends directly on the convexity of $\delta(m)$ captured by the maintenance demand elasticity.

There are two different ways to interpret the change in the composition of capital. The first is through the investment rate, which dictates how quickly capital is renewed. It is intuitive that younger capital requires less maintenance because it is new. If tax cuts spur new investment, then the aggregate maintenance rate may decline because capital is younger in the aggregate. In the long run, the investment rate corresponds to

$$\frac{X}{K} = \delta(m),$$

which means that tax cuts permanently increase the investment rate and hence the age distribution of capital permanently changes.[13] That is not possible in standard models.

13. Firms typically have an additional scrappage margin for adjustment, which we know is empirically

The second interpretation for why the input substitution effect matters is through the elasticity of the *level* of investment. Because in standard models, the tax elasticities of investment and capital are the same and capital maps directly into output, the partial equilibrium tax elasticity of investment is a sufficient statistic for the policy goals of tax reformers. That is not true when the demand for maintenance is positive. Since the steady state relationship between investment and capital is given by $X = \delta(m)K$, the tax elasticity of investment is approximately

$$\varepsilon_X \approx \varepsilon_\delta + \varepsilon_K. \tag{9}$$

where ε_δ is the tax elasticity of depreciation and ε_K is the tax elasticity of capital. In the edge case in which the input substitution effect is zero, $\varepsilon_\delta = 0$, and we return to the standard model in which the elasticities of capital and investment are identical. However, even in that case, standard approaches to recovering the tax elasticity of investment are flawed. A typical approach runs a cross-sectional regression like

$$f\left(X_{i,t}, K_{i,t}\right) = \alpha_i + T_t + \hat{\beta} \log\left(\frac{r^k + \delta}{1 - \tau_{i,t}}\right) + \epsilon_{i,t}, \tag{10}$$

where $f\left(X_{i,t}, K_{i,t}\right)$ is typically the investment rate $X_{i,t}/K_{i,t}$ or $\log X_{i,t}$, α_i is a firm fixed effect, and T_t is a time fixed effect. The estimated coefficient $\hat{\beta}$ yields the price elasticity of investment. For example, Kitchen and Knittel (2011), Zwick and Mahon (2017), and Garrett, Ohrn, and Suárez Serrato (2020) use such regressions to evaluate bonus depreciation, while Kennedy et al. (2023) and Chodorow-Reich et al. (2023) do the same for the the 2017 Tax Cuts and Jobs Act. The maintenance model suggests that (10) is misspecified. Instead, economists should estimate

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

Misspecification arises because the demand for investment depends on the demand for maintenance and hence standard regressions do not properly capture the true change in

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

the incentive to build new capital. This introduces an omitted variable bias in standard regressions which biases downward estimated investment elasticities.[14]

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

$$\beta = \frac{\hat{\beta}}{1 - \frac{\gamma}{r^k + \delta_0 + \frac{\gamma}{1-\omega}}}, \tag{12}$$

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

Proof: Appendix A.5.

Therefore, we cannot use the standard tools of public finance to assess the effects of tax reforms unless we also know the maintenance demand function.

3 Data

The central challenge of empirical maintenance analysis is a paucity of data in the United States. For example, the Bureau of Economic Analysis does not publish estimates of capital maintenance at the aggregate level and neither does Compustat at the firm level. The empirical analysis in this paper expands on the existing empirical investment literature with two new data sources. First, I rely on corporate tax data at the industry level from the Statistics of Income (SOI) published by the Internal Revenue Service. While these data are not new and have been used to analyze investment (*e.g.*, Zwick and Mahon (2017)), it is the first time the SOI has been used to analyze maintenance. Second, I construct a novel dataset on the maintenance behavior of Class I freight railroads. The remainder of this section details the construction of each dataset.

3.1 Corporate Tax Returns

First, I rely on a stratified industry-level sample of unaudited corporate tax returns produced by the Statistics of Income Division (SOI) of the IRS. Economists have used the underlying microdata to estimate tax elasticities of investment (Zwick and Mahon 2017;

14. The insight is analogous to the lesson of Goolsbee (1998a), which emphasizes that an underlying model of a perfectly competitive capital goods market leads to an underestimate of the investment demand elasticity if the supply of equipment is not perfectly competitive. In the same way that regressing investment on a tax term alone assumes perfect competition in the supply of investment goods, so too does omitting maintenance imply a particular model of capital production.

Kennedy et al. 2023). I do not have access to the administrative data and so I rely on the industry-level sample, which I aggregate to fifty industries at the the approximately three-digit NAICS level.[15]

Corporations report a large number of operating expenses and balance sheet items as line items on their tax forms to the IRS. The SOI samples across those tax returns to provide summary measures of each line item at a roughly three-digit NAICS level. This is the only economy-wide collection of maintenance data at an annual frequency in the United States. I take maintenance, investment, and book capital stock data from the SOI corporate reports from 1999-2019 using Table 12 and Table 13. This excludes filings made with Forms 1120S, 1120-REIT, and 1120-RIC. Table 12 has all corporate filings, while Table 13 summarizes firms with positive net income. I refer to the positive net income sample as "taxable" because most such firms are taxed. After 2013, the SOI changed the industry aggregation scheme, resulting in those tables being renamed Table 5.3 and Table 5.4. Using both tables together, I obtain corresponding data for a sample of firms which are not taxable. This is important because theory says that the tax wedge should only matter for taxable firms.

While the numerical magnitudes and properties of investment are well-known, we know considerably less about maintenance. The investment rate gives a notion of how intensely firms replace their capital, while maintenance rates tell us, similarly, how intensely firms maintain their existing capital. The average maintenance rate is around 5% across both taxed and untaxed firms.

However, the maintenance rate is biased downward by a peculiar feature of the IRS data. Maintenance expenditures are composed of three parts: external maintenance, materials expenditures for internal maintenance, and labor expenditures for internal maintenance. Any expenditures on internal labor are allocated to the line item for the wage bill to avoid double counting, which results in downward-biased maintenance rates. Both internal freight rail maintenance, which I discuss in the following subsection, and the Maintenance & Repair Sector (NAICS 811, Figure D.2) have labor cost shares around 30%. Using that figure to adjust the maintenance rate implies a rate closer to 7%, which is slightly larger than the corporate net investment rate and close to the gross investment rate in physical capital.

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

The tax wedge forms a key component of the relative price of maintenance to investment. Through variation in industry production technologies, we observe variation in tax wedges. Some industries use more structures, while others use more equipment. The end result, due to differential capital taxation, is that marginal tax rates vary widely by industry. For any capital type j, the marginal tax rate is

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

Under the permanent component of current law, investment in a locomotive is depreciated over five years, meaning that it is expensed in pre-determined parts over that time frame. By contrast, nonresidential structures are expensed over several decades. The difference in the timing of tax deductuctions yields differences in tax rates due to discounting. Such differences are determined by an asset's categorization in the IRS's Modified Accelerated Cost Recovery System (MACRS). Given a mapping from House and Shapiro (2008) of BEA assets to MACRS and capital weights for each industry from the BEA, I construct a panel of marginal tax rates by industry. I discuss this in greater detail in the context of identification in Section 4.1 and in Appendix B.2. Summary statistics for this variable and others are in Appendix B.2.

The SOI data offers a number of advantages and disadvantages. First, and most importantly, it is a nationally representative sample of maintenance behavior across several dozen industries. Second, the data allow for a simple identification strategy grounded in the investment literature, which I discuss in more detail below. However, the SOI presents several issues. First, the SOI is a repeated cross-section. This is problematic because the maintenance decision is dynamic and the IRS is not sampling the same firms over time. Second, SOI maintenance expenditures subtract labor. In static regressions, this is not a problem because maintenance labor costs are largely predetermined, but the key parameter in the model is γ, which depends critically on the baseline maintenance rate. Without labor included, that parameter is difficult to estimate without some additional assumptions on internal labor maintenance costs. Third, the line between maintenance and investment is blurry and the sample of firms is not audited by the IRS. For example, if I purchased a new engine for a car, that would be considered investment, but merely keeping the old one in working order would be considered maintenance, and firms may manipulate that blurriness to avoid paying taxes. Finally, it is practically impossible to granularly identify a pre-tax relative price of maintenance to investment by industry, and so I rely on a single component of that for prices: the tax wedge.

3.2 Freight Rail

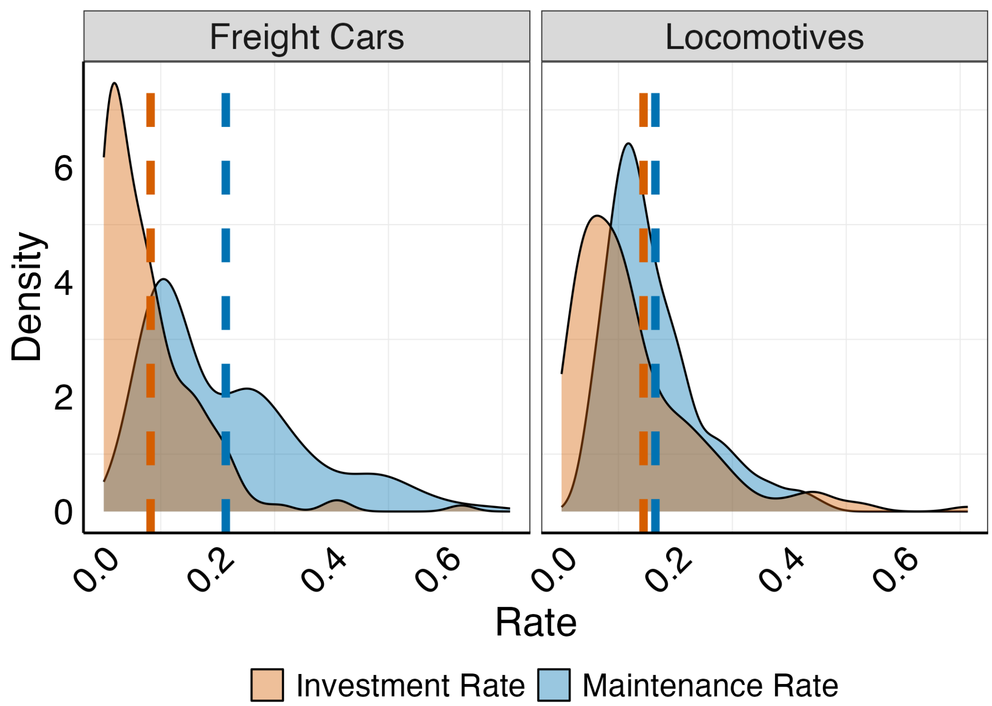
As a check on the industry results, I construct a novel and considerably more granular dataset of maintenance in the freight rail industry. Class I freight railroads—defined as having revenue greater than $500m—carry about 40% of all freight in the United States, with the rest largely taken by trucks. Although the industry used to be highly fragmented, it has consolidated considerably since deregulation in the early 1980s and has been in a stable competitive equilibrium of around seven large firms since the late 1990s, which is when my data begin. Seven companies carry most of the freight traffic: CSX Industries, Burlington Northern & Santa Fe, Union Pacific, Norfolk Southern, Kansas City Southern, Soo Line, and Grand Trunk, which is operated by the Canadian National Railway. The railroads are geographically dispersed but have one or two large local competitors along with smaller Class II and Class III competitors. Burlington Northern and Union Pacific dominate the western United States, CSX and Norfolk Southern the eastern seaboard, while the Soo, Kansas City Southern, and Grand Trunk operate more in the midwest. All of these railroads own their tracks and equipment and have faced relatively little financial trouble over the past 25 years. Railroads extensively maintain their own capital with either internal unionized labor or with externally purchased maintenance services.

By regulation, any freight railroad with sufficiently high revenue must file an annual R-1 report with the Surface Transportation Board (STB). The R-1 report can be thought of as a much more granular version of a 10-K filed by a publicly traded corporation. All reports are independently audited by firms like KPMG and PwC and then once more by the government. The main reason for the R-1 reporting requirement is that the predecessor to the STB, the Interstate Commerce Commission, extensively used the R-1 report to regulate rate setting prior to the 1990s. To some extent, the STB still plays that regulatory role, but rate setting disputes are far less common now.

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

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

Figure 1: Density plots for maintenance and gross investment rates.



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

To investigate the properties of maintenance, I use Schedule 410 Line 202 for locomotive maintenance and Schedule 410 Line 221 for freight car maintenance. These expenditures are the only ones which clearly and directly affect only locomotives and freight cars, respectively. I take the net book capital stock from Schedules 330 and 335 to construct the denominator of the maintenance rate. Similarly, I take gross investment from Schedule 330. Gross investment includes expenditures on new capital as well as expenditures on upgrading existing capital.

Figure 1 plots the density of maintenance rates and gross investment rates for both freight cars and locomotives along with their respective mean values from 1999-2023. The distribution of maintenance rates is shifted to the right of the investment rate distribution. This is more extreme for freight cars than for locomotives, but nevertheless implies that maintenance expenditures are, in some sense, more important than investment expenditures for freight railroads. Indeed, that is evident from the magnitudes of the investment and maintenance rates. The average maintenance rates for both freight cars and locomotives are around 20%, which is substantially larger than the typical investment rate of around 8%-14%. The latter figure is about twice as large as the national investment rate. If we assume that maintenance demand is inelastic, then the tax shield effect says that, given a standard 4% depreciation rate for locomotives and freight cars and a 6% discount rate, the tax elasticity of capital is more than halved.

I pair the maintenance rate with the after-tax relative price of maintenance to investment. I construct that price as

$$P_{i,j,t} = \frac{p^{m}_{i,j,t}(1-\tau_{i,t})}{p^{x}_{j,t}},$$

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

4 The Maintenance Demand Function

In this section, I estimate a constant elasticity maintenance demand function parameterized by a level shifter γ and a demand elasticity ω. γ roughly maps into the tax shield effect, while ω determines the input substitution effect. Conceptually, only the tax shield effect is first-order for capital and output, meaning that γ is fundamentally more important than ω for understanding the consequences of tax policy. In fact, we only need to know the demand elasticity so that we can residually determine γ and understand the extent to which there is a disconnect between capital and investment elasticities. The importance of the intercept relative to the slope therefore stands in contrast to the extensive empirical tax policy literature, in which only the tax elasticity of investment is relevant and the intercept is irrelevant. In the remainder of the section, I estimate the demand elasticity ω and the resulting level shifter γ in the tax and freight rail data.

4.1 Evidence from Corporate Tax Returns

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

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

$$\log m_{i,t} = \alpha_i + T_t + \omega \log(1 - \tau_{i,t}) + \text{Controls} + \varepsilon_{i,t}, \tag{13}$$

where α_i is an industry fixed effect and T_t is a time fixed effect. To construct the tax instrument $\tau_{i,t}$, I use a mix of pre-period capital weights through 2011 and capital weights lagged by ten years from 2012 onward. The idea is that, since the sample period is 1998-2019 and there were policy changes from essentially 2002 onward, it is best to strike a balance between exogeneity and relevance. Full exogeneity would guarantee weights are independent of future policy. This is what Zwick and Mahon (2017) rely on, but their study only runs through 2010 and hence weights from 1998 would plausibly still be relevant for the end of the sample period. On the other hand, capital weights from 1998 are considerably less relevant for firms in 2017 leading up to the Tax Cuts and Jobs Act than more recent weights, but weights from 2017 would similarly be endogenous to contemporaneous factors stemming from reverse causality and omitted variable bias. Figure B.5 plots $\tau_{i,t}$ by industry over the sample period.

The primary assumption is that the industry-by-year level policy variations are independent of other industry-by-year shocks that could simultaneously affect maintenance rates. These shocks might simultaneously influence both the implementation of tax policies and maintenance behaviors within industries, violating the assumption that policy variations are independent of other industry-year level factors. For example, policy around Covid-19 would plausibly not meet this criteria. Without adequately controlling for these time-varying confounders, the estimated relationship between tax policy and maintenance rates could be confounded by these unobserved influences. Toward mitigating that, I include broad linear and quadratic industry trends at the two-digit NAICS level.[16]

16. A further source of omitted variable bias may come from the assumption that maintenance and investment prices are unaffected by changes in the demand for maintenance and investment induced by tax policy. That is, I implicitly assume a perfectly competitive supply curve for the supply of investment and maintenance. Although evidence for the relevant period indicates that assumption is correct (Basu, Kim, and Singh 2021; House, Mocanu, and Shapiro 2017) for investment, Goolsbee (1998b) argues this may not be true. There is little corresponding evidence on the supply of maintenance.

Table 1: The Effect of Tax Changes on Industry-Level Maintenance Rates

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

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

Notes: This table estimates regressions using (13). The columns are grouped into three different categories. The first two contain estimates from the SOI sample including all firms, the second two contain firms with positive net income, and the final two for firms without net income. The first column in each group estimates the baseline regression of the log maintenance rate on the log tax rate for taxable firms with two-way fixed effects and both linear and quadratic industry trends. The second column in each group adds age, proxied as the ratio of gross to net book capital, as a control. In all regressions, standard errors are clustered by industry. In the bottom row, I estimate an implied value for γ by taking the sample mean of maintenance rates within the sample and dividing by the mean of the tax term raised to the estimated ω in the corresponding column.

Table 1 presents estimates of (13) for three separate groups. The first two columns correspond to the all firm sample, the second two columns to taxable firms, and final two columns to untaxable firms. The first column of each group is a simple regression of the log maintenance rate on the log tax term, while the second column includes a control for the age of capital proxied by the ratio of gross to net book capital, and both linear and quadratic trends for two-digit NAICS industries. Controlling for age accounts for the fact that older capital may require more maintenance. In the bottom row, I estimate an implied value for γ by taking the sample mean of maintenance rates within the sample and dividing by the mean of the tax term raised to ω. All specifications include industry and year fixed effects with standard errors clustered by industry.

In the sample for all firms, the demand elasticity ω is marginally statistically significant ($p < 0.1$) with a coefficient around two. Maintenance rises with capital age, implying that older capital does require significantly more maintenance. However, the All Firm sample is problematic due to heterogeneous treatment effects. Since a share of the firms in the sample are not exposed to tax policy and therefore the treatment is irrelevant for them, the estimate of the demand elasticity is biased downward. To account for that, columns 3 and 4 re-estimate (13) for the sample of firms with taxable income. The maintenance demand elasticity doubles to around four and becomes more statistically significant. For comparison, the tax semi-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). Finally columns 5 and 6 yield a convenient placebo test. Because firms without taxable income are generally not taxed, the resulting estimates of the elasticity should be indistinguishable from zero. That is indeed the case.

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

Appendix Table D.1 presents separate estimates of the maintenance elasticity using a BEA measure of capital instead. These data come from the detailed fixed asset tables by industry and come with the corresponding issue that the capital stock is a mix of corporate and non-corporate capital. Nevertheless, it is encouraging that the estimates are similar across specifications, though they become statistically insignificant for the All Firm sample. Another source of error, which is only relevant for the taxable and untaxable samples, is that lagged capital is for a different set of firms in the current than the previous period. I correct for this by using contemporaneous rather than lagged capital. The corresponding estimates in Appendix Table D.2 are largely the same as in Table 1.

Another source of measurement error comes from variation in maintenance expenditures. Maintenance expenditures in the SOI do not include internal labor expenditures because they are allocated to the wage bill. If there is heterogeneity in the labor cost share of maintenance by industry, that biases the estimated elasticity. However, assuming homogeneity in the cost share by industry, we can look to two sources to correct γ. In both the freight rail data (see Figure B.2b)—which I discuss below—and the maintenance and repair sector (see D.2), the cost share of maintenance is typically 30%. This implies that γ should be adjusted upward by about 1.4. Another issue is that the maintenance rate is an aggregate rate and therefore may reflect changes in composition of capital rather than changes in maintenance as a whole. I address these issues in the following subsection on freight rail.

There are two further potential issues. First, the SOI changed the number of industries sampled after 2013. Because some of the sampled industries are too small in that period, the IRS censored their reporting meant that some industries did not report maintenance expenditures, resulting in the possibility of some aggregation error. Second, there is some concern about endogeneity of the capital weights because they are not fixed starting in 2011. Toward addressing both issues at once, I re-estimate (14) using fixed weights over the period 1999-2013 in Appendix Table D.3. The results for the taxable and untaxable firm samples is largely the same as in the main text, but the all firm sample results are statistically insignificant. Finally, Appendix Figure D.1 plots the estimated tax elasticities as a function of the capital weight lag length. The shorter the lag length, the greater the endogeneity concern and the lesser the relevance concern. Although coefficients are larger with shorter lag length, they do not change very much as the lag length increases.

4.2 Freight Rail

Although the SOI data is nationally representative, it also gives a crude approximation of maintenance rates because there is measurement error in both the numerator and the denominator. The freight rail data are precise enough to largely overcome both issues.

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

$$\log m_{i,j,t} = \alpha_{ij} + T_t + \omega \log P_{i,j,t} + \text{Controls} + \epsilon_{i,j,t}, \tag{14}$$

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

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 (14) is biased. There could be several confounding factors. For instance, unobserved firm-level supply shocks could simultaneously affect both the intensity of maintenance and the relative price of that maintenance. Similarly, unobserved local demand conditions or region-specific economic expansions might simultaneously affect input prices and maintenance activity.

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

$$Z_{i,j,t} = \underbrace{\frac{\text{Materials}_{i,j,t-1}}{\text{Internal}_{i,j,t-1}} C_{t-1}}_{\text{Material Cost Exposure}} + \underbrace{\frac{\text{Labor}_{i,j,t-1}}{\text{Internal}_{i,j,t-1}} \sum_{s=1}^{S} \frac{\text{Rail Miles}_{i,s,t-1}}{\text{Rail Miles}_{i,t-1}} W_{s,t-1}}_{\text{Labor Cost Exposure}} . \tag{15}$$

$Z_{i,j,t}$ is the exposure of firm i and capital type j to input cost shocks, which can be broken down into material and labor cost exposure. Exposure comes from the ratio of internal materials maintenance costs to total internal maintenance costs. Figure B.4 indicates substantial variation in these shares between capital types and within firms over time. The firm i and capital type j exposure to materials cost shocks is given by the ratio of $t-1$ materials costs to total internal maintenance costs multiplied by a national materials cost index C_{t-1}, which is the producer price index "Intermediate Demand by Commodity Type: Materials and Components for Manufacturing." The idea here is to take a sufficiently broad category of materials costs that maintenance demand from freight rail could not affect. The labor cost exposure is slightly more complex. It takes the ratio of pre-period labor cost to internal maintenance cost and multiplies that ratio by a weighted average of state-level maintenance costs $W_{s,t-1}$. State weights are the ratio of rail miles in a particular state to total rail miles owned by firm i. The maintenance cost is the wage index for occupation code 49-0000, which is a broad category of maintenance workers. Within railroads, maintenance centers are geographically dispersed and not determined *ex ante* by local labor costs.

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

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

In Table 2, I present estimates of (14), where standard errors are clustered by firm and capital. Columns (1) and (2) are OLS estimates of the maintenance elasticity of demand, while columns (3) and (4) use the exposure instrument defined above as an instrument. Columns (2) and (4) use investment and capital age—defined as the ratio of net capital to gross capital—as controls. The top panel analyzes the response of the log total maintenance rate to the log relative price. The price elasticity is consistently between two and three, although the estimates with controls in columns (2) and (4) are slightly smaller. All are statistically significant. Therefore, the freight rail estimates agree closely with the

SOI estimates, though they are slightly smaller than the taxable firm sample. The coefficients on age and GDP exposure are both significant, indicating that they are important confounders.

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

	Dependent Variable: $\log m_{i,j,t}$			
	(1)	(2)	(3)	(4)
$\log P_{i,j,t}$	-2.182**	-2.708***	-3.092*	-3.442***
	(0.861)	(0.424)	(1.458)	(0.592)
Capital Age		0.781***		0.773***
		(0.147)		(0.138)
GDP Exposure		0.024		0.026*
		(0.013)		(0.012)
Observations	342	342	342	342
R^2	0.647	0.837	0.643	0.834
F-stat			131.3	133.0
Type	OLS	OLS	IV	IV
Firm-Year Trends	N	Y	N	Y

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

Notes: This table estimates regressions using (14). The first two columns are OLS regressions and the second two use the exposure share IV discussed in the main text. Columns 1 and 3 are the baseline regression of a log maintenance variable on log relative prices. Columns 2 and 4 add controls for the age of capital, local GDP exposure, and a firm-year trend. Age is net capital stock scaled by gross capital stock. All regressions include year and firm-capital type fixed effects. Standard errors are clustered by firm.

Appendix Table C.1 offers a more precise window into what drives the change in demand. In practice, we can think of maintenance as taking two forms. Either firms can outsource their maintenance to other firms or they can do it themselves. By analogy, we can choose to change the oil in our car engines at home in the garage or we can bring it to a mechanic. A unique feature of the R-1 data is that we observe how much maintenance is done internally versus externally. For freight railroads—and probably most firms—external maintenance is generally fixed contractually and hence is less flexible than internal maintenance. Splitting into internal and external maintenance and rerunning (14) yields that the estimated elasticity is around six for internal maintenance and zero for external maintenance. Thus, the main result—that maintenance is price-elastic—is driven by internal maintenance. This makes sense because internal maintenance is flexible while external maintenance is often contractually fixed. However, it does introduce a new source of concern about both the SOI results and the model. If there is considerable heterogeneity by industry, then exposure to tax policy changes depends not only on the composition of capital but on the composition of internal versus external maintenance as well. Moreover, the model does not account for this channel.

The key source of measurement error in the main specification is in the dependent variable. Theory says that the capital stock, which is the denominator for the maintenance rate, is likely mismeasured if maintenance plays some role in capital production. Firms may account for this when creating their useful life estimates for estimating depreciation, but that is not clear from their accounting statements in which they apply the perpetual inventory method. To try to account for that, I construct a measure of the capital stock which is purely physical rather than in dollar value. This is consistent with a one-hoss shay depreciation profile for capital and hence is an extreme assumption. The stock of locomotive capital is measure in units of horsepower, while it is measured in tons of capacity for freight cars. Both figures come from Schedule 710 of the R-1 report. This information comes from Schedule 710 of the R-1 reports. These measures have a high correlation (0.9) with the book value of the capital stock. As such, they yield essentially practically the same estimates for both the reduced form and instrumental variables regressions in Appendix Table C.2.[17]

5 Capital Maintenance and the 2017 Tax Cuts and Jobs Act

Theory suggests that positive and elastic maintenance demand significantly dampens traditional capital deepening effects of tax reform. In late 2017, Congress passed the Tax Cuts and Jobs Act, which considerably reduced the cost of corporate capital. Lawmakers permanently reduced the corporate tax rate from 35% to 21% and introduced 100% bonus depreciation for certain types of equipment.[18] The latter policy allows firms to immediately deduct investment from their tax bill, thereby eliminating the tax wedge in

17. Appendix Table C.3 examines the validity of the instrument when broken down into its respective components. Splitting the instrument into labor or materials yields the same results and the F-statistic remains greater than 100, indicating that the results are not primarily driven by one of them.

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

the maintenance-investment choice. President Trump's Council of Economic Advisors described the motivation and mechanism for the law's domestic business tax provisions through the traditional capital deepening channel:

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

Subsequent analyses started from the same perspective. For example, Chodorow-Reich et al. (2023) examine the empirical and quantitative dynamic effects of TCJA using a multinational Hall-Jorgenson framework, while Barro and Furman (2018) focus solely on the steady state effects in a closed economy neoclassical model featuring heterogeneous capital. In this section, I present a quantitative version of the model in Section 2 to study the effects of TCJA on domestic corporate capital. My approach takes the CEA view as given and asks how much maintenance alters the transmission mechanism beyond the traditional capital deepening channel.

5.1 Model and Calibration

The model is the same as in Section 2. There are several key differences which enable us to map short-run changes in the partial equilibrium model from Section 2 into the long run and from partial into general equilibrium. I largely rely on the domestic block of Chodorow-Reich et al. (2023) to carry out both mappings. The mapping from short-run into long-run arises from assuming that firms pay a convex Hayashi-style adjustment cost in units of labor given by

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

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

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

The ratio χ_{SR} pins down the adjustment cost parameter ϕ. This approach is identical to Chodorow-Reich et al. (2023), but with three key differences. First, I take β and ε_X as exogenous rather than χ_{SR}. The reasoning is that, in the limit as $\gamma \to 0$, the long-run tax elasticity of investment is the same as in Chodorow-Reich et al. (2023) because I calibrate α using their parameterization, which makes my estimates directly comparable to theirs. Second, because maintenance is in the model, we have to adjust the empirical short-run elasticity for that. From Corollary 2, my parameterization of the depreciation technology—which I discuss in more detail below—implies that estimated investment elasticities should be adjusted upward by a factor of 1.6. Using the Chodorow-Reich et al. (2023) estimate of the short-run tax elasticity of investment therefore implies that $\beta = -6.2$. Third, the long-run elasticity of investment does not equal the long-run tax elasticity of capital. In particular Appendix A.4 shows that

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

which is strictly larger than the tax elasticity of investment in the case with $\omega, \gamma > 0$ and strictly smaller when $\omega \to 0$. Under my calibration the tax elasticity of investment is $\varepsilon_X \approx -5$, which means that $\chi_{SR} \approx 1.24$. This estimate is close to the ratio used in Chodorow-Reich et al. (2023) of 1.3 and well within the broad range of 1-1.6 they consider.

Output is Cobb-Douglas in capital and labor with respective shares α_K and α_L. This representation is convenient because we can eliminate labor through the use of the static optimality condition for labor demand to yield

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

where

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

General equilibrium effects are therefore mediated entirely by changes in Z_t through changes in the wage.

Table 3: Calibrated Parameters

Parameter Name	**Symbol**	**Value**	**Source**
Maintenance Demand Elasticity	ω	2	Empirical moment
Maintenance Demand Level	γ	0.052	SOI (adjusted for labor)
Depreciation Level	δ_0	0.139	Corporate Physical X/Y from BEA
Discount Rate	r^k	0.06	Chodorow-Reich et al. (2023)
Short-Run Investment Elasticity	β	-6.2	Chodorow-Reich et al. (2023) adjusted for maintenance
Profit Elasticity	α	0.67	Chodorow-Reich et al. (2023)
Labor Share	α_L	0.65	Chodorow-Reich et al. (2023)
Capital Share	α_K	0.235	Chodorow-Reich et al. (2023)
Adjustment Cost (NGM)	ϕ	1.18	Estimated moment
Adjustment Cost (NGMM)	ϕ	7.22	Estimated moment
Non-corporate TFP (NGM)	A	0.7152	Set to match ratio of corporate to non-corporate gross output
Non-corporate TFP (NGMM)	A	0.8875	
Tax Change	$\Delta\tau$	0.033	Chodorow-Reich et al. (2023)

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

Next, consistent with a constant elasticity maintenance demand function, I assume that

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

which maps neatly into estimated empirical moments. Following the empirical estimates from the All Firms sample, I set the maintenance demand elasticity $\omega = 2$.[19] To calibrate γ, I solve $\gamma = \bar{m} \times (1 - \bar{\tau})^2 \times \frac{1}{0.7}$, where $\bar{m}$ and $\bar{\tau}$ are the average maintenance and tax rates in the SOI data in the All Firm sample. I further adjust this for parameter for the fact that labor is not included in the SOI maintenance costs, yielding $\gamma = 0.052$. The factor

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

of adjustment for labor costs comes from the R-1 data and the labor cost share in the maintenance and repair sector (NAICS code 811), both of which have a labor cost share of 0.3. I set $\delta_0 = 0.1389$ such that the pre-TCJA ratio of gross investment to gross output is 0.13, consistent with the average ratio of corporate physical investment to corporate gross output from 2000-2016.

Next, I calibrate the tax change by taking a capital-weighted average of the domestic block in Table E.10 of Chodorow-Reich et al. (2023). Importantly, all of the main quantitative results assume that bonus depreciation is permanent. I also import their assumption that the non-corporate sector is taxed at 28% pre- and post-TCJA. Finally, I normalize corporate productivity to one and set non-corporate productivity A such that the ratio of corporate to non-corporate gross output is 0.35, consistent with the Flow of Funds. Table 3 gives a summary of the calibrated parameters.

Finally, to map partial into general equilibrium, I assume that output is produced by two identical sectors facing differential taxation and competing over an inelastic labor supply. The mapping from partial into general equilibrium is consistent with balanced growth preferences. The equilibrium conditions are similar to in Section 2 and are in Appendix A.2. Since taxes hardly changed for the non-corporate sector during TCJA, I focus on corporate capital alone.[20]

5.2 Capital Accumulation and TCJA

Table 4 summarizes the long-run effects of TCJA on maintenance, investment, and capital accumulation in partial equilibrium and general equilibrium across the neoclassical model with maintenance (NGMM) and the neoclassical growth model. The latter is the exact same model as the NGMM but with $\gamma = 0$. The NGMM partial equilibrium increase in capital is around 6.7%, while the general equilibrium increase is 3.9%. The corresponding figures in the NGM are 10.9% and 6.6%, respectively. Both are similar to those reported by the comparable results on domestic corporate capital from Chodorow-Reich et al. (2023). The general equilibrium results are also similar to those from Sedlacek and Sterk (2019) and Zeida (2022) despite the fact that both focus on firm dynamics and so the transmission of tax policy to growth is different. In both partial and general equilibrium, the NGMM increase in capital is approximately 60% as large as the NGM prediction.

The source of the discrepancy between the NGM and the NGMM is the broken link between the capital and investment elasticities in the NGMM. In the standard model, the

20. For this reason, I assume that the non-corporate sector does not maintain its capital, but this assumption is irrelevant since I am similarly assuming that its tax treatment does not change.

long-run elasticity of investment is identical to the long-run elasticity of capital. With a second input to produce capital, investment becomes about three times as responsive as capital to changes in tax policy, which implies that the investment elasticity is uninformative about capital and wages unless we know the maintenance elasticity. Indeed, in the NGMM, investment increases in the long run by more three times as much as capital.

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

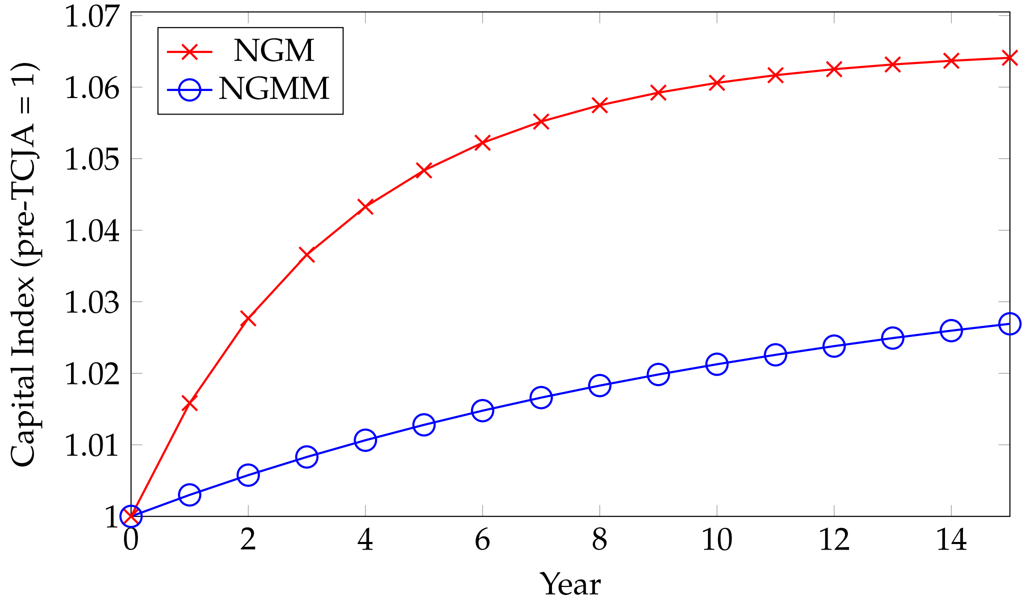
Table 4: Long-run Responses of Maintenance, Investment, and Capital to TCJA

	Partial Equilibrium			General Equilibrium			
	M	X	K	M	X	K	w
NGMM	-0.32%	20.1%	6.7%	-3.0%	17.0%	3.9%	0.48%
NGM		10.9%	10.9%		6.6%	6.6%	0.71%

The partial equilibrium estimates assume the wage is fixed, while the general equilibrium estimates assume perfectly inelastic labor supply rationed across corporate and non-corporate sectors.

Figure 2 plots the general equilibrium paths of capital in the NGM and the NGMM. Since the implied adjustment costs are higher in the NGMM, the difference between the two models is more dramatic in the short run. For example, by 2027, projected capital growth in the NGMM is about 40% as large as in the NGM. Capital adjustment costs are higher in the NGMM than the NGM to account for the fact that both inputs to capital are more elastic than in the standard NGM.

Figure 2: General Equilibrium Path of Domestic Capital



Notes: The solid red line with crosses depicts the NGM path of capital and the blue line with circles depicts the NGMM path.

Appendix E contains two additional results. First, Appendix E.1 gives the maintenance, investment, and capital elasticities across a variety of values for the maintenance elasticity of demand. Because the input substitution effect is second order, the resulting change in the capital stock does not vary much across different values of the demand elasticity ω. For example, if $\omega = 0$, then capital increases by 4.1%. In this edge case, the capital and investment elasticities are the same, but are nevertheless given a haircut by the existence of the maintenance-investment distortion. As ω rises, the change in capital does not vary by much, but the way capital changes does. As the demand elasticity rises, maintenance and investment become increasingly substitutable. Second, Appendix E.2 breaks down the change in capital for equipment and structures. There is little heterogeneity in capital accumulation across capital types.

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

6 Concluding Remarks

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

Positive and elastic maintenance demand raises troubling questions for standard approaches to capital theory and measurement. Perhaps the central issue in capital theory is the fact that capital is unobserved. To varying degrees of uncertainty, we observe what are presumably inputs into capital accumulation like investment, but it has historically been a source of controversy how to translate those observations into capital itself (Hayek 1935; Pigou 1941; Feldstein and Rothschild 1974). In recent years, this issue has become particularly salient for many types of intangible capital (Peters and Taylor 2017; Haskel and Westlake 2018; McGrattan 2020). A differentially taxed secondary input for physical capital production implies that measurement issues are perhaps as abundant for physical capital production as they are for intangibles. This finding raises a host of difficult questions far beyond the issues discussed in this paper around tax policy counterfactuals. Indeed, practically any researcher who relies on proper measurement of the capital stock and the cost of capital must consider the extent to which their question is contaminated by maintenance, which extends from growth accounting to the labor share and beyond.

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

References

Albonico, Alice, Sarantis Kalyvitis, and Evi Pappa. 2014. "Capital maintenance and depreciation over the business cycle." *Journal of Economic Dynamics and Control* 39 (February): 273–286. ISSN: 01651889. https://doi.org/10.1016/j.jedc.2013.12.008.

Altig, David, Alan J Auerbach, Laurence J Kotlikoff, Kent A Smetters, and Jan Walliser. 2001. "Simulating Fundamental Tax Reform in the United States." *American Economic Review* 91, no. 3 (June): 574–595. ISSN: 0002-8282. https://doi.org/10.1257/aer.91.3.574.

Angelopoulou, Eleni, and Sarantis Kalyvitis. 2012. "Estimating the Euler Equation for Aggregate Investment with Endogenous Capital Depreciation." *Southern Economic Journal* 78, no. 3 (January): 1057–1078. ISSN: 0038-4038. https://doi.org/10.4284/0038-4038-78.3.1057.

Auerbach, Alan J. 1983. "Corporate Taxation in the United States." *Brookings Papers on Economic Activity* 2.

Bachmann, Rüdiger, Ricardo J. Caballero, and Eduardo M. R. A. Engel. 2013. "Aggregate Implications of Lumpy Investment: New Evidence and a DSGE Model." *American Economic Journal: Macroeconomics* 5, no. 4 (October): 29–67. ISSN: 1945-7707. https://doi.org/10.1257/mac.5.4.29.

Barro, Robert J., and Jason Furman. 2018. "The macroeconomic effects of the 2017 tax reform."

Basu, Riddha, Doyeon Kim, and Manpreet Singh. 2021. "Tax Incentives, Small Businesses, and Physical Capital Reallocation."

Bitros, George C. 1976. "A Statistical Theory of Expenditures in Capital Maintenance and Repair." *Journal of Political Economy* 84, no. 5 (October): 917–936. ISSN: 0022-3808. https://doi.org/10.1086/260490.

Borusyak, Kirill, Peter Hull, and Xavier Jaravel. 2024. *A Practical Guide to Shift-Share Instruments.* Technical report.

Boucekkine, R., G. Fabbri, and F. Gozzi. 2010. "Maintenance and investment: Complements or substitutes? A reappraisal." *Journal of Economic Dynamics and Control* 34, no. 12 (December): 2420–2439. ISSN: 01651889. https://doi.org/10.1016/j.jedc.2010.06.007.

Brazell, David W., Lowell Dworin, and Michael Walsh. 1989. "A History of Federal Tax Depreciation Policy." May.

CEA. 2018. *Economic Report of the President.* Technical report.

Chodorow-Reich, Gabriel, Matthew Smith, Owen Zidar, and Eric Zwick. 2023. "Tax Policy and Investment in a Global Economy."

Clausing, Kimberly A. 2024. "US International Corporate Taxation after the Tax Cuts and Jobs Act." *Journal of Economic Perspectives* 38, no. 3 (August): 89–112. ISSN: 0895-3309. https://doi.org/10.1257/jep.38.3.89.

Cooley, Thomas F., Jeremy Greenwood, and Mehmet Yorukoglu. 1997. "The replacement problem." *Journal of Monetary Economics* 40, no. 3 (December): 457–499. ISSN: 03043932. https://doi.org/10.1016/S0304-3932(97)00055-X.

Cunningham, Christopher R., and Gary V. Engelhardt. 2008. "Housing capital-gains taxation and homeowner mobility: Evidence from the Taxpayer Relief Act of 1997." *Journal of Urban Economics* 63, no. 3 (May): 803–815. ISSN: 00941190. https://doi.org/10.1016/j.jue.2007.05.002.

Dioikitopoulos, Evangelos V., and Sarantis Kalyvitis. 2008. "Public capital maintenance and congestion: Long-run growth and fiscal policies." *Journal of Economic Dynamics and Control* 32, no. 12 (December): 3760–3779. ISSN: 01651889. https://doi.org/10.1016/j.jedc.2008.04.001.

Feldstein, Martin S., and Michael Rothschild. 1974. "Towards an Economic Theory of Replacement Investment." *Econometrica* 42 (3): 393–424.

Gale, William G., Hilary Gelfond, Aaron Krupkin, Mark J. Mazur, and Eric Toder. 2018. *Effects of the Tax Cuts and Jobs Act: A Preliminary Analysis.* Technical report. Tax Policy Center (Urban Institute and Brookings Institution).

Gale, William G., Jeffrey L. Hoopes, and Kyle Pomerleau. 2024. "Sweeping Changes and an Uncertain Legacy: The Tax Cuts and Jobs Act of 2017." *Journal of Economic Perspectives* 38, no. 3 (August): 3–32. ISSN: 0895-3309. https://doi.org/10.1257/jep.38.3.3.

Gale, William G., Aaron Krupkin, and Kim Rueben. 2015. "THE RELATIONSHIP BETWEEN TAXES AND GROWTH AT THE STATE LEVEL: NEW EVIDENCE." *National Tax Journal* 68, no. 4 (December): 919–941. ISSN: 0028-0283. https://doi.org/10.17310/ntj.2015.4.02.

Garrett, Daniel G., Eric Ohrn, and Juan Carlos Suárez Serrato. 2020. "Tax Policy and Local Labor Market Behavior." *American Economic Review: Insights* 2, no. 1 (March): 83–100. ISSN: 2640-205X. https://doi.org/10.1257/aeri.20190041.

Gechert, Sebastian, and Philipp Heimberger. 2022. "Do corporate tax cuts boost economic growth?" *European Economic Review* 147 (August): 104157. ISSN: 00142921. https://doi.org/10.1016/j.euroecorev.2022.104157.

Goolsbee, Austan. 1998a. "Investment Tax Incentives, Prices, and the Supply of Capital Goods." *The Quarterly Journal of Economics* 113, no. 1 (February): 121–148. ISSN: 0033-5533. https://doi.org/10.1162/003355398555540.

———. 1998b. "The Business Cycle, Financial Performance, and the Retirement of Capital Goods." *Review of Economic Dynamics* 1, no. 2 (April): 474–496. ISSN: 10942025. https://doi.org/10.1006/redy.1998.0012.

———. 2004. "Taxes and the quality of capital." *Journal of Public Economics* 88, nos. 3-4 (March): 519–543. ISSN: 00472727. https://doi.org/10.1016/S0047-2727(02)00190-1.

Gormsen, Niels, and Kilian Huber. 2022. "Discount Rates: Measurement and Implications for Investment."

Hall, Robert E., and Dale Jorgenson. 1967. "Tax Policy and Investment Behavior." *American Economic Review* 57:391–414.

Harding, John P., Stuart S. Rosenthal, and C.F. Sirmans. 2007. "Depreciation of housing capital, maintenance, and house price inflation: Estimates from a repeat sales model." *Journal of Urban Economics* 61, no. 2 (March): 193–217. ISSN: 00941190. https://doi.org/10.1016/j.jue.2006.07.007.

Harris, Adam, and Maggie Yellen. 2023. "Decision-Making with Machine Prediction: Evidence from Prediction Maintenance in Trucking."

Haskel, Jonathan, and Stian Westlake. 2018. *Capitalism without Capital: The Rise of the Intangible Economy.* Princeton University Press. ISBN: 9780691175034.

Hassett, Kevin A., and R. Glenn Hubbard. 2002. "Tax Policy and Business Investment," 1293–1343. https://doi.org/10.1016/S1573-4420(02)80024-6.

Hayek, Friedrich A. 1935. "The Maintenance of Capital." *Economica* 2 (7): 241–276.

Hernandez, Manuel A., and Danilo R. Trupkin. 2021. "Asset maintenance as hidden investment among the poor and rich: Application to housing." *Review of Economic Dynamics* 40 (April): 128–145. ISSN: 10942025. https://doi.org/10.1016/j.red.2020.09.004.

House, Christopher, Ana-Maria Mocanu, and Matthew Shapiro. 2017. *Stimulus Effects of Investment Tax Incentives: Production versus Purchases.* Technical report. Cambridge, MA: National Bureau of Economic Research, May. https://doi.org/10.3386/w23391.

House, Christopher L, and Matthew D Shapiro. 2008. "Temporary Investment Tax Incentives: Theory with Evidence from Bonus Depreciation." *American Economic Review* 98, no. 3 (May): 737–768. ISSN: 0002-8282. https://doi.org/10.1257/aer.98.3.737. https://pubs.aeaweb.org/doi/10.1257/aer.98.3.737.

House, Christopher L. 2014. "Fixed costs and long-lived investments." *Journal of Monetary Economics* 68 (November): 86–100. ISSN: 03043932. https://doi.org/10.1016/j.jmoneco.2014.07.011.

Jorgenson, Dale W., and Kun-Young Yun. 1991. *Tax Reform and the Cost of Capital.* Oxford University Press, August. ISBN: 0198285930. https://doi.org/10.1093/0198285930.001.0001.

Kabir, Poorya, and Eugene Tan. 2024. *Maintenance Volatility, Firm Productivity, and the User Cost of Capital *.* Technical report.

Kabir, Poorya, Eugene Tan, and Ia Vardishvili. 2024. *Quantifying the Allocative Efficiency of Capital: The Role of Capital Utilization *.* Technical report.

Kalaitzidakis, Pantelis, and Sarantis Kalyvitis. 2004. "On the macroeconomic implications of maintenance in public capital." *Journal of Public Economics* 88, nos. 3-4 (March): 695–712. ISSN: 00472727. https://doi.org/10.1016/S0047-2727(02)00221-9.

———. 2005. ""New" Public Investment and/or Public Capital Maintenance for Growth? The Canadian Experience." *Economic Inquiry* 43, no. 3 (July): 586–600. ISSN: 00952583. https://doi.org/10.1093/ei/cbi040.

Kennedy, Patrick J, Christine Dobridge, Paul Landefeld, and Jacob Mortenson. 2023. *The Efficiency-Equity Tradeoff of the Corporate Income Tax: Evidence from the Tax Cuts and Jobs Act.* Technical report.

Khan, Aubhik, and Julia K. Thomas. 2008. "Idiosyncratic Shocks and the Role of Nonconvexities in Plant and Aggregate Investment Dynamics." *Econometrica* 76, no. 2 (March): 395–436. ISSN: 0012-9682. https://doi.org/10.1111/j.1468-0262.2008.00837.x.

Kitchen, John, and Matthew Knittel. 2011. "Business Use of Special Provisions for Accelerated Depreciation: Section 179 Expensing and Bonus Depreciation, 2002-2009." *SSRN Electronic Journal,* ISSN: 1556-5068. https://doi.org/10.2139/ssrn.2789660.

Knight, John R., and C.F. Sirmans. 1996. "Depreciation, Maintenance, and Housing Prices." *Journal of Housing Economics* 5, no. 4 (December): 369–389. ISSN: 10511377. https://doi.org/10.1006/jhec.1996.0019.

McGrattan, Ellen R. 2020. "Intangible capital and measured productivity." *Review of Economic Dynamics* 37 (August): S147–S166. ISSN: 10942025. https://doi.org/10.1016/j.red.2020.06.007. https://linkinghub.elsevier.com/retrieve/pii/S1094202520300466.

McGrattan, Ellen R., and James A. Schmitz Jr. 1999. "Maintenance and Repair: Too Big to Ignore." *Federal Reserve Bank of Minneapolis Quarterly Review,* no. Fall, 213.

McKay, Alisdair, and Johannes F. Wieland. 2021. "Lumpy Durable Consumption Demand and the Limited Ammunition of Monetary Policy." *Econometrica* 89 (6): 2717–2749. ISSN: 0012-9682. https://doi.org/10.3982/ECTA18821.

Mertens, Karel, and Morten O. Ravn. 2013. "The Dynamic Effects of Personal and Corporate Income Taxes in the United States." *American Economic Review* 103:1212–1247.

Motahar, Eshragh. 1992. "Endogenous capital utilization and the q theory of investment." *Economics Letters* 40, no. 1 (September): 71–75. ISSN: 01651765. https://doi.org/10.1016/0165-1765(92)90247-V.

Peters, Ryan H., and Lucian A. Taylor. 2017. "Intangible capital and the investment-q relation." *Journal of Financial Economics* 123 (2): 251–272. ISSN: 0304405X. https://doi.org/10.1016/j.jfineco.2016.03.011.

Pfeifer, Sylvia. 2023. *Boom time for the $110bn a year industry keeping airlines flying.* London, October.

Pigou, A. C. 1941. "Maintaining Capital Intact." *Economica* 8, no. 31 (August): 271. ISSN: 00130427. https://doi.org/10.2307/2549333.

Pinsker, Joe. 2024. *The New Math of Driving Your Car Till the Wheels Fall Off,* May.

PWBM. 2019. *Penn Wharton Budget Model: Dynamic OLG Model.* Technical report. Penn Wharton Budget Model. www.budgetmodel.wharton.upenn.edu.

Romer, Christina D, and David H Romer. 2010. "The Macroeconomic Effects of Tax Changes: Estimates Based on a New Measure of Fiscal Shocks." *American Economic Review* 100 (3): 763–801.

Rust, John. 1987. "Optimal Replacement of GMC Bus Engines: An Empirical Model of Harold Zurcher." *Econometrica* 55, no. 5 (September): 999. ISSN: 00129682. https://doi.org/10.2307/1911259.

Sedlacek, Petr, and Vincent Sterk. 2019. "Reviving american entrepreneurship? tax reform and business dynamism." *Journal of Monetary Economics* 105 (August): 94–108. ISSN: 03043932. https://doi.org/10.1016/j.jmoneco.2019.04.009.

Shan, Hui. 2011. "The effect of capital gains taxation on home sales: Evidence from the Taxpayer Relief Act of 1997." *Journal of Public Economics* 95, nos. 1-2 (February): 177–188. ISSN: 00472727. https://doi.org/10.1016/j.jpubeco.2010.10.006.

Suárez Serrato, Juan Carlos, and Owen Zidar. 2018. "The structure of state corporate taxation and its impact on state tax revenues and economic activity." *Journal of Public Economics* 167 (November): 158–176. ISSN: 00472727. https://doi.org/10.1016/j.jpubeco.2018.09.006.

Summers, Lawrence H. 1981. "Taxation and Corporate Investment: A q-Theory Approach." *Brookings Papers on Economic Activity* 1:67–127.

Winberry, Thomas. 2021. "Lumpy Investment, Business Cycles, and Stimulus Policy." *American Economic Review* 111, no. 1 (January): 364–396. ISSN: 0002-8282. https://doi.org/10.1257/aer.20161723.

Zeida, Teegawende H. 2022. "The Tax Cuts and Jobs Act (TCJA): A quantitative evaluation of key provisions." *Review of Economic Dynamics* 46 (October): 74–97. ISSN: 10942025. https://doi.org/10.1016/j.red.2021.08.003.

Zwick, Eric, and James Mahon. 2017. "Tax Policy and Heterogeneous Investment Behavior." *American Economic Review* 107, no. 1 (January): 217–248. ISSN: 0002-8282. https://doi.org/10.1257/aer.20140855. https://pubs.aeaweb.org/doi/10.1257/aer.20140855.

Appendices

A Model Derivations

A.1 Profit Function

Consider a firm with Cobb-Douglas production

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

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

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

we can rewrite income net of the wage bill as

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

where

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

A.2 Linearized System

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

$$h(\bar{\lambda}) = 0 \tag{A.1}$$

$$h'(\bar{\lambda}) = \frac{1}{\phi(1 - \tau)}. \tag{A.2}$$

The linearized system therefore reduces to

$$\hat{\lambda}_t(1+r^k) = (1-\tau)F''(\bar{K})\bar{K}\hat{K}_{t+1} + \hat{\lambda}_{t+1}\left(1-\delta(m)+\delta'(\bar{m})\bar{m}\right) \tag{A.3}$$

$$\hat{K}_{t+1} = \frac{\hat{\lambda}_t}{\phi(1-\tau)} + \hat{K}_t \tag{A.4}$$

From Equations (A.3) and (A.4), the system can be represented as:

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

where

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

This matrix has eigenvalues

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

where

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

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

and associated eigenvector

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

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

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

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

where

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

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

$$\begin{aligned}
\frac{1}{T+1}\sum_{t=0}^{T}\frac{X_t-X_0}{X_0} &= \frac{1}{T+1}\sum_{t=0}^{T}\frac{K_{t+1}-(1-\delta(m))K_t-\delta(m)K_0}{\delta(m)K_0} \\
&= \frac{1}{\delta(m)\,(T+1)}\sum_{t=0}^{T}\left(\delta(m)\frac{K_t-K_0}{K_0}+\frac{K_{t+1}-K_t}{K_0}\right) \\
&= \frac{1}{\delta(m)\,(T+1)}\sum_{t=0}^{T}\left(\delta(m)\frac{K_t-K_0}{K_0}+(1-\mu_1)\mu_1^t\tilde{k}\right) \\
&\approx \frac{1}{\delta(m)\,(T+1)}\sum_{t=0}^{T}\left(\delta(m)\left(\tilde{k}+\frac{K_t-\bar{K}}{K_0}\right)+(1-\mu_1)\mu_1^t\tilde{k}\right) \\
&\approx \frac{1}{\delta(m)\,(T+1)}\sum_{t=0}^{T}\left(\delta(m)\left(\tilde{k}-\mu_1^t\tilde{k}\right)+(1-\mu_1)\mu_1^t\tilde{k}\right) \\
&= \tilde{k}\left(1+\frac{(1-\mu_1-\delta(m))(1-\mu^{T+1})}{\delta(m)(1-\mu_1)(T+1)}\right)
\end{aligned}$$

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

$$\begin{aligned}
\chi_{SR} = \frac{\text{Average Deviation}}{\text{Long-Run Deviation}} &= \tilde{k}\left(1+\frac{(1-\mu_1-\delta(m))(1-\mu^{T+1})}{\delta(m)(1-\mu_1)(T+1)}\right)/\tilde{k} \\
&= 1+\frac{(1-\mu_1-\delta(m))(1-\mu^{T+1})}{\delta(m)(1-\mu_1)(T+1)}.
\end{aligned} \tag{A.5}$$

A.4 The Tax Elasticity of Investment

In steady state, investment is given by $X = \delta(m)K$. With the specification that the depreciation technology is

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

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

$$X = \left(\delta_0 - \frac{\gamma}{1-1/\omega}(1-\tau)^{1-\omega}\right)\left(\frac{r^k + \delta_0 + \frac{\gamma}{1-\omega}(1-\tau)^{1-\omega}}{\alpha(1-\tau)}\right)^{\frac{-1}{1-\alpha}}, \tag{A.6}$$

where again I use the definition of the marginal tax rate as

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

To first order, the tax semi-elasticity of investment is given as

$$\varepsilon_X \approx \varepsilon_\delta + \varepsilon_K.$$

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

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

Since

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

the tax semi-elasticity is

$$\varepsilon_\delta \approx \frac{-\gamma\omega}{\delta_0 + \frac{\gamma\omega}{1-\omega}}, \tag{A.7}$$

where I assume that $\tau \approx 0$. Since the pre-reform tax rate is 4%, this is a sensible approximation. Now consider the tax semi-elasticity of capital. In the first step,

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

To first order, the semi-elasticity becomes approximately

$$\varepsilon_K \approx \frac{-1}{1-\alpha}\left(1 - \frac{\gamma}{r^k + \delta_0 + \frac{\gamma}{1-\omega}}\right). \tag{A.8}$$

Consequently, the tax semi-elasticity of investment is approximately

$$\begin{aligned} \varepsilon_X &\approx \varepsilon_\delta + \varepsilon_K \\ &\approx \frac{-\gamma\omega}{\delta_0 + \frac{\gamma\omega}{1-\omega}} + \frac{-1}{1-\alpha}\left(1 - \frac{\gamma}{r^k + \delta_0 + \frac{\gamma}{1-\omega}}\right). \end{aligned} \tag{A.9}$$

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

A.5 Omitted Variable Bias in Investment Regressions

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

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

Proof. Consider the regressions

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

and

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

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

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

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

$$\begin{aligned}
\text{Bias} &= \beta\cdot\frac{\text{Cov}\left(\log\left(r^k+\delta\right)-\log\left(1-\tau_{i,t}\right)\right), \frac{\gamma\tau_{i,t}}{r^k+\delta_0+\frac{\gamma}{1-\omega}}\right)}{\text{Var}\left(\log\left(\frac{r^k+\delta}{1-\tau_{i,t}}\right)\right)} \\
&\approx \beta\cdot\frac{\text{Cov}\left(\tau_{i,t}, \frac{\gamma\tau_{i,t}}{r^k+\delta_0+\frac{\gamma}{1-\omega}}\right)}{\text{Var}\left(\tau_{i,t}\right)} \\
&= \beta\cdot\frac{\gamma}{r^k+\delta_0+\frac{\gamma}{1-\omega}}
\end{aligned} \tag{A.13}$$

Since we can write

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

a general expression for the true elasticity parameter is

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

Under this paper's parameterization, that corresponds to boosting the estimated elasticity by a factor of about 1.5. Note, moreover, that this formula corresponds to many estimated elasticities. For example, many papers regress investment or the investment rate on the tax term alone, which itself comes from an approximation of the log user cost above. Therefore, the consensus range of investment rate elasticities from Hassett and Hubbard (2002) of 0.5-1 is perhaps more like 0.75-1.5. □

B Data

B.1 Freight Rail

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

- All components of **maintenance** come from Schedule 410, Line 202 (Locomotives) and Line 221 (Freight Cars)
- All components of investment and capital come from Schedules 330 and 335 from the lines pertaining to locomotives and equipment
- The miles of rail per state come from Schedule 702
- Data on capital inventories come from Schedule 710

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

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

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

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

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

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

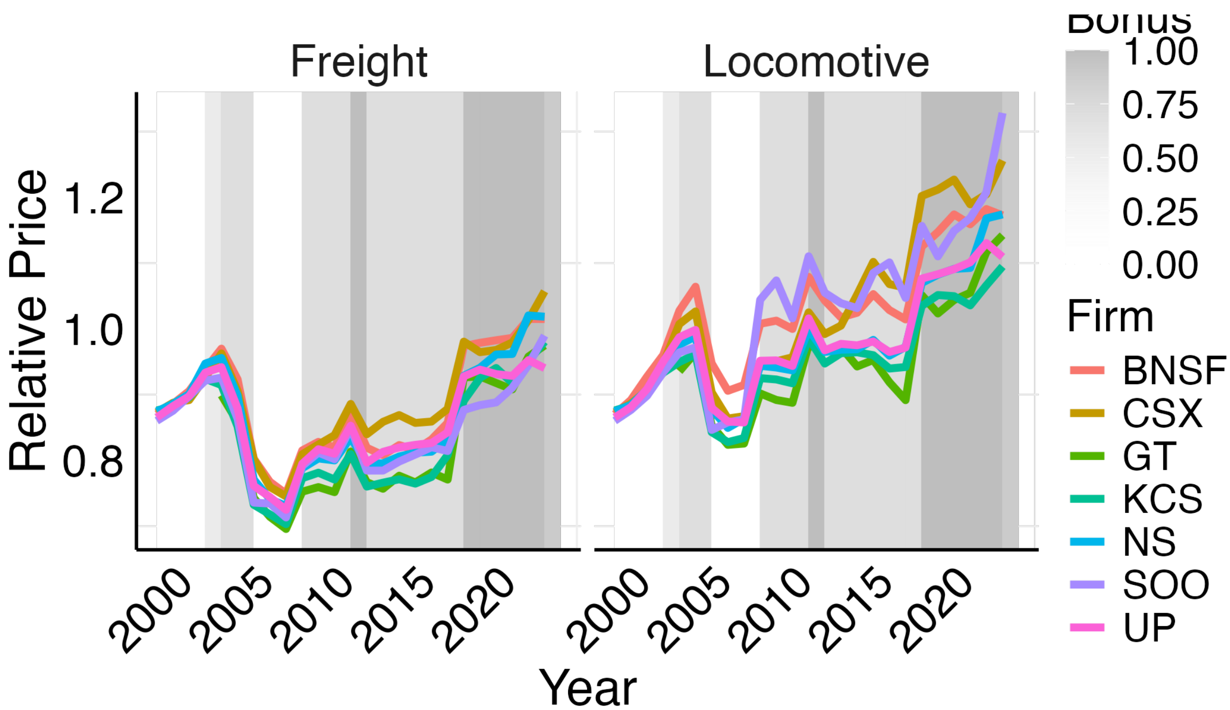
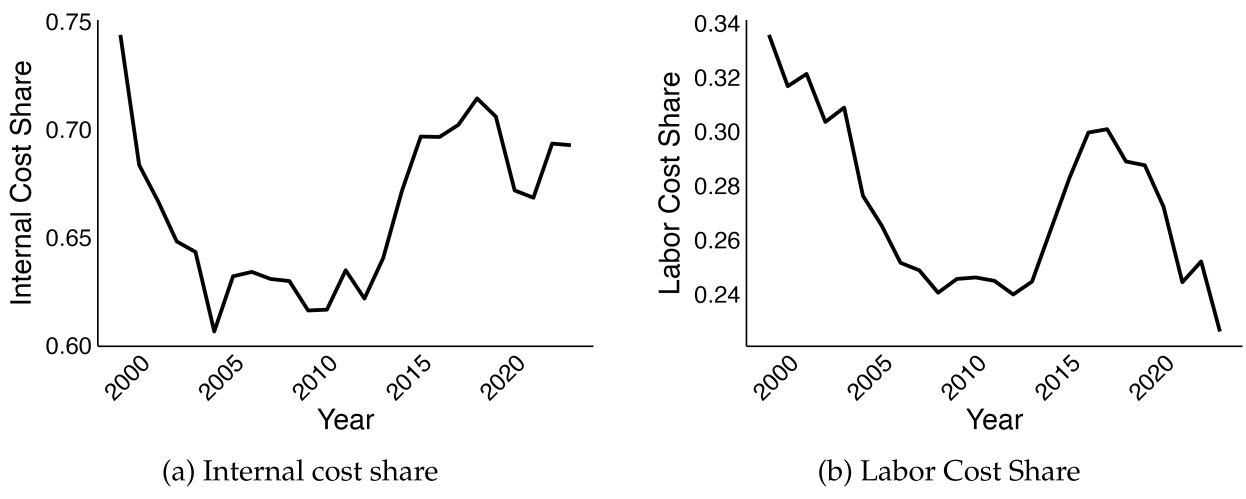


Figure B.1: The relative price of maintaining freight cars (left) and locomotives (right). The degree of shading corresponds to the strength of bonus depreciation.

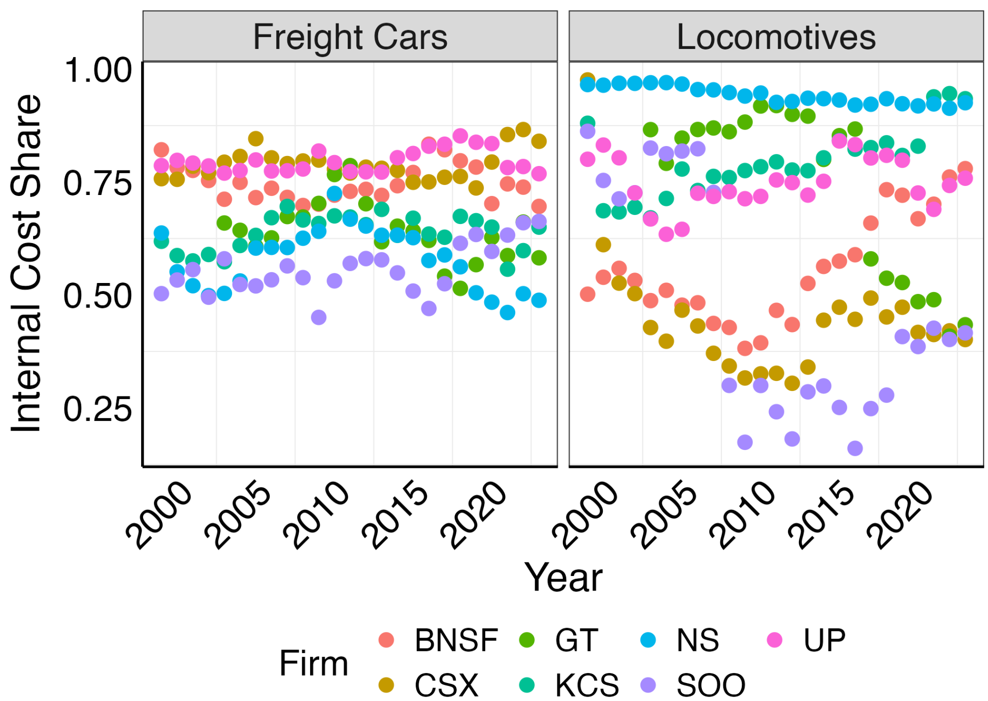
Figure B.2: Aggregate internal and labor cost share



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

There is significant variability between firms and capital types in their internal maintenance practices. Figure B.3 plots the share of internal maintenance done by firms on freight cars and locomotives, respectively. The shares are quite persistent within firms and capital types but vary considerably. For example, Norfolk Southern does practically all of their locomotive maintenance internally, whereas their main similarly sized regional competitor, CSX, does only around 30% internally. Additionally, variability is considerably larger for locomotives than freight cars, which may be because locomotives are more complicated capital types. In the aggregate, around 65% of total maintenance is internal. This is important because internal maintenance is more flexible than external maintenance since the latter is usually a function of predetermined contracts. If the demand for maintenance is elastic, then it will almost surely be solely on the internal maintenance margin in the short run.

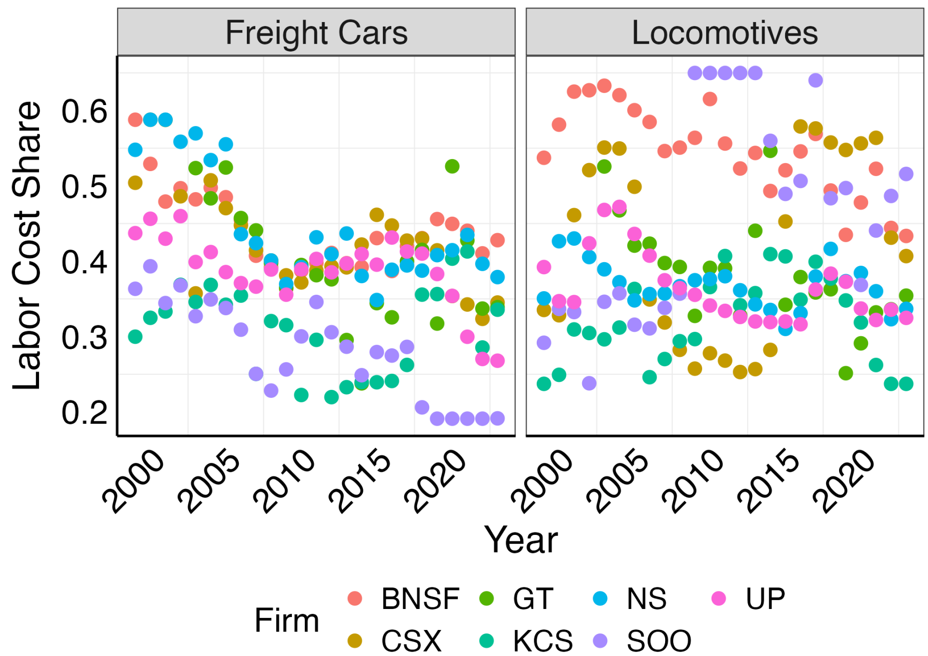
Figure B.3: Internal Maintenance Share by Firm & Capital Type



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

Firms and capital types also vary in how much of their internal maintenance expenditures are devoted to labor and materials. Figure B.4 plots the internal labor cost share by firm and capital type. Labor costs are typically between 20% and 70% of the total internal maintenance costs and on average around 30% of total maintenance expenditures. Whereas labor costs are typically fixed in advance by union contracts, materials costs are a function of the capital types themselves and the productivity of internal labor. Labor cost shares are considerably less persistent than internal cost shares, which suggests that factors like shocks to materials prices drive changes in the internal composition of maintenance spending.

Figure B.4: Internal Labor Cost Share by Firm & Capital type



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

B.2 SOI

Table B.2: Summary statistics for the SOI.

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

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

Table B.3: NAICS Industries and Maintenance Rates

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

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

Tax Policy Construction

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

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

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

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

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

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

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

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

$$\tau^a_{i,t} = 1 - \frac{1 - \tau^c_t}{1 - \mathrm{ITC}^a_{i,t} - z^a_{i,t}\tau^c_t}, \tag{A.15}$$

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

$z_{i,t}$ is more difficult and requires some level of judgment. Suppose an asset has allowable depreciation $D^a_{i,t}$ and define $d^a_{i,t}$ as the share of the asset's allowable depreciation under tax law each period. This is nontrivial because companies are allowed to use different methods of depreciation. For each asset j, I define the present value of depreciation allowances as

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

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

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

$$\tilde{z}_{i,t}^{a} \begin{cases} \theta + (1-\theta_t) z_{i,t}^{a} & \text{if eligible} \\ z_{i,t}^{a} & \text{if ineligible,} \end{cases} \tag{A.16}$$

where $\tilde{z}_{i,t}^{a}$ takes the place of $z_{i,t}^{a}$ in equation A.15. At various points, $\theta = 1$ for some assets, so the marginal effective tax rate is zero. Conveniently, House and Shapiro (2008) also map whether or not each BEA asset is eligible for bonus depreciation, so I use their mapping.

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

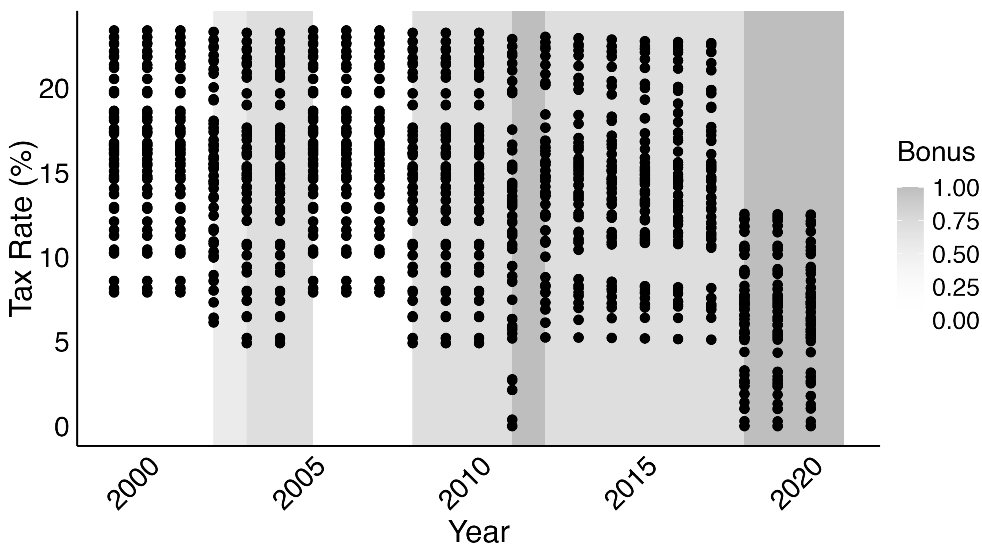
$$\alpha_{i,j,t} = \frac{k_{i,j,t}^{a}}{K_{j,t}^{a}},$$

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

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

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

Figure B.5: Marginal tax rates by industry



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

C Additional Results: Freight Rail

Table C.1: The Effect of Relative Price Changes on Maintenance Rates

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

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

Notes: This table estimates regressions using (14). The first two columns are OLS regressions and the second two use the exposure share IV discussed in the main text. Columns 1 and 3 are the baseline regression of a log maintenance variable on log relative prices. Columns 2 and 4 add controls for the age of capital and either log investment (for the case with maintenance in levels) or a log investment rate (when the maintenance rate is on the LHS). Age is net capital stock scaled by gross capital stock. All regressions include firm, year, and capital type fixed effects. Standard errors are clustered by firm.

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

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

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

Notes: This table estimates regressions using (14) with a measure of physical capital in the denominator. The first two columns are OLS regressions and the second two use the exposure share IV discussed in the main text. Columns 1 and 3 are the baseline regression of a log maintenance variable on log relative prices. Columns 2 and 4 add controls for the age of capital, local GDP exposure, and both linear and quadratic firm-year trends. Age is the inverse net capital stock scaled by gross capital stock. All regressions include firm-type and year fixed effects. Standard errors are clustered by firm and capital type.

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

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

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

Notes: This table estimates regressions using (14) broken down by the components of the instrument. The first two columns are the labor component of the instrument and the second two use the materials component. Columns 1 and 3 are the baseline regression of a log maintenance variable on log relative prices. Columns 2 and 4 add controls for the age of capital, local GDP exposure, and linear and quadratic firm-year trends. Age is net capital stock scaled by gross capital stock. All regressions include year and firm-capital type fixed effects. Standard errors are clustered by firm.

D Additional Results: SOI

Table D.1: The Effect of Tax Changes on Industry-Level Maintenance Rates (BEA Capital)

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

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

Notes: This table estimates regressions using (13). These estimates use BEA capital as the denominator, which come from estimates of the net capital stock in the detailed fixed asset data. The columns are grouped into three different categories. The first two contain estimates from the SOI sample including all firms, the second two contain firms with positive net income, and the final two for firms without net income. The first column in each group estimates the baseline regression of the log maintenance rate on the log tax rate for taxable firms with two-way fixed effects and industry linear and quadratic trends. The second column in each group adds age, proxied as the ratio of gross to net book capital, as a control. In all regressions, standard errors are clustered by industry. In the bottom row, I estimate an implied value for γ by taking the sample mean of maintenance rates within the sample and dividing by the mean of the tax term raised to the estimated ω in the corresponding column.

Table D.2: The Effect of Tax Changes on Industry-Level Maintenance Rates (Contemporaneous Capital)

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

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

Notes: This table estimates regressions using (13) using contemporaneous capital in the denominator. The columns are grouped into three different categories. The first two contain estimates from the SOI sample including all firms, the second two contain firms with positive net income, and the final two for firms without net income. The first column in each group estimates the baseline regression of the log maintenance rate on the log tax rate for taxable firms with two-way fixed effects and linear and quadratic industry trends. The second column in each group adds age, proxied as the ratio of gross to net book capital, as a control. In all regressions, standard errors are clustered by industry. In the bottom row, I estimate an implied value for γ by taking the sample mean of maintenance rates within the sample and dividing by the mean of the tax term raised to the estimated ω in the corresponding column.

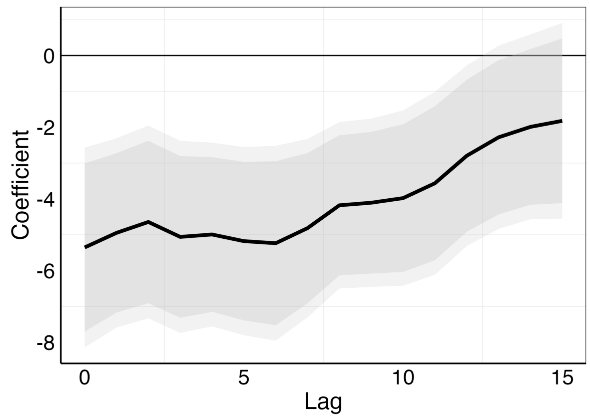
Table D.3: The Effect of Tax Changes on Industry-Level Maintenance Rates (1998-2013)

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

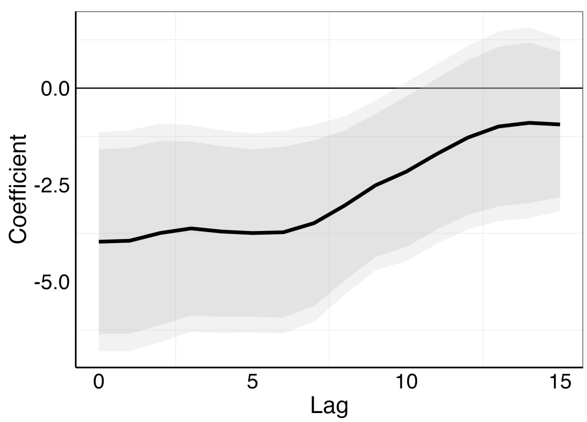
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: This table estimates regressions using (13) from 1998-2013 with fixed tax exposure weights. The columns are grouped into three different categories. The first two contain estimates from the SOI sample including all firms, the second two contain firms with positive net income, and the final two for firms without net income. The first column in each group estimates the baseline regression of the log maintenance rate on the log tax rate for taxable firms with two-way fixed effects and linear and quadratic industry trends. The second column in each group adds age, proxied as the ratio of gross to net book capital, as a control. In all regressions, standard errors are clustered by industry. In the bottom row, I estimate an implied value for γ by taking the sample mean of maintenance rates within the sample and dividing by the mean of the tax term raised to the estimated ω in the corresponding column.

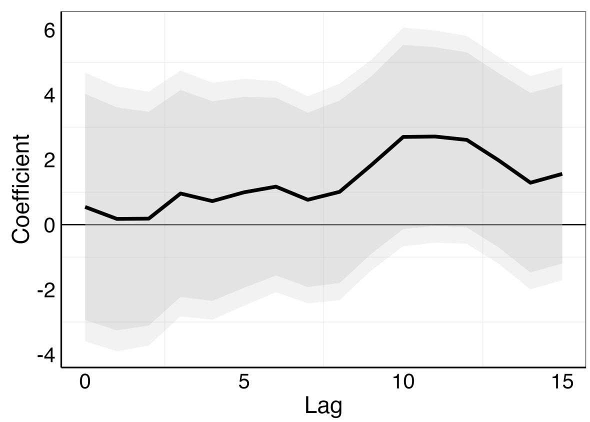
Figure D.1: Maintenance demand elasticity coefficients as a function of capital weight lag length



(a) Taxable Firms



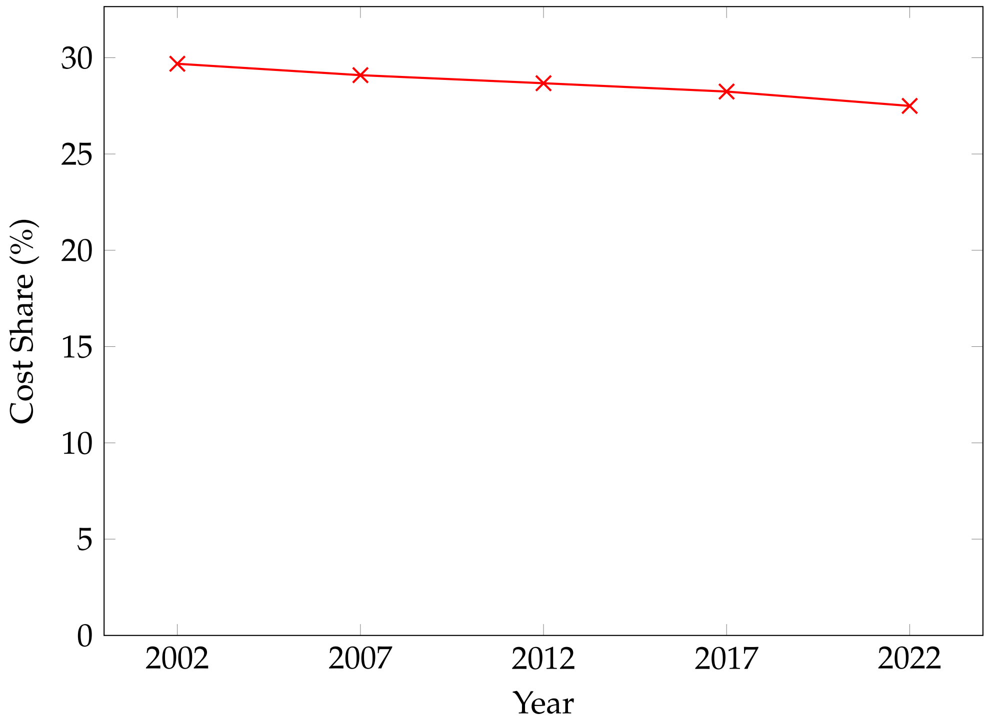
(b) All Firms



(c) Untaxable Firms

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

Figure D.2: Labor Cost Share from the Maintenance and Repair Industry



Notes: This figure depicts payroll as a share of total receipts for the NAICS code 811, which is the maintenance and repair sector, from 2002-2022. Each data point comes from the Economic Census.

E Additional Quantitative Results

E.1 Robustness to variation in ω

Table E.1: Results for Alternative Maintenance Demand Parameter Combinations

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

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

E.2 Heterogeneous Capital

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

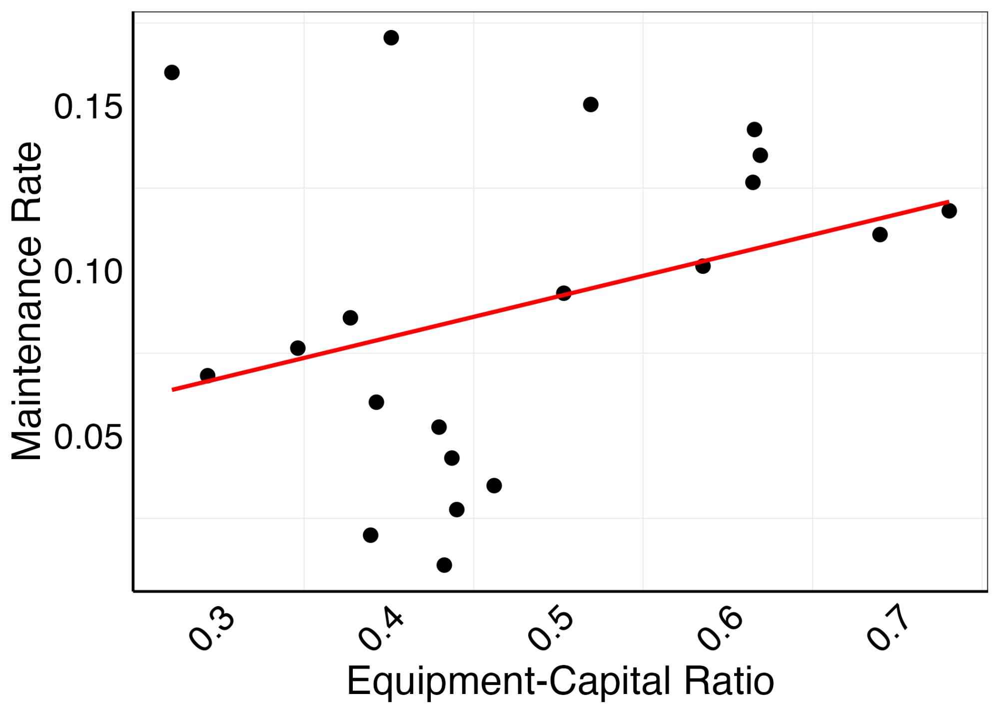
The key question is the extent to which maintenance dampens the long-run response of each capital type to changes in tax policy. That requires three new calibrations. First, suppose that capital is a Cobb-Douglas aggregator of structures and equipment

$$K_t^{\alpha} = K_{t,S}^{\alpha_S} K_{t,E}^{\alpha_E}.$$

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

Calibrating the depreciation technologies is more difficult. While we cannot granularly identify differences in specific types of capital with SOI data, we can approximate an answer for equipment and structures. Figure E.1 bins maintenance rates into twenty points and plots the sample mean industry equipment-capital ratio on the x-axis against the corresponding maintenance rate on the y-axis. There is a moderately positive relationship. Consequently, it appears that equipment is more intensively maintained than structures, which is suggestive of heterogeneity in tax elasticities. A simple OLS regression of the full sample maintenance rate on the equipment-capital ratio yields an intercept of 0.045 (SE = 0.003) with a coefficient of 0.016 (SE = 0.006). That suggests a small but economically significant difference in the baseline levels of maintenance rates and hence tax elasticities of capital. For example, suppose maintenance demand is completely inelastic, the discount rate r^k is 0.06 and the depreciation rates are $\delta_S = 0.03$ and $\delta_E = 0.12$. The depreciation rates are consistent with BEA data. In that case, after making the adjustment for labor cost exclusion, equipment has a tax elasticity of capital 67% as large as in the baseline no-maintenance model, while the structures elasticity is 58% as large.

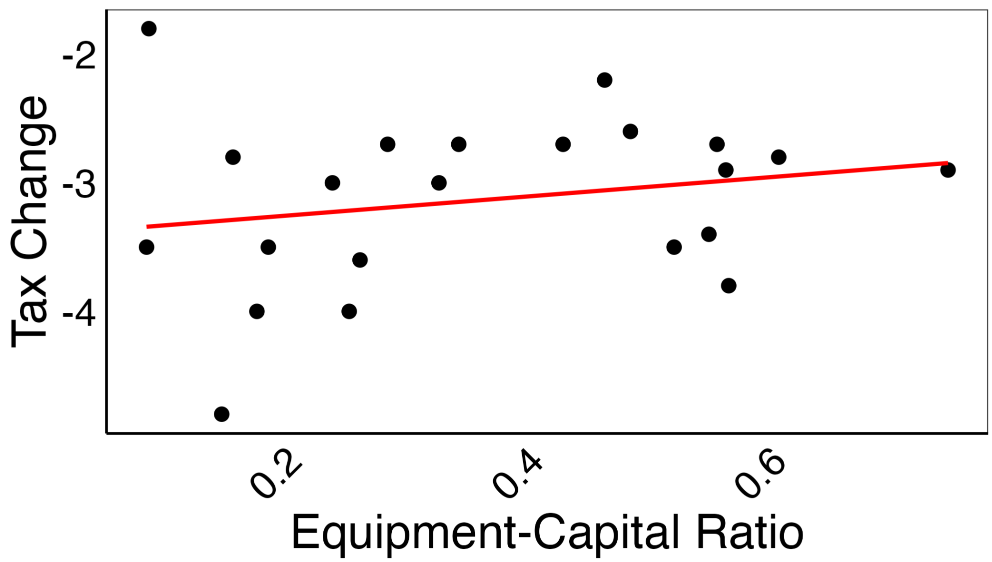
Figure E.1: The maintenance rate increases for shorter-lived capital.



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

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

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



(13) through the regression

$$\log m_{i,t} = \alpha_i + T_t + \omega_1 \log(1-\tau_{i,t}) + \omega_2 \left(\frac{K_{E,i,t}}{K_{i,t}}\right) \times \log(1-\tau_{i,t}) + \beta \left(\frac{K_{E,i,t}}{K_{i,t}}\right) + \text{Controls} + \epsilon_{i,t}, \tag{A.17}$$

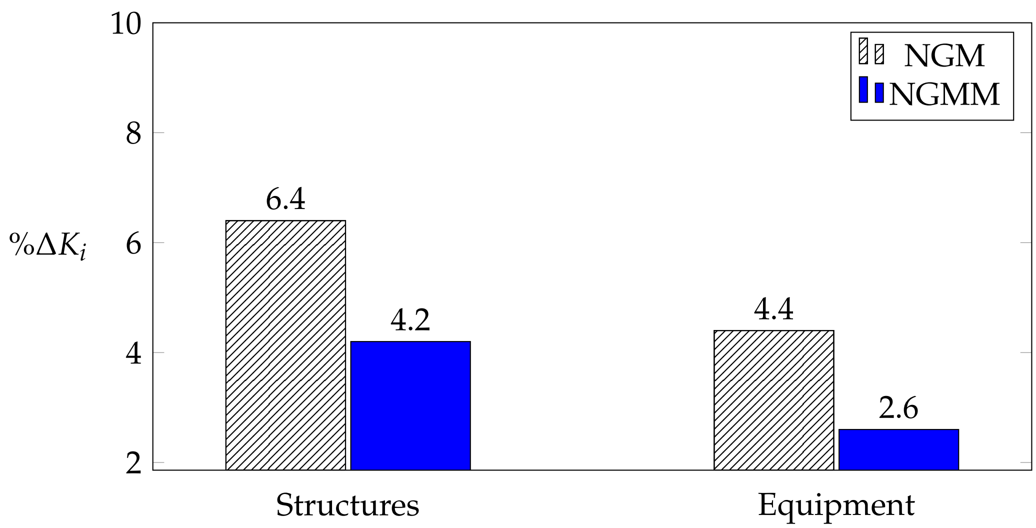
where $\frac{K_{E,i,t}}{K_{i,t}}$ is the ratio of equipment capital to total physical capital for industry i. The sum of ω_1 and ω_2 therefore would give the demand elasticity for equipment, while ω_1 would be the structures demand elasticity. This suffers from the fatal flaw that the tax rate and the equipment-capital ratio are highly correlated. Since the results from the homogeneous capital case suggest that setting the elasticity right is only about composition of capital and not the outcome itself, I calibrate both elasticities to be the same.

Chodorow-Reich et al. (2023) do not break down the change in marginal tax rates by asset type. I take Table E.14 from their Appendix, which breaks down the tax change by domestic industry, and plot the domestic tax rate change against the 2017 equipment-capital ratio in Figure E.2 where the equipment-capital ratio comes from the BEA fixed asset table. The line of best fit has an intercept of -3.4 (SE = 0.32) with a slope of 0.75 (SE = 0.76). Although the slope is insignificant, I choose to interpret it as saying that the tax rate change was smaller for equipment than for structures by the size of the slope.

I calibrate the demand functions by setting a common ω and solving for γ_S and γ_E using the baseline equipment and structures maintenance rates from the regression of maintenance on the equipment-capital ratio. Finally, I set $\delta_{0,S}$ and $\delta_{0,E}$ such that the pre-reform investment-output ratios are 4.6% and 8.4%, respectively. These figures are consistent with the 2000-2016 average of the respective corporate investment-gross output ratios from the BEA. A summary of calibrated parameters is in Table E.2.

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

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



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

Table E.2: Additional Calibrated Parameters

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

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